Comparing productivity-cost of roadside processing system and road side chipping system in Western Australia

M.R. Ghaffariyan

University of the Sunshine Coast, Hobart, Australia

ABSTRACT: This research compared roadside chipping and road side processing systems. Two sites planted with *Eucalyptus globulus* were selected to study these harvesting systems. A time and motion study was applied to collect the data for both harvesting systems. The working cycles for each machine were recorded as well as the variables affecting the working productivity. Using the multiple regression method the appropriate models were developed. The results showed that the productivity of feller-buncher and processor was significantly affected by tree size. Productivity of skidders was dependent on extraction distance and load weight. Productivity for road side processing was higher than for road side chipping, which resulted in a lower unit cost. The unit cost (from stand to the mill) for road side processing and road side chipping averaged 22.68 AUD·t^{-1} and 21.07 AUD·t^{-1}, respectively.

Keywords: productivity; cost; road side chipping; road side processing; productivity model; feller-buncher; skidder

The total harvest per annum is 17 million m^3 from plantations in Australia. The harvesting system in the plantations is mostly based on application of feller-buncher and skidders to extract the trees or combination of feller-buncher and forwarder to extract the logs. The chippers can be static at the mill or road side chipper. Road side chipping utilizes a mobile chipper to produce acceptable grade chips at the forest edge. It can be performed either by debarking the stems at the stump using a single grip harvester, or alternatively, by debarking the stems with a chain flail delimber and debarker at the forest edge prior to chipping (Lambert 2006). Harvesting small trees for producing chips can be completed by different machinery and methods. In the flat terrain a combination of feller-buncher and skidder can be used. For skidding operation, harvesting productivity studies have indicated that skidding distance, piece size, load volume and slope of the trail highly impact the productivity of this phase of logging element (Sobhany, Stuart 1991; Abeli 1993; Daxner et al. 1997; Egan, Baumgras 2003; Sabo, Porsinsky 2005; Zecic et al. 2005). Skidding productivity ranged from 32.7 to 35.8 m^3·PMH^{-1} (productive machine hours) in Alabama for grapple skidders (Klepac et al. 2001).

This paper investigates the productivity of road side chipping and road side processing system in Western Australia. Both options are highly mechanized harvesting systems operating with the most expensive equipment. There has not been enough information on economics of these systems. Therefore this project aimed to investigate the work efficiency and cost of both harvesting systems to create sufficient knowledge for the research and development purposes.

The objectives of this study were:
– studying the effect of the parameters affecting the productivity of each machine in both harvesting systems,
– developing the predictive productivity equations using the statistical regression method,
– evaluation of productivity rate for two harvesting alternatives,
– comparing productivity-cost of the harvesting machines based on tree size and skidding distance,
– comparing productivity-cost of two harvesting systems in the study area.

The information of this research paper mainly focuses on the productivity of individual machines used in road side chipping and road side processing.

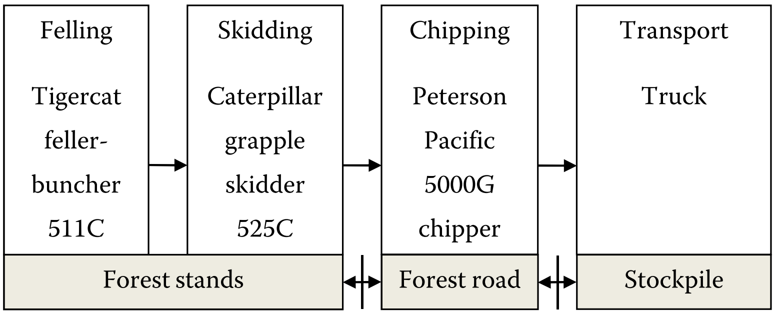

Fig. 1. Road side chipping system at Range Montana

MATERIALS AND METHODS

Study area

The road side chipping system (Fig. 1) was located in a 13-years-old *Eucalyptus globulus* plantation at Range Montana in Western Australia. The study area (1.52 ha of flat terrain) had a standing volume of 114 $m^3 \cdot ha^{-1}$ and 640 $stems \cdot ha^{-1}$ were clear felled. Tree volume averaged 0.178 m^3.

A road side processing system (Fig. 2) was located in an 11-years-old *Eucalyptus globulus* plantation at Clear Hills in Western Australia. The study area (1.07 ha of flat terrain) had a standing volume of 156 $m^3 \cdot ha^{-1}$ and 760 $stems \cdot ha^{-1}$ were clear felled. Tree volume averaged 0.205 m^3.

Study design

The road side chipping site included 10 rows of the trees. This study site was divided into 5 plots (two rows per each plot) with similar area and tree size. The road side processing site consisted of 6 rows of the Eucalypt trees divided into three blocks containing two rows each. The plots enabled to replicate the harvesting systems (study treatments) to determine the difference between the productivity and costs.

Data collection

The elemental time study method was applied to evaluate the productivity rate of both systems. Firstly the working cycle was defined for each machine. Working cycle is a complete set of operations or tasks that is repeated for each machine. Each cycle contains different elements (Table 1).

Productivity for each machine was computed by dividing the produced wood in tonnes to PMH_0 (productive machine hours without delays). The unit cost ($AUD \cdot t^{-1}$) was evaluated based on productivity and hourly cost of each machine.

For the feller-buncher it was assumed that the productivity is a function of tree volume. Tree volume was measured using a volume estimating formula based on the DBH class of each tree. For skidders, the dependent variable was skidding time per cycle. The independent variables such as skidding distance and weight of bunches were recorded during the time study. The skidding distance was measured during each cycle. The weight of bunches was evaluated using the number of trees per bunch and average tree size. Table 2 presents the data base of this research.

Statistical analysis

The working delays were recorded as well as the variables impacting 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 dependent variable to develop the model. The statistical procedure for modelling includes:

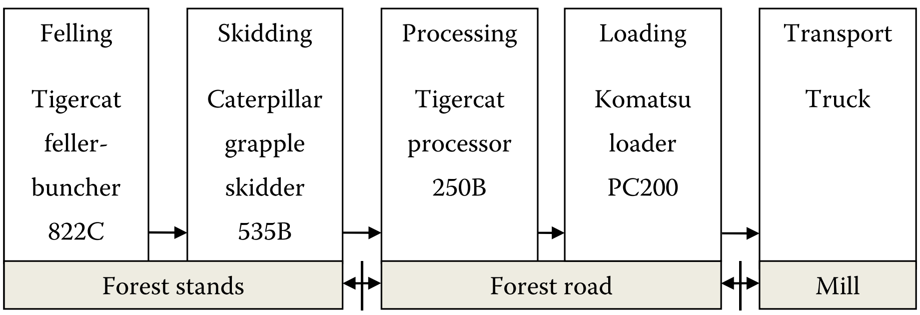

Fig. 2. Road side processing system at Clear Hills

Table 1. Work elements of feller-buncher and skidder

Machine	Work elements	Definition
Feller-buncher	felling-bunching	starts when the felling head is attached to a tree to start cutting, it finishes when the operator lays the felled tree on the ground
	moving	begins when the machine starts to travel to next tree and ends when the machine stops moving to perform another activity
	brushing/cleaning	starts when the machine stops moving or felling/bunching to dispose of non-merchantable material and stops when felling/bunching or moving recommences
Skidder	debris cleaning	any time spent for clearing debris and removal to the stockpile or return to the block
	travel empty	starts when the machine commences travel into the block and ends when loading of a bunch commences
	loading	starts with grappling the bunch and picking up and ends when travel loaded commences
	travel loaded	starts when wheels commence turning after loading, and ends when a skid distance to the landing is reached
	unloading	time to drop a load and turn around to commence travel empty. Starts when a skid distance to the deck is reached and ends when the turnaround is completed

– plotting the working time/productivity depending on the parameters,
– collinearity test for verifying the correlation among the variables,
– multiple regression application to develop the working time equation,
– checking the model consistency, fit and plausibility,
– analysis of variance to test the significance of the model,
– examination of the residuals of the model and model validation.

A sensitivity analysis was conducted to quantify the impact of each variable on productivity and cost for all models. This analysis was carried out by changing one parameter within its range while holding the other parameters constant at their mean value to see the impact on the productivity and cost. The cost of two systems was derived through the hourly machine cost and the productivity rate.

Table 2. Data base for time study

Harvest system	Components	Number of work cycles
Road side chipping	feller-buncher	65
	skidder	56
	chipper	4
Road side processing	feller-buncher	58
	skidder	58
	processor	350
	loader	4

RESULTS AND DISCUSSION

Productivity of the feller-buncher at both sites significantly depended on tree volume at a probability level of $\alpha = 0.05$ (Fig. 3). However, the productivity rate of felling and bunching operation in Clear Hills site was higher than in Montana site.

Felling and bunching in Range Montana site are more expensive than in Clear Hill site due to higher machine cost and lower productivity rate. The productivity models are presented in Table 3. All models were significant at a probability level of $\alpha = 0.05$.

Productivity of skidding operation in the road side processing system was higher compared with the in-field chipping site (Fig. 5). Although the average weight of bunch in road side processing (2.83 t) was smaller than in the in-field chipping site (3.03 t), the average skidding time in Range Montana (road side chipping) was much higher than in Clear Hills due to a long time spent for removal and clearing of debris and re-skidding. The minimum, maximum and mean skidding distance for Clear Hills (road side processing) was 20 m, 430 m and 219 m, respectively, while the minimum, maximum and mean skidding distance for Range Montana (road side chipping) was 55 m, 292 m and 160 m. The minimum and maximum weight of bunch (weigh of load) for Clear Hills (road side processing) site was 1.76 t and 3.81 t while for the Range Montana site (road side chipping) the minimum weight of bunch was about 0.98 t with maximum of 5.46 t.

Using the same hourly machine cost of 142.42 AUD per h, the skidding cost was evaluated depending on skidding distance. Increasing the distance will

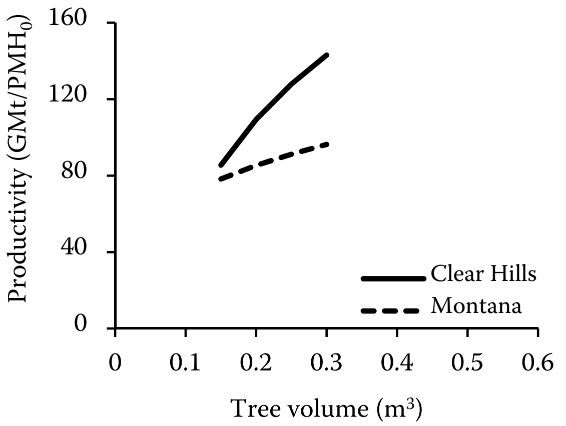

Fig. 3. Effect of tree volume on the productivity of a feller-buncher

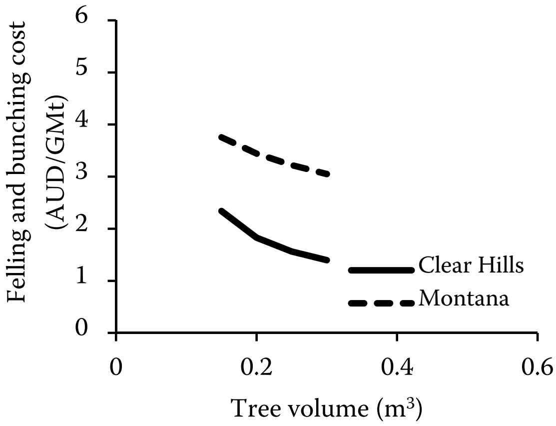

Fig. 4. Comparison of felling-bunching costs

increase the extraction cost (Fig. 6). The productivity of the processor significantly depended on tree volume at the probability level of $\alpha = 0.05$ (Table 3). From the model, the larger the tree volume, the higher the productivity and the lower the processing cost per tonne (Figs 7 and 8).

The share of working elements in percent for feller-buncher and skidder is presented in Tables 4 and 5. For the feller-buncher, felling and bunching elements account for the largest share of working cycle in both study sites. The skidder in the road side chipping site spent 41% of the working time to clean the debris. The longest work element for skidding in Clear Hill was travel loaded (36% of working time). Skidding operation in Range Montana had 6% delay time although for road side processing the skidder did not have any delay.

The net productivity and cost of the chipper in Range Montana averaged 33.9 $t\cdot PMH_0^{-1}$ and 10.27 $AUD\cdot t^{-1}$. The operational delays covered 27% of the operating time, which was mostly caused by waiting for wood and trucks. Only 2% of the chipping time was spent for mechanical delays. Table 6 presents the summary of productivity and cost for road side chipping and road side processing. An average chipping cost of 6 $AUD\cdot t^{-1}$ was assumed for centralized chipping at the mill for road side processing.

The productivity of the feller-buncher in this case study is lower than the average productivity (138.0 $t\cdot PMH_0^{-1}$) reported for a similar Valmet 445 EXL tracked self-levelling feller-buncher working in the pine plantations of the South Gippsland coast of Victoria (Acuna et al. 2011). The main reason is likely to consist in the smaller tree size handled in this study. Similar results were also reported by Spinelli et al. (2009), who studied a range of feller-bunchers used for Eucalypt clearfell and obtained figures between 14 and 20 $t\cdot PMH_0^{-1}$ for smaller DBH and steeper slopes than covered by this study.

The average productivity of skidder in the road side processing site (in Range Montana) is higher than the productivity (44.6 $t\cdot PMH_0^{-1}$) of a Tiger Cat 730C grapple skidder used for extracting small

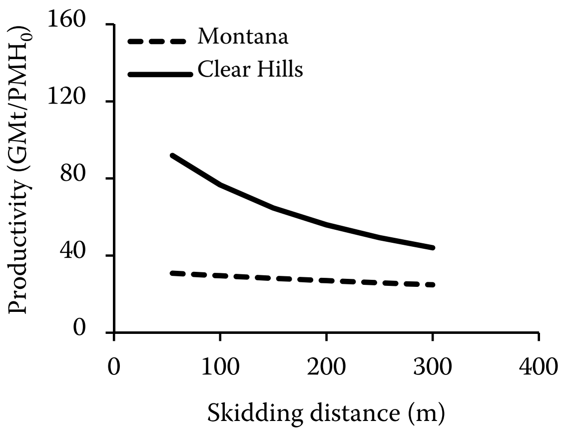

Fig. 5. Effect of skidding distance on the productivity of skidders at two sites

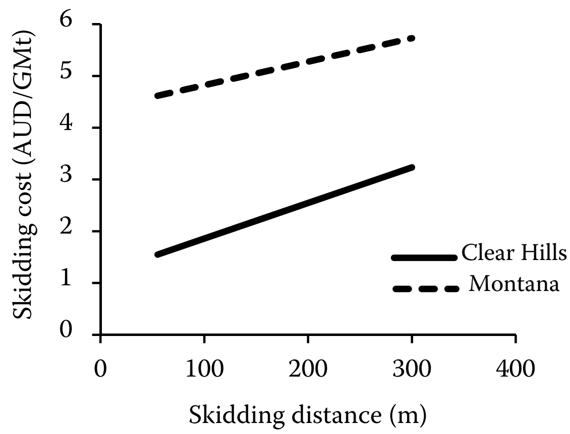

Fig. 6. Comparison of skidding costs at two sites

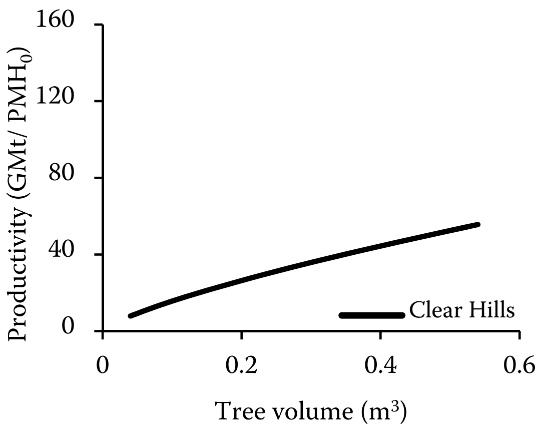

Fig. 7. Effect of tree volume on the productivity of a processor at Clear Hills site

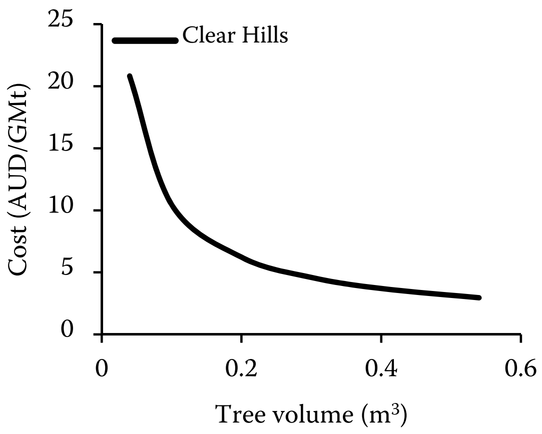

Fig. 8. Effect of tree volume on processing cost at Clear Hills site

whole eucalypt trees in Western Australia (Ghaffariyan et al. 2011). Productivity rate in this study is higher than 47.5 $t \cdot PMH_0^{-1}$ reported for whole eucalypt tree skidding in Brazil (Valverde et al.1996). This could be a result of the shorter skidding distance in Range Montana site.

The productivity of processor (25.1 $t \cdot PMH_0^{-1}$) and loader (86.2 $t \cdot PMH_0^{-1}$) in Range Montana site is lower than processing and loading large tree sizes (average volume of 1.8 m^3) in old pine stands in Tasmania in which processing productivity at the site was 61.9 $t \cdot PMH_0^{-1}$ and loading at the road side had a productivity of 100.8 $t \cdot PMH_0^{-1}$ due to a very large tree size (Ghaffariyan, Sessions 2012).

The chipping productivity recorded in this study (33.9 $t \cdot PMH_0^{-1}$) is close to reported productivity for a Peterson Pacific chipper tested in whole tree chipping for biomass (33.90 $t \cdot PMH_0^{-1}$) in Western Australia, possibly due to a similar tree size (Ghaffariyan et al. 2011). Tree size and machine power are main factors impacting the chipper productivity (Spinelli, Hartsough 2001).

The higher chipping cost in road side chipping can be explained by lower productivity compared

Table 3. Productivity and time equations for feller-buncher, grapple skidder and processor

Machine	Clear Hills (road processing)	Range Montana (road side chipping)
Feller-buncher	productivity ($t \cdot PMH_0^{-1}$) = 242.94 + 83.012 × ln [tree volume (m^3)]	net working time ($min \cdot cycle^{-1}$) = 0.115 × tree volume$^{-0.3}$ (m^3)
	$R^2 = 0.32$, $n = 59$	$R^2 = 0.73$, $n = 65$
Skidder	net skidding time ($min \cdot cycle^{-1}$) = 1.3958 + 0.0082 × skidding distance (m)	net skidding time ($min \cdot cycle^{-1}$) = 4.4289 + 0.0058 × skidding distance (m) + 0.378 × weight of bunch (t)
	$R^2 = 0.91$, $n = 58$	$R^2 = 0.36$, $n = 56$
Processor	productivity ($t \cdot PMH_0^{-1}$) = 88.351× tree volume$^{0.7504}$ (m^3)	–
	$R^2 = 0.72$, $n = 350$	–

n – number of observations

Table 4. Distribution (in %) of working elements for feller-buncher

	Range Montana (road side chipping)	Clear Hills (road side processing)
Fell/bunch	97	93
Move	1	5
Brush	2	1
Delay	–	1

Table 5. Distribution of working elements for skidder (in %)

Work elements	Range Montana (road side chipping)	Clear Hills (road side processing)
Debris cleaning	41	2
Travel empty	10	29
Loading	12	20
Travel loaded	27	36
Unloading	4	13
Delays	6	–

Table 6. Summary of productivity – cost evaluation of two harvesting systems

Elements	Road side processing system			Road side chipping system		
	productivity ($t·PMH_0^{-1}$)	hourly cost ($AUD·h^{-1}$)	unit cost ($AUD·t^{-1}$)	productivity ($t·PMH_0^{-1}$)	hourly cost ($AUD·h^{-1}$)	unit cost ($AUD·t^{-1}$)
Harvesting (feller-buncher)	109.1	294	2.69	73.6	294	3.99
Extraction (skidding)	53.8	190	3.53	27.9	190	6.81
Processing	25.1	219	8.72	–	–	–
Loading	86.2	150	1.74	–	–	–
Chipping	–	–	6	33.9	348.17	10.27
Total cost		22.68			21.07	

with the large stationary at the forest company for road side processing (the average cost of chipping at the mill was taken in consideration). A similar result was found by another study in Western Australia indicating that the road side chipping system delivers the chips with lower cost than road side processing (transporting logs and chipping at the mill) (Ghaffariyan, Sessions 2012).

CONCLUSIONS

Tree size has a significant impact on the productivity of feller-buncher and processor. A larger tree size results in higher productivity. Since the average tree size in Clear Hills was larger than in Range Montana site, the productivity rate of felling and bunching was higher. Skidding distance and weight of load (bunches) were significant variables in skidding time equations. Increasing these variables resulted in higher skidding time and cost. In Range Montana, the skidder spent a significant time for removal and clearing of the debris and re-skidding. This caused a longer working time per tonne which dropped the productivity down. The total cost per tonne for the road side chipping system was relatively cheaper than road side processing. Future studies can investigate the yield and chip quality of the harvesting systems.

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Corresponding author:
Dr. Mohammad Reza Ghaffariyan, University of the Sunshine Coast, Private Bag 12, Hobart, 7001, Australia
e-mail: ghafari901@yahoo.com