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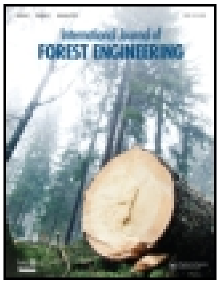

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A log-by-log productivity analysis of two Valmet 475EX harvesters

Muhammad Alam[a], Damian Walsh[b], Martin Strandgard[b] & Mark Brown[c]

[a] Department of Forest and Ecosystem Sciences The University of Melbourne, Richmond, Australia

[b] Australian Forest Operations Research Alliance (AFORA) University of the Sunshine Coast, Richmond, Australia

[c] Australian Forest Operations Research Alliance (AFORA) University of the Sunshine Coast, Maroochydore DC, Australia

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A log-by-log productivity analysis of two Valmet 475EX harvesters

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[a]*Department of Forest and Ecosystem Sciences The University of Melbourne, Richmond, Australia;* [b]*Australian Forest Operations Research Alliance (AFORA) University of the Sunshine Coast, Richmond, Australia;* [c]*Australian Forest Operations Research Alliance (AFORA) University of the Sunshine Coast, Maroochydore DC, Australia*

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Productivity of a mechanized harvesting system is influenced by stand and terrain conditions, operator performance, and machinery limitations or design. The purpose of the study was to compare the productivity of two near-identical single-grip harvesters in similar Australian *Pinus radiata* clearfell harvesting operations on a log-by-log basis. The study first compared the productivity of each harvester against tree volume for cycle times and for tree processing times only. Significant differences in productivity between the harvesters were found to be largely due to significant differences in tree processing times. Comparisons between each component of processing time (dragging-out time, disc-cutting time, cross-cutting time, harvester head travel time and delimbing time) for a subset of 6.1 m sawlogs at each study site found operator working technique differences to be the main driver of productivity differences between the harvesters. In particular, the operator of the less productive harvester dragged out most trees after felling and cut discs on most trees to reset the length-measuring device, whereas the operator of the other, more productive harvester rarely carried out these activities.

Keywords: cycle time; processing time; time study; Australia

Introduction

Productivity of mechanized harvesting systems generally depends on the interaction between forest and harvester characteristics, bucking instructions and operator performance (Nurminen et al. 2006; Ovaskainen 2009; Visser et al. 2009). *Forest* refers to stand conditions (tree form, tree size, crown size and the type and density of trees), terrain conditions (slope, ground roughness, ground strength, streams and drainage features, etc.) and climate. *Harvester characteristics* refers to engine and hydraulic power, harvester head (feeding motors and rolls, delimbing knives and sawing motor), lifting capacity and crane reach, and processing speeds (delimbing and cross-cutting) (Nurminen et al. 2006). *Bucking instructions* refer to the allowable dimensions and quality of each potential log product to be cut or 'bucked' from the tree, and its priority relative to other products. *Operator performance* refers to the operator's mental (Nåbo 1990; Gellerstedt 1997) and physical capacities (e.g. fatigue levels) (Nicholls et al. 2004) and working technique (work location selection, tree processing order and working cycle) (Ovaskainen et al. 2004; Ovaskainen 2009).

Many studies have demonstrated tree size to be the most influential factor in determining harvester productivity, with productivity increasing and costs decreasing with increasing tree size (Kellogg & Bettinger 1994; Nakagawa et al. 2007; Visser et al. 2009). This relationship is not linear (Ovaskainen 2009): the rate of increase in harvester productivity is less for larger trees, and beyond a 'sweet spot', further increases in tree size reduce productivity, because the extra time to cut and process the stem outweighs the volume gain (Visser et al. 2009).

Operator performance is believed to be another major factor in determining harvester productivity (Purfürst & Erler 2012). Kärhä et al. (2004) found productivity differences of up to 40%, and Ovaskainen et al. (2004) up to 55%, between operators operating the same machine in similar conditions. Purfürst (2010) reported that operator productivity can double during the time that they

Corresponding author. Muhammad Alam, The University of Melbourne, 500 Yarra Boulevard, Richmond, 3121 Australia. Email: mmalam@student.unimelb.edu.au

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are learning to operate a harvester proficiently (approximately nine months).

Few studies have examined the influence of the characteristics of a harvester on its productivity. These studies identified engine power as the most important characteristic (Spinelli et al. 2010; Jiroušek et al. 2007). Crane characteristics, such as reach and lifting capacity, have also been found to be important (Lindroos et al. 2008), as have harvester head characteristics, such as feed speed, roller design (Nuutinen et al. 2010) and maintenance (Gerasimov et al. 2012).

Most harvester productivity studies examine harvester activities at a 'macro level' (moving, felling, processing, etc.), which limits their ability to identify causes of productivity losses that occur within an activity. Detailed 'micro-level' studies of individual activities might be better able to identify causes of productivity losses, but few have been done (e.g. Marshall & Murphy 2004) because they are costly and time-consuming. The most efficient use of resources may be to focus a study on the most time-consuming harvester activity because this activity would be expected to have the greatest scope for productivity improvement. In clearfell cut-to-length (CTL) operations, processing of trees into logs (delimbing, measuring and cross-cutting) is the largest single component of the harvest cycle. Published processing times as a percentage of cycle time range from 47% for a stand of small trees (mean volume 0.28 m^3), with a significant proportion of the harvester's time spent brushing (11%) and moving/positioning the head (31%) (Turner 2004), to 72% for a stand with large trees (mean volume 2.2 m^3), with little of the harvester's time spent brushing (3%) or moving/positioning the head (13%) (Walsh 2011).

A recent Australian study (Strandgard et al. 2013) found a large difference in the productivity of two near-identical single-grip harvesters performing CTL clearfelling harvesting operations in thinned *Pinus radiata* (radiata pine) plantations. The objective of the current study was to identify the reasons for the productivity differences between these harvesters by investigating the influence of detailed 'micro-level' log processing time elements, such as dragging out, disc-cutting, harvester head travel time (HHTT), and delimbing and cross-cutting time, on the productivity of each harvester. The study findings may identify potential changes to harvesters or operator techniques that could improve harvester productivity in other operations.

Material and methods

Study sites

The study was conducted in radiata pine clearfell harvesting operations at two Australian sites, one in South Australia managed by Forestry South Australia (FSA), and one in New South Wales managed by Forests New South Wales (FNSW) (Table 1).

Time and motion study

Harvester details

Details of the harvesters used in the study are given in Table 2.

All other features of the harvesters were the same or very similar. The harvester heads were calibrated at the beginning of harvest operation. The harvesters were designed to efficiently perform harvesting operations on slopes of up to 20° and to handle trees with diameters of up to 80 cm. The operator at the FSA site had eight years experience, and the operator at the FNSW site two years experience, in operating harvesters.

Harvesting operation recording

The harvesting operations were recorded using a digital video camera in fine, sunny conditions, 3 February 2011 at the FSA site and 23 April 2010 at the FNSW site. One hundred and ninety trees at the FSA site and 201 trees at the FNSW site were felled and processed for the study. Standard harvesting practice at both sites was to harvest in a four-row

Table 1. Study site characteristics.

Site attribute	FSA site	FNSW site
Location	Mount Burr Reserve Forest, South Australia	Buccleuch State Forest, New South Wales
Plantation age at harvest	35 years	34 years
Tree form and quality	Good	Good
Branchiness	Light branching	Medium/heavy branching
Number of thinnings	3	2
Undergrowth	Negligible	Blackberry and bracken fern, <1 m high
Soil composition	Aeolian sands	Red earths/basalt
Ground strength	Good	Good
Slope	<5°	<5°

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Table 2. Comparison of the main technical features of the harvesters.

Item	FSA harvester	FNSW harvester
Make and model	Valmet 475EX	Valmet 475EX
Manufacture year	2007	2004
Harvester head	Rosin 997 (2006 model, no. 5)	Rosin 997 (2006 model, no. 2)
Onboard computer system	Dasa 4	Dasa 4
Working hours	3,500	28,000

swath along the edge (face) of the stand, felling trees into the uncut stand and processing them to deposit the logs into piles in the previously harvested area, ready for forwarding to roadside.

Tree characteristics extraction

As noted in the introduction, tree form can influence harvesting productivity. To remove this potentially confounding effect, trees with multiple leaders, broken-tops (trees with tops broken during felling) and plantation-edge trees were excluded from analysis. The remaining trees are referred to as 'normal trees'. There were 153 and 103 normal trees at the FSA and the FNSW site, respectively.

Stem file data recorded by the harvesters' onboard computers (OBCs) to the StanForD standard (Skogforsk 2011) were used to estimate tree characteristics: diameter at breast height over bark (DBHOB); processed length and volume at the FSA site; and processed length and processed volume at the FNSW site. DBHOB and tree height were obtained from a preharvest inventory at the FNSW site. Processed tree length and volume for each tree were estimated by summing the lengths and volumes of individual component logs as measured by the harvester's OBC. Each tree video-recorded was linked to the corresponding stem file(s) from the OBC, by using the felling order at the FSA site and by using numbers painted on each tree at the FNSW site.

Sawlogs were cut to nominal lengths of 6.1 m, 4.3 m and 3.7 m at the FSA site and 6.1 m, 4.9 m and 3.7 m at the FNSW site. Variable-length pulplogs and stemwood waste were cut at both sites. Only 6.1 m sawlogs were selected for further study because they made up the majority of the log volume at both sites. Because collection of detailed log-level time-element data is a very time-consuming process, representative subsets of logs were selected for further analysis. The subsets were selected from the first three logs in the stem, because the lower stem contained most of the stem volume and was predominantly cut to 6.1 m sawlogs at both study sites. Each subset of 6.1 m sawlogs was made up from the first 3 logs cut from 31 trees from each site (93 logs at each site). Within each subset, the sawlogs were identified by log-order class (first, second or third log cut). Some log-level processing-time elements only occurred on some logs, so the subsets were selected using a combination of an initial random selection followed by a small amount of substitution to ensure that the proportions of logs with these time elements was the same as that in the initial population of normal trees.

Tree processing time extraction

The time for each time element (Table 3) was extracted from the video recordings using Timer Pro Professional software (www.acsco.com). Tree processing time for each normal tree was extracted first, and then log-level processing-time elements were extracted for each 6.1 m sawlog in each subset. Cycle time starts when the harvester or boom starts to move towards a tree to fell and process it and ends when the harvester has completed processing the tree and is about to move to the next tree.

A flowchart of the time elements is presented in Figure 1.

Harvester productivity analysis

- **Cycle-time productivity model**

Cycle-time productivity (in m^3 per productive machine hour [PMH] with all delays excluded) was estimated from cycle time (in productive machine minutes) as:

$$\text{Productivity} = (\text{Volume}/\text{Cycle time}) \times 60 \quad (m^3/\text{PMH}) \qquad (1)$$

where *volume* refers to the processed tree volume (m^3) over bark from the harvester's OBC, and *cycle time* is defined above.

- **Tree-processing-time productivity model**

Tree-processing productivity was estimated from tree processing time (in minutes) as:

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Table 3. Description of time elements.

Time element	Definition
Moving/positioning	Starts when the harvester begins to move and/or swing its boom towards a tree and ends when the head clamps onto the tree base.
Felling	Starts when the harvesting head clamps onto the base of the tree, immediately prior to the felling cut, and any machine movement momentarily ceases, and ends when feed rollers are activated, or the tree is horizontal, or the first bucking cut is made to reset the harvester's length measurement (whichever occurs first).
Log processing	Starts when feed rollers are activated, or the tree is horizontal, or the first cut is made to reset the harvester's length measurement (whichever occurs first), and ends when the log is cut and dropped on the ground or log pile.
Tree processing	Starts when feed rollers are activated, or the tree is horizontal, or the first cut is made to reset the harvester's length measurement (whichever occurs first), and ends when the last log is cut and dropped on the log pile.
Dragging out	Starts when the harvester grabs the felled (horizontal) tree and ends when the feed rollers are activated or the first cut is made to reset the harvester's length measurement (whichever occurs first).
Disc-cutting	Starts when the harvester head is prepared to saw a disc from the tree (at the large end of the next log) and ends when the waste-disc is cut off the log and dropped on the ground.
Delimbing	Starts when the harvester head begins to move along the stem to delimb the tree and ends when delimbing is complete.
Harvester head travel time (HHTT)	Starts when the harvester head begins to move forward along the lightly branched or unbranched stem and ends when the harvester head stops to cross-cut the stem into a log.
Cross-cutting	Starts when the harvester head has stopped to cross-cut the tree into a log and ends when the cross-cut is finished and the new log drops onto the pile.
Delay	Any interruption to the previous time elements. The cause of the delay (e.g. operational, personal, mechanical, or study induced) is recorded.

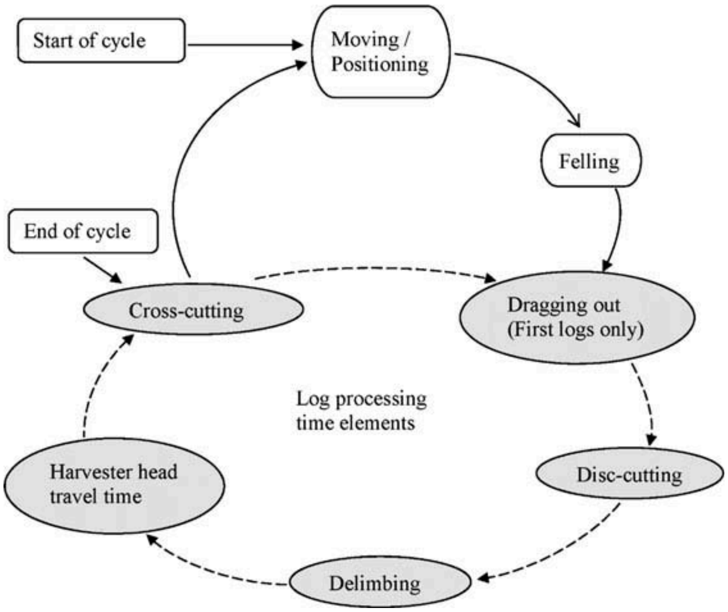

Figure 1. Flowchart of harvest cycle and log processing time elements. Note that log processing time elements (except dragging out) are repeated up to a maximum of seven times; disc-cutting and delimbing did not occur to all logs; and the dragging-out time element occurred only with first logs.

$$\text{Productivity} = (\text{Volume}/\text{Tree processing time}) \times 60 \quad (\text{m}^3/\text{PMH}) \quad (2)$$

where *tree processing time* is defined in Table 3 and *volume* is defined as for Equation (1).

For normal trees at both sites, regression models were developed for both cycle-time and tree-processing-time productivity against processed volume based on natural logarithm transformations of the independent variable (ln-*x* model) and both the

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dependent and independent variables (ln-*x*-&-*y* model). The model forms were compared for goodness of fit using mean bias, mean absolute deviation, root mean square error, coefficient of determination, and distribution of residuals. Best-fit productivity models for each site were compared using an F-test (Motulsky & Christopoulos 2003) to determine whether harvester productivity differed between sites. The shapes of the cycle-time and tree-processing-time productivity curves were visually compared to determine whether tree processing time was the major influence on cycle-time productivity.

- **Productivity calculation**

To remove the effect of tree size, the productivity of each harvester was compared at the mean tree volume calculated from the pooled tree volumes from both sites.

Analysis of 6.1 m sawlog time elements

Dragging-out, disc-cutting and delimbing time elements did not occur for every log in the data-set. Mean values for these time elements were calculated for each log-order class for the FSA and FNSW harvesters by summing the times for each time element and dividing by the number of logs where that time element occurred.

The nature of the data-set, that is, consecutive logs along each stem, suggested that log-size attributes might be strongly correlated with the variables being tested. This was tested using linear regression. If the relationships were found to be strong, the log-size attributes were tested as potential covariates in a two-way analysis of covariance (ANCOVA); if not, a two-way analysis of variance (ANOVA) was performed (assuming the data met the ANCOVA or ANOVA assumptions).

A two-way ANCOVA or ANOVA was carried out for HHTT, cross-cut time and log processing time elements for each log-order class and harvester. A general linear model was used to analyze the model, and pair-wise comparisons were performed using Tukey's post hoc test. ANCOVA or ANOVA could not be carried out for the other time elements (i.e. dragging-out time, disc-cutting time and delimbing time) because these time elements did not occur for every log. To examine the significance of these elements, the mentioned tests on the log processing times were redone following subtraction of the less frequent time elements. All statistical tests were done in Minitab 16 software, with the critical significance level set to 5% ($p = .05$).

Results

Tree measurements

Normal trees on the FNSW site were larger than those on the FSA site in terms of their mean processed length, DBHOB and processed volume (Table 4).

Harvester productivity analysis

- **Best-fit productivity models**

The model form which best fit the data at each site for harvester productivity based on cycle time and tree processing time was a natural logarithm transformation of processed volume (Eq.3):

$$\text{productivity} = \beta_0 + \beta_1 \times \ln(\text{processed volume}) \tag{3}$$

Model coefficients and fit statistics for the productivity models are shown in Table 5.

Mean harvester productivity based on cycle time for a merchantable volume of 2.04 m^3 was higher at the FSA site (124 m^3/PMH) than at the FNSW site (105 m^3/PMH). The harvester productivity models based on cycle time for the range of tree sizes processed at each site were significantly different (Figure 2).

The FSA and FNSW harvesters spent 68% and 71% of their respective cycle times processing trees, respectively. Mean harvester productivity based on tree processing time for a merchantable volume of 2.04 m^3 was higher at the FSA site (185 m^3/PMH) than at the FNSW site (151 m^3/PMH). The harvester productivity models based on tree processing time for the estimated tree sizes processed for each site were significantly different (Figure 3).

The similarity of the productivity models for each harvester based on tree processing time (Figure 3) to those based on cycle time (Figure 2) implies that tree

Table 4. Summary of normal tree measurements for the study sites.

Attribute	FSA site	FNSW site
Mean tree height (m)	35.4 *	34.0
Mean processed length (m)	26.4	27.9
Mean DBHOB (cm)	39.0	51.2
Mean processed tree volume (m^3)	1.8	2.4
Number of normal trees	153	103

* Estimated from 'site quality' for the study site as determined using the standard FSA method (Lewis et al. 1976).

Table 5. Model coefficients and goodness-of fit-statistics for each harvester's cycle-time and tree-processing-time productivity models (Equations (1) and (2)).

		Model coefficients		Goodness-of-fit statistics			
Time component	Harvester	β_0	β_1	Mean bias	MAD	RMSE	R^2
Cycle time	FSA	74.58	71.45	0	12.1	15.7	0.58
	FNSW	70.59	48.16	0	15.7	20.8	0.33
Tree processing time	FSA	118.34	93.92	0	23.93	30.2	0.40
	FNSW	119.16	44.92	0	25.16	81.8	0.15

Note. MAD = mean absolute deviation. RMSE = root mean square error. R^2 = coefficient of determination.

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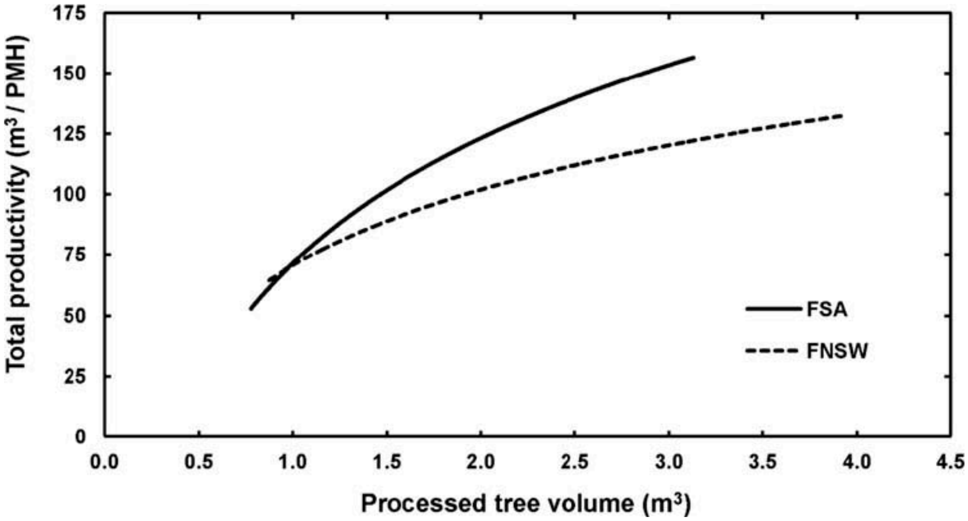

Figure 2. Comparison of harvester productivity models based on cycle time against processed tree volume at the study sites.

processing time has the greatest influence on cycle-time productivity.

- **Mean time consumption by log-order class**

There were clear differences between the two harvesters in the number of logs which had dragging out, disc-cutting and delimbing performed on them (Table 6). Dragging out was performed on almost every first log by the FNSW harvester, but was not carried out at all by the FSA harvester. Similarly, disc-cutting was performed on every first log by the FNSW harvester but on only 3 third logs by the FSA harvester. Delimbing was performed on almost 50% of the third logs by the FNSW harvester, and on 2 first and second logs, but on only 3 third logs by the FSA harvester.

The variables which occurred on every log (HHTT, cross-cut time and log processing time) were not found to be strongly linearly related to potential covariates log volume or log small-end diameter over bark, and therefore a two-way ANOVA was performed. The inverse of log processing and HHTT elements satisfied the ANOVA assumptions. Therefore, ANOVA results of these two time elements were back-transformed to obtain their mean values.

HHTTs were significantly shorter for the FSA harvester than for the FNSW harvester for all log-order classes and for the harvester mean values (Table 7).

Cross-cutting times generally decreased from the first to the third log-order class for each harvester (Table 7). The mean cross-cutting time for the FNSW harvester was significantly shorter than that for the FSA harvester (Table 7). Harvester-by-log-class interaction was not significant.

The FSA harvester's mean log processing times were relatively consistent across all log-order classes, whereas there was considerable variation in log processing times across log-order classes for the FNSW harvester. Mean log processing times were significantly longer at the FNSW site than at the FSA site

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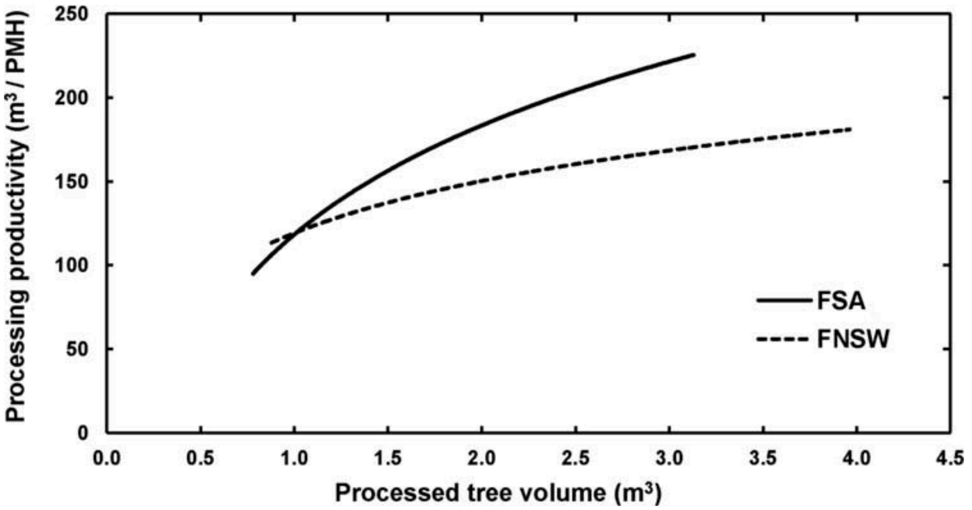

Figure 3. Comparison of harvester productivity based on tree processing time against processed tree volume at the study sites.

Table 6. Mean log-level dragging-out, disc-cutting and delimbing time-element values, with standard deviation (SD, seconds) and observation number (*N*) for each harvester and log-order class.

	FSA harvester			FNSW harvester									
	Third log			First log			Second log			Third log			Mean of all logs pooled (s)
Time element	Mean	SD	*N*	Mean	SD	*N*	Mean	SD	*N*	Mean	SD	*N*	
Dragging-out time	–	–	–	5.18	2.54	29	–	–	–	–	–	–	5.18
Disc-cutting time	2.04	0.16	3	2.83	0.66	31	–	–	–	2.76	–	1	2.82
Delimbing time	5.08	0.25	3	6.54	1.10	2	5.70	1.44	2	6.77	1.76	14	6.63

Table 7. Log-level harvester head travel time, cross-cut time and log processing element values – mean values (standard deviation), in seconds – for the three log-order classes at the two study sites (*N* = 31 within log orders, and *N* = 3 for mean values within harvesters).

	FSA harvester				FNSW harvester			
Time element	First log	Second log	Third log	Mean	First log	Second log	Third log	Mean
Harvester head travel time (HHTT)	2.43^{A} (0.35)	2.38^{A} (0.39)	2.27^{A} (0.28)	2.36^{a}	3.13^{B} (0.61)	3.37^{B} (0.99)	3.08^{B} (0.94)	3.20^{b}
Cross-cutting time	1.93^{A} (0.28)	1.80^{B} (0.35)	1.73^{B} (0.31)	1.82^{a}	1.85^{A} (0.38)	1.62^{B} (0.29)	1.45^{C} (0.22)	1.64^{b}
Log processing time	4.36^{A} (0.48)	4.14^{A} (0.63)	4.21^{A} (2.34)	4.24^{a}	12.14^{B} (3.78)	5.21^{C} (1.73)	6.10^{C} (4.12)	7.82^{b}
Log processing time (HHTT and cross-cutting times only)	4.36^{AB} (0.48)	4.14^{AB} (0.63)	3.98^{A} (0.48)	4.15^{a}	4.97^{C} (0.82)	5.00^{C} (1.20)	4.57^{BC} (1.01)	4.84^{b}

Note. Means along a row that do not share a letter with the same case are significantly different.

for all log-order classes and for the harvester means (Table 7). The greatest difference was in the first log-order classes, where the FNSW mean log processing time was approximately three times that of the FSA first log-order classes.

Subtracting dragging-out time, disc-cutting time and delimbing time from the log processing times for each log-order class and harvester had little effect on the FSA harvester's mean log processing times. There was a substantial drop in the mean log processing time

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for the first log of the FNSW harvester, which resulted in there being no significant differences between the mean log processing times for this harvester.

Discussion

Mean log processing times were longer for all three FNSW log-order classes than for the FSA log-order classes (Table 7), and the predicted productivity of the FNSW harvester was lower than that of the FSA harvester for trees with processed volumes of 1–3 m^3 (Figure 2).

The major determinants of the longer log processing times and lower productivity of the FNSW harvester were found to be dragging-out of trees and disc-cutting for the first log cut; delimbing of the third log cut (as these activities were rare or non-existent for the FSA harvester); and HHTT for all three log-order classes (Tables 6 and 7).

Dragging-out time was the most important factor overall in the longer tree processing time, and hence lower productivity, of the FNSW harvester, accounting for over 5 seconds of additional time for most trees (Table 6). The FNSW harvester operator dragged out most of the trees after felling by slewing the machine around. The FSA harvester operator did not drag out any tree, instead moving the trees using their gravitational momentum as they fell by feeding them through feed rollers and simultaneously slewing the machine (if necessary). The impact of dragging-out time on the productivity of the FNSW harvester is highlighted by the fact that trees with a processed volume of less than 1 m^3, for which both harvesters had comparable productivities (Figures 2 and 3), were not dragged out by the FNSW harvester.

The FNSW harvester operator also spent time cutting discs from the base of every first log and one third log to reset the length-measurement device to zero. The FSA harvester operator did not cut discs from any first log and only three third logs in the sampled logs. Cutting discs needs to be done if the tree is dropped or after repeated delimbing passes (Plamondon 1999), but at times appeared to be excessive and/or unnecessary and further reduced the FNSW harvester's productivity.

HHTTs were significantly longer for the FNSW log-order classes than for the FSA log-order classes. After the trial, the FNSW harvester operator was found to have set the delimbing knife pressure higher than normal, which may have in part caused the greater HHTTs for the FNSW harvester by creating excessive friction and slowing the harvester head. HHTT may have been expected to decrease as each 6.1 m sawlog was cut, because this would have substantially reduced the weight of the remaining stem. However, there were no significant differences between log-order class HHTTs for each harvester (Table 7), which implies that tree weight was not the major factor affecting HHTTs. Potential other causes include feed-roller slippage (Nuutinen et al. 2010), the feed rollers achieving close to their maximum speed on the first log, and the friction of the crown contacting the ground.

There were several other factors that may have caused longer tree processing times at the FNSW site. For instance, the FNSW harvester operator was observed to start processing trees only after they had been felled and were horizontal on the ground, whereas the operator in the FSA harvester was regularly observed to start processing trees while they were falling. Hence, processing of the first log started much earlier at the FSA site. The FNSW harvester operator also frequently undertook a long sweep up the tree with the harvester head to delimb it well into the crown. This generally occurred for the second and/or third log to be processed. Ovaskainen (2009) noted that this work technique is used to maintain the momentum of the harvester head to more efficiently delimb more heavily branched trees. Although this did not seem to restrict the operability of the harvester, it added some extra time to the processing time for the third log-order class at the FNSW site, which reduced the processing productivity for these logs and the overall productivity. Marshall and Murphy (2004) found that moving the harvester head further along the stem before cross-cutting improves the prediction of stem dimensions and hence value recovery. Further study would be required to learn whether the long sweeping delimbing passes improve the FNSW harvester's ability to recover greater value from the trees. The finer branches at the FSA site allowed the FSA harvester operator to delimb the trees without a separate sweep of the harvester head along the stem.

Although the differences in machine age and working hours between the two harvesters were not believed to be a significant factor in their productivity differences, these differences were not investigated in this study and so further study would be required to determine their influence on productivity.

Conclusions

Operator working technique was identified as the major cause of the difference in productivity between the FSA and FNSW harvesters. In particular, the study identified 'micro-level' log processing time elements such as dragging-out of trees, disc-cutting, harvester head travel time (possibly caused by incorrect delimbing knife pressure settings) and

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delimbing as causing the lower productivity of the FNSW harvester. This result suggests the need for greater formal training of harvester operators in Australia. Although opportunities exist for formal operator training, many operators are still largely trained 'on the job'. Refresher training is most likely required to acquaint operators with new machine operation techniques and to redress any bad habits they have developed over time.

References

Gellerstedt S. 1997. Mechanised cleaning of young forest — The strain on the operator. Int J Ind Ergonom. 20:137–143. 10.1016/S0169-8141(96)00046-7

Gerasimov Y, Seliverstov A, Syunev V. 2012. Industrial round-wood damage and operational efficiency losses associated with the maintenance of a single-grip harvester head model: A case study in Russia Forests. 3(4):864–880.

Jiroušek R, Klvac R, Skoupy A. 2007. Productivity and costs of the mechanised cut-tolength wood harvesting system in clear-felling operations. J. For. Sci. 53(10):476–482.

Kärhä K, Ronkko E, Gums SI. 2004. Productivity and cutting costs of thinning harvesters. Int J For Eng. 15:43–56.

Kellogg LD, Bettinger P. 1994. Thinning productivity and cost for mechanized cut-to-length system in the Northwest pacific coast region of the USA. Int J For Eng. 5:43–54.

Lewis NB, Keeves A, Leech JW. 1976. Yield regulation in South Australian Pinus radiata plantations (Bulletin 23). Adelaide, South Australia: Woods and Forests Department.

Lindroos O, Bergström D, Johansson P, Nordfjell T. 2008. Cutting Corners with a New Crane Concept. Int. J. For. Eng. 19(2):21–28.

Marshall H, Murphy G. 2004. Economic evaluation of implementing improved stem scanning systems on mechanical harvesters/processors. N Z J For Sci. 34:158–174.

Motulsky HJ, Christopoulos A. 2003. Fitting models to biological data using linear and nonlinear regression: a practical guide to curve fitting. San Diego (CA): GraphPad Software Inc.

Nåbo A. 1990. Skogmaskinförarens arbetslastning – Studier av arbete I röjning, gallring och slutavverkning (Operator work load in forest machines – Studies in precommercial thinning-, thinning- and final felling operations). Sveriges lantbruksuniversitet. Rapport nr 185. Institutionen för skogsteknik, Garpenberg. p. 40.

Nakagawa M, Hamatsu J, Saitou T, Ishida H. 2007. Effects of tree size on productivity and time required for work elements in selective thinning by a harvester. Int J For Eng. 18:43–48.

Nicholls A, Bren L, Humphreys N. 2004. Harvester productivity and operator fatigue: working extended hours. J For Eng. 15:57–65.

Nurminen T, Korpunen H, Uusitalo J. 2006. Time consumption analysis of the mechanized cut-to-length harvesting system. Silva Fenn. 40:335–363.

Nuutinen Y, Väätäinen K, Asikainen A, Prinz R, Heinonen J. 2010. Operational efficiency and damage to sawlogs by feed rollers of the harvester head. Silva Fenn. 44:121–139.

Ovaskainen H. 2009. Timber harvester operators' working technique in first thinning and the importance of cognitive abilities on work productivity. Doctoral Thesis, University of Joensuu, Finland.

Ovaskainen H, Uusitalo J, Väätäinen K. 2004. Characteristics and significance of a harvester operators' working technique in thinnings. Int J For Eng. 15:67–77.

Plamondon JA. 1999. Log-length measurement errors with six single-grip harvester heads. Techical Note TN-297. Forest Engineering Research Institute of Canada (FERIC), Pointe-Claire, Que'bec. p. 6.

Purfürst F, Erler J. 2012. The human influence on productivity in harvester operations. Int J For Eng. 22:15–22.

Purfürst FT. 2010. Learning curves of harvester operators. Croat J For Eng. 31:89–97.

Skogforsk. 2011. StanForD. Listing of variables by category. Available from: http://www.skogforsk.se/PageFiles/60712/AllVarGrp_ENG_110504.pdf [Accessed 13 October 2011].

Spinelli R, Hartsough BR, Magagnotti N. 2010. Productivity standards for harvesters and processors in Italy. Forest Prod. J. 60(3):226–235.

Strandgard M, Walsh D, Acuna M. 2013. Estimating harvester productivity in Pinus radiata plantations using StanForD stem files. Scand J For Res. 28:73–80. 10.1080/02827581.2012.706633

Turner DR. 2004. Productivity of a small cut-to-length harvester in northern Idaho. Master of Science Master Thesis, University of Idaho.

Visser R, Spinelli R, Saathof J, Fairbrother S. 2009. Finding the 'Sweet-Spot' of mechanised felling machines. In: Proceedings of USA: 32nd Annual Meeting of the Council on Forest Engineering (COFE); 2009; Kings Beach (CA). p. 10.

Walsh D. 2011. Optimisation study-quantifying the value recovery improvement using in-forest optimisation. CRC for Forestry Internal Report. p. 21.