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A MECHANISED HARVESTING SYSTEM IN A CLEARFELL RADIATA PINE OPERATION IN AUSTRALIA

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Figure 1 - The Timberline ST3530 delimber

ABSTRACT

A mechanised harvesting system was evaluated in a radiata pine clearfell operation in Bago State Forest, New South Wales, Australia. A Timbco T430 feller-buncher, Timberline ST3530 delimber and a wide-tyred Kockums 85-35 forwarder were studied.

Estimated productivity for the Timbco T430 feller-buncher was 119 m³ per productive machine hour in an average merchantable tree size of 2.2m³. Mechanical availability was 90% and machine utilisation was 76%.

Estimated productivity for the Timberline ST3530 delimber was 59m³ per productive machine hour. A regression equation for total processing time is given. Mechanical availability was 86% and machine utilisation was 68%.

Estimated productivity for the Kockums 85-35 forwarder was 33m³ per productive machine hour. Regression equations for both travel times empty and loaded are given. Mechanical availability was 99% and machine utilisation was 82%

INTRODUCTION

The suitability of mechanised harvesting systems for the clearfelling of New Zealand's new crop radiata pine is a topical issue. Legislation signalling increased concern for the safety and health of manual workers in the logging industry, and the increasing costs associated with manual labour, have heightened interest in alternatives to motor-manual logging systems.

To date, there have been numerous studies of mechanised operations in New Zealand in production thinnings (Evanson and McConchie, 1992; Hill, 1991; Vaughan, 1990; Raymond, 1989). Mechanised clearfell operations have been largely limited to the logging of minor species, and consequently, small (< 1 m^3) tree size (Hill and Raymond, 1991; McConchie, 1980; Raymond and Hawinkels, 1988).

The development and use of machines for clearfell operations in large timber (> 1m^3) has mostly taken place in the United States and Canada. The use of these machines has also been limited to these countries, with the exception of Australia. Here, mechanised harvesting in thinnings has a much longer history, and machines developed in the United States and Canada are also being used for the clearfelling of radiata pine. The notable exception to this has been the introduction in New Zealand last year of the Waratah Hydraulic Tree Harvester Model 234.

A study was carried out on an established mechanised clearfell operation in Australia. The system chosen was owned by Jim Crozier, an experienced contractor in both clearfell and production thinning operations. Machines of interest were primarily a Timbco T430 feller-buncher (Timbco) equipped with an 82 cm bar saw and a Timberline ST3530 stroke delimber (Timberline). Also part of the system, extracting log length wood, was a Kockums 85-35 forwarder (Kockums) which was equipped with wide tyres. Specific attention was given to the effect of tree factors, such as volume and tree form on production. Length measurement accuracy of the delimber, system soil disturbance, and merchantable and unmerchantable residue were also assessed.

Machines Studied

Figure 2 - Timbco T430 feller-buncher

The Timbco is a 25 tonne feller buncher made by Timbco Hydraulics Inc. in the United States (Figure 2). The model T 430 studied was equipped with a Timbco felling head with an 82 cm bar saw and 3/8 inch chain. The carrier has a self-levelling cab, and is powered by a Cummins 128 kW motor (in an engine-up configuration) and has Caterpillar D6 (60 cm track shoes) undercarriage componentry. The manufacturer claims that it can operate on slopes of up to 30°.

The Timberline (Figure 1) is a purpose-built stroke delimber with motor, cab and undercarriage componentry in common with the Timbco. It has a 12 metre boom, tunnel opening of 85 cm by 95 cm, and 95 cm capacity front and rear grapples. It includes a computerised measuring system, and a manual over-ride of this function.

The Kockums used was a nine year old machine, recently equipped with wide tyres (66 x 43 x 25 - front, 48 x 31 x 28 - rear). These tyres have been specified by the forest owner in order to reduce levels of soil disturbance, especially in wet conditions.

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OPERATION DESCRIPTION

Stand Description

The stand was located in Bago Forest, on land owned and managed by the New South Wales Forestry Commission. The contractor, J. and P. Crozier Limited was contracted to timber purchaser, Boral Timber Limited. Pre-assessment data estimated sawlog recovery in the 35 year old stand at 331 m^3/ha. Predominant mean height was 38.8 metres, and sectional measurements indicated a merchantable tree length of approximately 26 metres, with a small-end diameter of 22cm. Mean diameter at breast height (DBH) of felled trees in the study was 50 cm.

Terrain

The terrain was flat to rolling, with the maximum slope being 15°. The N.S.W. Forestry Commission classes forestry operations as suitable for either summer, intermediate, or winter seasons. This stand was classified as being a winter block because of the proximity of an all-weather road, and the terrain slope. Soils were clay and were granite based (Greenhills granite), and the site had an erosion rating of "average". The study was carried out in mid-September, and conditions were wet.

Weather and Environmental Constraints

Heavy rains had preceded the study period. Wet weather logging controls designed to reduce accelerated soil disturbance and water turbidity were applied in this operation, and meant that slash was required to be distributed evenly on extraction tracks. Loaded forwarder operations were to cease if water was running in water table drains or in ruts; operations could continue in wet conditions if rutting did not exceed 250mm within 30 metres of a stockpile or on major extraction tracks. Within compartments rutting should not exceed 100mm.

Harvesting System

The logging system consisted of one feller-buncher, one stroke delimber and one forwarder. The feller-buncher felled trees uphill moving from the top of a slope downhill. Having completed a swathe, the feller-buncher would travel back to the top and start again. This enabled easier breaking out of trees for delimbing; it was carried out in an uphill direction, as gravity enabled easier and faster processing. Having delimbed and processed a swathe of felled trees, the delimber travelled back to the bottom and repeated the process. Log length wood was extracted by forwarder via access rows (Figure 3) to a roadside dump and loaded out via a wheeled hydraulic loader (owned by the contractor, who also operated his own logging trucks). The logging site was approximately 40 km from the mill.

Figure 3 - Layout of logs for forwarder extraction

In this operation, no pulp wood was processed. Log length specifications for sawlogs were effectively : -5cm and +9cm (14cm). If, for instance, a 6.0m log was required at the mill, a log of length 6.1m would be specified and length of between 6.05 and 6.15 metres (10cm) would be accepted. Sawlog lengths required were : 6.0 metres (over 25cm SED), 4.8 (over 20cm SED), 3.0, 3.3, 3.6, 3.9, 4.2 metres, (minimum 20cm SED). A scanner at the mill infeed assessed the logs for length, and results formed the basis for payment to the contractor. An overall in-specification result of > 90% was considered acceptable.

STUDY METHOD

Continuous time studies were carried out on the Timbco, Timberline and Kockums for defined elements of the work cycle. Tree volume felled and processed was estimated using a one-dimensional volume table derived from 40 trees scaled in the setting. All delays were measured and changes in the method of operation noted.

A sample of 629 logs was measured to assess length measuring accuracy. Stump height was measured by marking DBH on a standing tree, then measuring from the butt to DBH mark, once felled.

Studies of some harvesters in New Zealand, mainly in thinning operations, have indicated that tree processing time is affected by tree form (Raymond et al, 1988). To determine whether tree form affected stroke delimber productivity, a tree form index was noted for each tree processed (Table 1).

Table 1 - Tree form class (after Raymond et al, 1988)

Form Class	Description
1	Straight trees with light branching
2	Trees with moderate sweep and/or heavy branching
3	Forked trees and malformed stems

Assessments were also made of soil disturbance and of merchantable waste using a modified transect-based system. Soil disturbance was classified into undisturbed, slight and severe disturbance (Miller and Sirois, 1987). A Wagner waste procedure was carried out (Van Wagner, 1968) to determine levels of waste.

RESULTS AND DISCUSSION

Timbco T430

The Timbco was studied for two days. Average merchantable tree size felled was estimated at 2.2m^3 with a standard deviation of 0.8m³ (ranging from 0.1 to 4.1m³). Mean DBH was 50.4cm (ranging from 20cm to 74cm). A summary of time-study results is shown in Table 2.

Table 2 - Summary of results for the Timbco

No. of pieces processed	509
Study time (hours)	13.47
Productive time (hours)	10.24
Machine utilisation	76 %
Machine availability	90 %
Mean tree size (m^3)	2.2
Estimated trees processed per PMH	54.0
Estimated production per PMH (m^3)	119

Delay-free cycle time was 1.11 minutes per felled tree. A summary of cycle time, showing the distribution of cycle elements, is shown in Table 3.

Table 3 - Cycle time summary

Element	Number of Cycles	Mean time per Occurr-ence	Mean time per cycle	Range (±)	% of total
Fell	509	0.37	0.37	0.02	25
Bunch	79	0.34	0.05	0.02	3
Move to fell	512	0.56	0.55	0.04	38
Reposition	22	3.04	0.13	0.06	9
DELAY- FREE TOTAL			1.11		
Personal delay	6	16.1	0.19		10
Operational delay	4	1.42	0.01		-
Mechanical delay	12	6.63	0.15		15
			0.35		
TOTAL CYCLE TIME			1.46		

* Range for 95% confidence Interval

The largest contributor to delay-free process time was the "move to fell" element. This is consistent with findings by other researchers (Gingras, 1989). Fell time was not significantly related to tree volume ($p > 0.05$).

Timberline Delimber

The Timberline was studied for two days. Average merchantable tree size processed was estimated at 2.2m³. A summary of time-study results is shown in Table 4.

Table 4 - Summary of results for the Timberline

No. of pieces processed	293
Study time (hours)	15.31
Productive time (hours)	10.41
Machine utilisation	68 %
Machine availability	86 %
Mean tree size (m^3)	2.2
Logs per tree	3.7
Estimated trees processed per PMH	27.0
Estimated production per PMH (m^3)	59

Trees were processed in two phases: a tree was picked up and delimbed to approximately 12 metres, cut, and the butt piece processed into an average 1.7 logs; the top piece was then picked up and delimbed and processed, into an average 2.2 logs. Of the total time per tree, 42% was spent processing the butt and 58% on the top piece.

Delay free cycle time was 2.2 minutes per processed tree length. A summary of cycle time, showing the distribution of cycle elements, is shown in Table 5.

Table 5 - Cycle time summary (minutes)

Element	Number of Cycles	Mean time per Occurr-ence	Mean time per cycle	Range (±)*	% of total
Pick up tree	293	0.39	0.39	0.02	12
Process	290	1.28	1.27	0.05	40
Move	135	0.49	0.24	0.03	7
Re-position	12	5.62	0.23	0.15	7
Clear slash	94	0.21	0.07	0.01	2
DELAY-FREE TOTAL			2.20		
Personal delay	9	12.75	0.39		13
Operational delay	16	3.12	0.17		5
Mechanical delay	18	6.99	0.43		14
			0.99		
TOTAL CYCLE TIME			3.19		

* Range for 95% confidence interval

Data were analysed to determine the effects of tree volume, and the number of logs cut, on a combined time of "pick up and process". Tree volume was found to be significant ($p > 0.05$), but explained only 22% of the time variation. Using a stepwise regression procedure, and adding the number of logs processed per cycle variable, created a model explaining 49% of the variation (see equation below). A form class assessment showed : 10% of processed trees in class 3, 37% in class 2 and 53% in class 1. Tree form had no significant ($p > 0.5$) effect on "process" time.

Total process time (minutes) =

(-27.81+(21.90 x TreeVolume) + 36.93 x (Number of logs))/100

$r^2 = 0.49$

As with the Timbco, move time can be divided into time spent moving from bunch to bunch within a row, and repositioning to the start of a new processing row. These rows were then used by the forwarder for access to stacks of processed logs (Figure 3). Reposition time comprised 38% of the total moving time. The number of trees processed per row ranged from an average of 33 on slopes of less than 5° to 18 trees on slopes of up to 13°. The row pattern was dependent on terrain. If trees in a gully were being processed, rows would be short, and linked to longer rows on a broad spur.

Where possible, trees to be processed were bunched by the Timbco so that butts were in line. This maximised the number of trees that could be reached by the delimber from a single location. On average, 2.2 trees were processed at each site along the row.

It has been suggested that tree length delimbing by stroke delimber might be an option for delimbing radiata pine while preserving the perceived advantages of motor-manual log making. This method was attempted on several trees at our request, but the lack of butt support meant that trees tended to break at the delimbing knives under their own weight. A support or extension for tree length delimbing is available, and would probably work well in a system where the pruned butt log could be cut prior to delimbing the remainder of the tree.

Length Measurement, Delimbing Quality, and Log Quality

A total of 440 logs were measured. A breakdown of results by log type is shown in Table 6. Results are also presented showing the percentage of logs falling out of specification for a range of tolerances (Table 7).

Table 6 - Log measurement results by grade

Log type	Number of logs measured	Mean length (m)	Standar deviatio (cm)
4.0 m sawlog	26	3.99	3.6
4.3 m sawlog	20	4.31	3.2
4.9 m sawlog	75	4.90	4.5
6.1 m sawlog	280	6.11	6.6

Delimbing quality assessment of 260 logs showed that 54% of logs had branches cut flush or had stubs of less than 1cm. Draw wood occurrence was examined in stubs on 104 logs, 14% showed evidence of draw wood of an estimated 2.8 cm average depth. Splitting or slabbing at log small ends was assessed on 394 logs; 10% had either splits or slabs of > 4 cm thickness.

Table 7 - Logs out of specification (as percentages) for different tolerances

Log type	Tolerances (cm) ± 1	± 2	± 3	± 4	± 5	± 6	± 7	±10	±15
4.9 m sawlog	73	55	27	17	12	8	7	3	3
6.1 m sawlog	71	54	35	24	14	10	8	3	1

Kockums Forwarder

A Kockums, equipped with wide tyres, was studied on two different days. Estimated average log size was 0.6 m^3. A summary of time-study results is shown in Table 8.

Table 8 - Summary of results for the Kockums forwarder

No. of loads	17
Study time (hours)	6.37
Productive time (hours)	5.22
Machine utilisation	82 %
Machine Availability	99 %
Mean load size (m^3)	9.9
Logs per load	16.5
Average haul distance (m)	192
Estimated loads per PMH	3.3
Estimated production per PMH (m^3	33

Delay-free cycle time was 18.25 minutes per load. A summary of cycle time, showing the distribution of cycle elements, is shown in Table 9.

Table 9 - Cycle time summary (minutes)

Element	Number of Cycles	Mean time per Occurrence	Mean time per cycle	Range (±)*	% of total
Travel empty (208m)	17	3.54	3.54	0.81	16
Load	17	5.54	5.54	0.48	24
Move loaded (sum)	17	1.03	1.03	0.44	5
Travel loaded (192m)	17	3.79	3.79	1.0	17
Unload	17	4.35	4.35	0.37	19
DELAY- FREE TOTAL			18.25		
Personal delay	2	13.33	1.57		7
Operational delay	4	10.72	2.52		11
Mechanical delay	2	1.07	0.13		1
			4.22		
TOTAL CYCLE TIME			22.47		

* Range for 95% confidence Interval

Table 10 - Costing schedule

Cost Item	Timbco 430 Feller buncher	Timberline ST3530	FMG Timberjack 18 40 (18 Tonne)
New Price (NZ$)	$531 000	$670 000	$650 000
Resale at 9000 hrs	$225 000	$300 000	$280 000
Operator cost/day	$170	$170	$170
Share of overheads	$30	$30	$30
Depreciation	$215	$260	$241
Interest	$195	$253	$243
Insurance	$26	$33	$32
Fuel and oil	$78	$78	$96
Repairs and Maint.	$130	$156	$169
Tyres	-	-	$39
Total cost/day	$844	$980	$1020
+ 10% profit	$928	$1080	$1122
Total Cost/hr	$143	$166	$173
Cost/m^3	$1.20 (119$m^3$/PMH)	$2.81 (59$m^3$/PMH)	$5.24 (33$m^3$/PMH)

Regression equations relating travel loaded and travel empty times versus distance travelled were developed :

Travel empty time (min) =
0.764 + 0.013 x Distance (metres)
$r^2 = 0.97$

Travel loaded time (min) =
0.631 + 0.016 x Distance (metres)
$r^2 = 0.98$

Soil Disturbance

Undisturbed soil was assessed at 20% by area, slightly disturbed at 68% and severely disturbed at 12%.

Of the slightly disturbed area, 31% was classified as slash cover with only slight evidence of machine passage, and 41% was classified as slightly compacted slash where grouser marks could be seen. Of the severely disturbed area, 45% was classed as compacted, exposed subsoil and 26% as compacted slash. Only 16% of the severely disturbed area, or 2% of the total area, was identified as being rutted.

Waste and Slash Assessment

An assessment of cutover waste produced estimates of sawlog waste of 3.9m^3/ha, pulp waste of 25.8m^3/ha and unmerchantable material (diameter > 6cm) of 23.5m^3/ha. The levels of pulp waste are consistent with operations that do not have a market for pulp logs.

System Balance

Under normal conditions, in Australia, this system would comprise one feller-buncher, two delimbers and two forwarders. During the study abnormal conditions prevailed, consequently no evaluation of balance could be made. Because the machines studied produce at different rates, care needs to be taken when designing logging systems in order to achieve system balance.

COSTS

A costing (Wells, 1981) ($/day (6.5 productive machine hours)) of two of the machines studied, and one example machine is shown in Table 10.

CONCLUSIONS

Estimated productivity for the Timbco was $119m^3$ per productive machine hour in an average merchantable tree size of 2.2 m^3. Mechanical availability was 90% and machine utilisation was 76%. The effect of tree volume on fell time was tested and was found not to be significant ($p > 0.05$).

Estimated productivity for the Timberline was $59m^3$ per productive machine hour. Mechanical availability was 86% and machine utilisation was 68%. Tree volume had a significant ($p > 0.05$) effect on "pick up and process" time, as did the number of logs processed. Tree form had no significant effect ($p > 0.05$) on process time.

Estimated productivity for the Kockums was $33m^3$ per productive machine hour. Mechanical availability was 99% and machine utilisation was 82%.

A soil disturbance assessment following harvesting showed that undisturbed soil comprised 20% by area, with 68% slightly disturbed, and 12% severely disturbed.

The relative productivity components of the system studied suggest that the balancing of mechanised systems should be accorded a high priority by planners and contractors. In this case, environmental and operational considerations precluded operation of such a balanced system.

Study results, demonstrating performance in a merchantable tree size comparable to New Zealand conditions, indicate that the Timbco and Timberline could be considered as candidates for a mechanised system for the clearfelling and processing of New Zealand's new crop radiata pine.

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The costs stated in this report have been derived using the procedure shown in the LIRA Costing Handbook for Logging Contractors. They are an indicative estimate only and do not necessarily represent the actual costs for this operation.

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