Silva Balcanica, 13(1)/2012

PRODUCTIVITY OF ROADSIDE PROCESSING SYSTEM IN WESTERN AUSTRALIA

Mohammad Reza Ghaffariyan, Mauricio Acuna
Office of Research, University Sunshine Coast,
Private Bag 12, Hobart, Tasmania, Australia

Loren Kellogg
Department of Forest Engineering, Oregon State University, USA

Abstract: This research studied the productivity of a roadside processing system in a plantation of *Eucalyptus globulus* (blue gum) in Western Australia. A time and motion study was applied to collect the data for the harvesting system. The harvest system included a feller-buncher, grapple skidder, processor and loader. The working cycles for each machine were recorded as well as the variables affecting productivity. Appropriate models were developed using the multiple regression method. The results showed that productivity of the feller-buncher and processor were significantly affected by tree size. Productivity of the skidder was dependent on extraction distance. The unit cost (from stand to roadside) averaged AD 18.68/m^3.

Key words: productivity; cost; roadside processing; model; feller-buncher; skidder

INTRODUCTION

The total harvest from plantations in Australia is 17 million cubic metres per year. The harvesting system in most plantations involves the use of a feller-buncher and skidders to extract the trees, or a combination of feller-buncher and forwarder to extract cut-to-length logs. Woodchips are generated either by a static chipper at a mill or an in-field chipper. In-field chipping uses a mobile chipper to produce acceptable grade chips at the forest edge. The stems can be debarked at the stump using a single grip harvester, or with a chain flail delimber and debarker at the forest edge prior to chipping (Lambert, 2006). Harvesting small trees for producing chips is completed using different machinery and methods. In flat terrain a combination of feller-buncher and skidder can be used.Harvesting productivity studies have indicated that skidding distance, piece size, load volume and slope of the trail highly impact productivityof the skidding element (Sobhany, Stuart, 1991; Abeli, 1993; Daxner et al., 1997; Egan, Baumgras, 2003; Sabo, Porsinsky, 2005; Zecic et al., 2005). Skidding productivity of grapple skidders ranged from 32.7 to 35.8 m^3/h in a study in Alabama (Klepac et al., 2001).

This study investigated the productivity of a roadside processing system used in Western Australia. The harvesting system is a highly mechanised system operating with expensive equipment. There has been inadequate assessment of the productivity and cost efficiency of this system.

The **objectives** of this study were:

to study the effect of the parameters affecting the productivity of feller-buncher, grapple skidder, processor and loader;

to develop productivity equations using the statistical regression method;

to evaluate productivity and cost of this roadside processing system.

This paper focuses on the productivity of the individual machines used in this roadside processing system.

MATERIALS AND METHODS

Study area

A roadside processing system was located in an 11-year-old *Eucalytus globulus* (blue gum) plantation at Clear Hills in Western Australia. The study area (1.07 ha of flat terrain) had a standing volume of 156 m^3/ha and 760 sph was clear felled. Tree volume averaged 0.205 m^3.

Work organisation and harvest equipment

Felling was carried out by a tracked feller-buncher equipped with shears in its felling head. Then the whole trees, accumulated in bunches, were skidded to the roadside using a rubber-tyred grapple skidder. The skidder picked up the debris from processing at roadside and delivered the trees to the cut-over area. A Tiger processor equipped with a Waratah felling head processed the trees to short logs. Then the logs were loaded by an excavator-based Komatsu loader into a truck. Fig. 1 illustrates the roadside processing system at this site. The characteristics of the equipment are described in Table 1.

Data collection

The elemental time study method was applied to evaluate the production rate of the system. First the working cycle was defined for each machine. A working cycle is a complete set of operations or tasks that is repeated for each machine. Each cycle contains different elements and work delays (Table 2, 3).

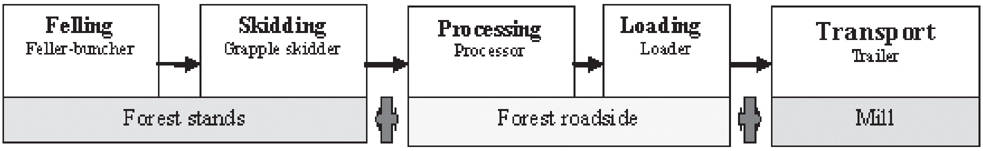

Fig. 1. Roadside processing system at Clear Hills, Western Australia

Table 1
Harvesting machines used at study site

	Type	Make	Model	Hours used	Operator experience (years)
Machine 1	Feller-buncher (shear)	Tigercat	822C	4000	0.5
Machine 2	Skidder (Rubber-tyred grapple)	Caterpillar	535B	6000	0.67
Machine 3	Processor (tree harvester with dangle head)	Tigercat/ Waratah	250B; HTH.616	2500; 10000	12
Machine 4	Loader (excavator base)	Komatsu/ Randalls grapple	PC200; Randalls 801R22	7220	7

Productivity for each machine was computed by dividing the quantity of wood produced (tonnes) by PMH0 (productive machine hours without delays). The unit cost (AD/m^3) was calculated based on production and hourly running cost of each machine.

For the feller-buncher it was assumed that productivity was a function of tree volume. Tree volume was measured using a volume estimating formula based on the DBH (diameter at breast height) class of each tree. For skidders, the dependent variable was skidding time per cycle. The independent variables such as skidding distance and volume of bunches were recorded during the time study. The skidding distance was measured during each cycle. The volume of bunches was evaluated using the number of trees per bunch and average tree size. Table 4 presents the study layout of this research.

Statistical analysis

The working delays were recorded as well as the variables that affected the productivity. The working time and productivity were plotted depending on the parameters. Productivity models were developed using the multiple and simple regression methods. When the productivity did not have enough correlation with independent variables, the working cycle time was used as a dependent variable to develop the model. The statistical procedure for modelling included:

- plotting the working time depending on the parameters
- collinarity test to verify the correlation among the variables
- multiple regression application to develop the working time equation
- checking model consistency
- analysing the variance to test significance of the model

Table 2
Work elements of feller-buncher, skidder and processor

	Work elements	Definition
Feller-buncher	Moving	Any move between trees, but with no trees in the accumulator, provided the boom is not already swinging into position for the first tree. Starts with track movement and ends with swing of the boom to the first tree in the new accumulation.
	Felling-bunching	Starts when felling head is attached to tree to start cutting and finishes when operator puts the felled tree on the ground.
	Clearing	Use of head to remove non-merchantable material. Starts when the machine stops moving or felling/bunching to dispose of non-merchantable material and stops when feller/bunching or moving recommences.
Skidder	Travel empty	Starts when machine begins travel into the block and ends when manoeuvring at bunch commences.
	Loading	Starts with grappling the bunch and picking up and ends when ‘travel loaded’ commences.
	Travel loaded	Starts when wheels begin rotating and ends when skid distance to the landing is reached.
	Unloading	Time to drop load and turn around to begin ‘travel empty’. Starts when skid distance to deck is reached and ends when turn around is completed.
	Debris cleaning	Any time spent clearing debris and removing to stockpile or returning to the block.
Processor	Moving	Any machine movement between bunched trees or along pile. Starts with track movement and ends when boom swings to the next tree to be processed.
	Processing	Starts when boom starts to swing to next tree-length log to be processed after arriving at bunch from move or dropping top of previous tree, and ends when that tree’s top is dropped.
	Debris clearing	Any interruption to previous elements to remove unmerchantable trees or clear processing debris.

Table 3
Working delay

Delay	Definition
Delay/Non-productive time	Any interruption to previous elements. (Note cause of delay: operational, personal or mechanical). Delay will be treated as follows: o Delays < 0.1 min (6 sec) are included in the element in which they occur as the time interruption is considered too short to constitute a delay. o Delays <15 min are recorded as delays and included in productive time. o Delays >15 min are considered non-productive time and excluded.

Table 4
Study layout for productivity assessment based on collect cycle times

Harvest system	Components	Number of collected cycle time
Roadside processing	Feller-buncher	58
	Skidder	58
	Processor	350
	Loader	4

- examining the residuals of the model and model evaluation

A sensitivity analysis was conducted to quantify the impact of each variable on productivity and cost for all models. The cost of roadside processing was derived from the hourly machine cost and the production rate.

RESULTS AND DISCUSSION

Felling-bunching

Productivity of the feller-buncher was significantly dependent on tree volume, at a probability level of $\alpha=0.05$ (Fig. 3). The logarithmic model was found to have best fit to the time study data. The significance level of the analysis of variance table is less than 0.05, thus the model is significant at the probability level of 5 per cent (Table 5).

Productivity of feller-buncher (m^3/PMH0) = 83.012× ln(tree volume (m^3)) + 242.94

R-sq= 0.32, number of observations =58.

The sensitivity analysis in Fig. 4 shows that the felling and bunching cost

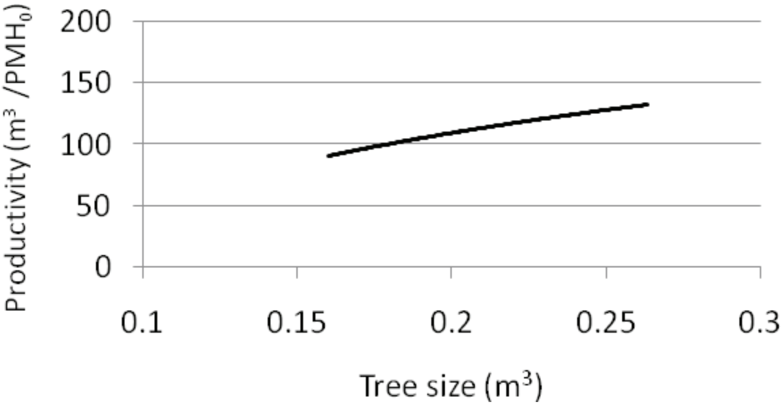

Fig. 3. Effect of tree volume on productivity of feller-buncher

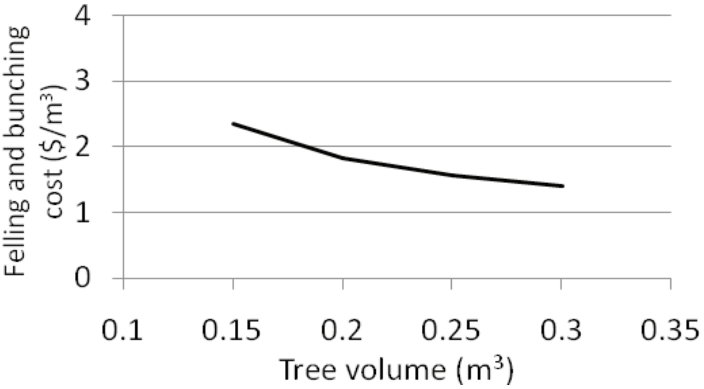

Fig. 4. Impact of tree volume on felling and bunching cost

per cubic metre diminishes as tree volume increases. Larger trees increased productivity of the feller-buncher.

Table 5
Analysis of variance for feller-buncher model

	Sum of squares	df	Mean square	F	Sig.
Regression	7171.81	1	7171.81	27.51	0.00
Residual	14 862.64	57	260.75		
Total	22 034.45	58			

The share (in percentage of work cycle) of working elements for the feller-buncher is presented in Table 6. The felling and bunching element represents the largest share of the working cycle in the study site.

Table 6

Distribution of working elements for feller-buncher

	% of work cycle
Felling/bunching	93
Moving	5
Clearing	1
Delay (operational delay)	1

Skidding

For the skidding model, firstly we tried to use productivity as the dependent variable for the regression. Skidding distance and load weight were independent variables. Productivity did not result in a significant variable thus the free delay skidding time was used as the dependent variable. The following model was developed. Load weight did not significantly impact the residual mean square of the model; therefore it was not included in the equation.

Free delay skidding time (min/cycle) = 1.3958 + 0.0082 × Skidding distance (m)

Rsq= 0.91, Number of observations=58

An analysis of variance found the skidding model makes sense at the probability level of $\alpha=0.05$ (Table 7). The summary statistic of the parameters used in the skidding time predicting equation is presented in Table 8. Fig. 5 and 6 show the impact of skidding distance on skidding cycle time and cost per cubic metre. For the range of skidding distance of 55 to 300 metres, the productivity varies from 44 to 91.9 m^3/PMH0. The skidding cost differs from AD 1.5/PMH0 to AD 3.2/PMH0. These figures indicate that the longer the skid distance, the longer the cycle time and the higher the extraction cost.

Travel loaded, travel empty and loading the bunches consumed the longest times among the skidding work elements. No delay was observed during this study (Table 9).

Processing

Productivity of the processor was highly impacted by tree volume. A power model was fitted to the scattergram of time study data. Analysis of variance (Table 10) shows the model is significant at $\alpha=0.05$. The R-sq of 0.72 indicates that 72

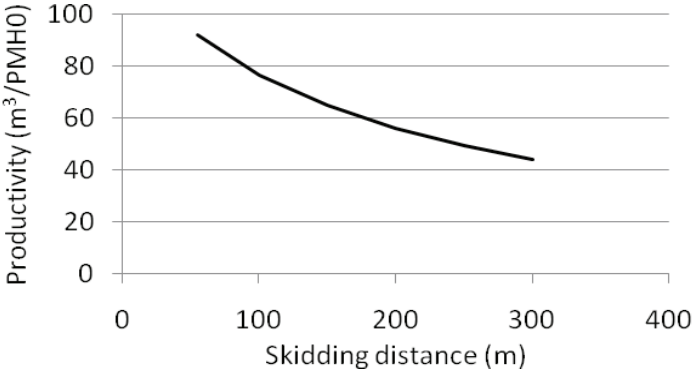

Fig. 5. Skidding distance vs productivity

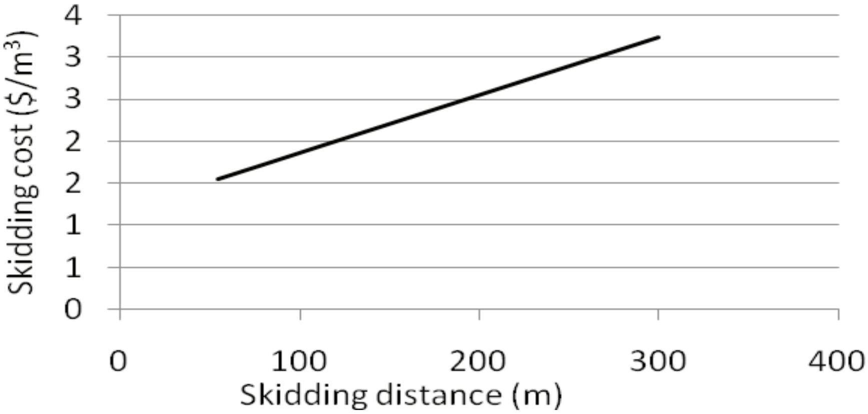

Fig. 6. Skidding distance vs skidding cost

Table 7
Analysis of variance for skidding model

	Sum of squares	df	Mean square	F	Sig.
Regression	5642.89	1	5642.89	583.31	0.00
Residual	551.41	57	9.67		
Total	6194.31	58			

Table 8
Descriptive statistics for skidding model

	Minimum	Maximum	Mean
Skidding distance (m)	20	430	218.98
Volume per bunch (m^3)	1.76	3.81	2.83
Free delay skidding cycle time (min)	1.3	5.6	3.18

Table 9
Distribution of working elements for grapple skidder

Work elements	% of work time
Debris cleaning	2
Travel empty	29
Loading	20
Travel loaded	36
Unloading	13
Delays	-

per cent of total variability is explained by the model. Descriptive statistics of the model are included in Table 11. Larger tree size resulted in higher productivity and lower processing cost (Fig. 7, 8).

Productivity (m^3/PMH0) = 88.351× Tree Volume$^{0.7504}$ (m^3)
Rsq= 0.72, Number of observations=350

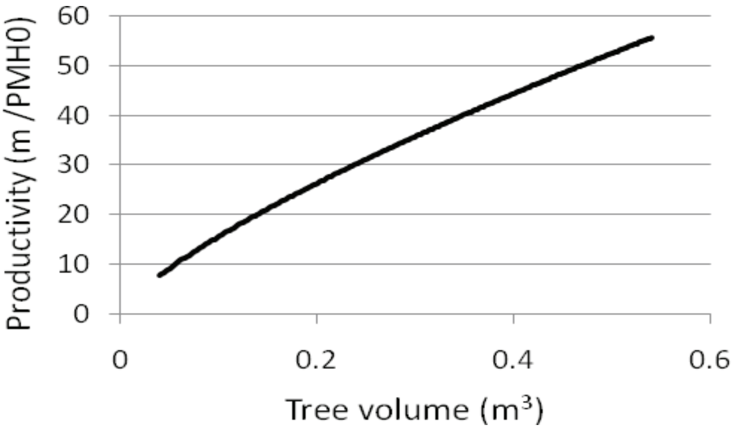

Fig. 7. Effect of tree volume on production of processing

For Tigercat processor, 86.6 per cent of work time was spent processing the trees. Delays totalled 7 per cent of work time for the processing operation (Table 12).

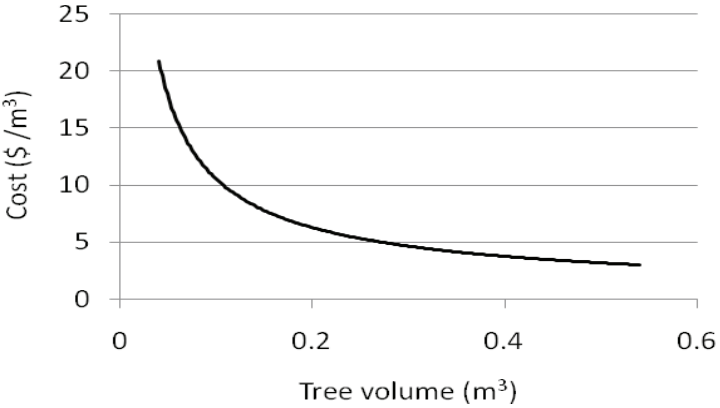

Fig. 8. Effect of tree volume on processing cost

Table 10
ANOVA of processor model

	Sum of squares	df	Mean square	F	Sig.
Regression	86.99	1	86.99	903.19	0.00
Residual	33.62	349	0.09		
Total	120.61	350			

Table 11
Descriptive statistics of processor model

	Minimum	Maximum	Mean
Productivity (m^3/PMH)	4	89	25.1
DBH (cm)	10	30	17.98
Tree volume (m^3)	0.04	0.54	0.19

Table 12
Distribution of working elements for processor

Work element	% of work cycle
Processing	86.6
Moving	4.3
Debris clearing	2.1
Mechanical delay	4.3
Operational delay	0.2
Personal delay	2.5

Loader

Based on the time study results, the productivity of Komatsu loader averaged 86.2 m^3/PMH0. The percentage of work time lost to delay (mostly operational delay) was about 8.1 percent.

Summary of system cost-production evaluation

Table 13 summarises the evaluation of production and cost of the roadside processing system. Processing has the highest cost of the components of harvesting system, at Australian dollar (AD) 8.72/m^3. Loading cost averaged AD 1.74/m^3 which was the lowest expense. The cost-estimation analysis yielded a total cost of AD16.68/m^3.

Table 6

Summary of cost-production evaluation of the system (cost are based on Australian dollar)

Component	Production (m^3/PMH0)	Hourly cost (AD/h)	Unit cost (AD/m^3)
Felling-bunching (Feller-buncher)	109.1	294	2.69
Extraction (Skidding)	53.8	190	3.53
Processing	25.1	219	8.72
Loading	86.2	150	1.74
Total cost	-	-	16.68

CONCLUSIONS

This study confirmed that tree size has a significant impact on the productivity of both feller-buncher and processor. Larger tree size results in higher productivity. Skidding distance was a significant variable in skidding time equations.

Our study found the feller-buncher and skidder had relatively low machine downtime. However the percentage of work cycle time lost to delay for the loader and processor was relatively high, which indicates the need for better machine management to reduce downtime.

The total cost per m^3 for roadside processing can be useful basic information to estimate the cost and efficiency of harvesting at similar timber harvesting sites. The information about this roadside processing system may be applied to compare it with other harvesting systems such as in-field chipping or cut-to-length systems.

Acknowledgement: We thank John Wiedermann from WAPRES who helped with data collection.

REFERENCES

Abeli, W. 1993. Comparing productivity and costs of three subgrading machines. International J. of Forest Engineering, 5(1), 33-39.

Daxner, P., Gutmann, A., Hager, H., Kroiher, F., Sagl, W., Stampfer, K., Sterba, H. 1997. Naturnahe Waldwirtschaft und deren Auswirkung auf das Oekosystem Wald; eineoekologische, waldwachstumkundliche, forsttechnische und soziooekonomische Studie. Universität für Bodenkultur Wien. 91 p.

Egan, A., Baumgras, G. E. 2003. Ground skidding and harvested stands attributes in Appalachian hardwood stands in West Virginia. Forest Product Journal, 53(9), 59-63.

Kanzian, C., Holzleitner, F. 2006. Wertsch.pfungsketten für Waldhackgut – Einsatz eines selbstladenden Lkw für den Transport. 39th International Symposium on Forestry Mechanization. Sofia, Bulgaria, 300 p.

Klepac, J., Stokes, B., Roberson, J. 2001. Effect of tire size on skidder productivity under wet conditions. International Journal of Forest Engineering, 12(2), 61-69.

Lambert, J. 2006. Growth in blue gum forest harvesting and haulage requirements in the Green Triangle 2007-2020. CRC Forestry report. 119 p.

Sabo, A., Porsinsky, T. 2005. Skidding of fir round wood by timberjack 240c. Croatian J. of Forest Engineering, 26 (1), 13-27.

Sobhany, H., Stuart, W. B. 1991. Harvesting Systems Evaluation in Caspian Forests. International J. of Forest Engineering, 2(2), 21-24.

Zecic, Z., Krpan, A.B.P.,Vukusic, S. 2005. Productivity of C Holder 870 F tractor with double drum winch Igland 4002 in thinning beech stands. Croatian J. of Forest Engineering, 26(2), 49-57.

E-mail: ghafari901@yahoo.com