LOGGING INDUSTRY RESEARCH ASSOCIATION

NEW ZEALAND

PROJECT REPORT

MECHANISED SHORTWOOD THINNING WITH FORWARDER EXTRACTION

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Project Report

P.R. 42

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ABSTRACT

A study of a fully mechanised Radiata pine thinning operation producing measured shortwood lengths was undertaken. A Waratah delimber-feller-buncher (DFB) partially delimbed then felled and bunched the trees. A Waratah grapple processor completed the delimbing, then cut to measured length and stacked the shortwood for forwarder extraction. The Volvo 861 forwarder extracted over distances averaging 658m and loaded trucks both directly from the forwarder and from roadside stockpiles. Productivity rates averaged 83 trees per PMH for the DFB (15.8 tonnes/PMH) and 66 trees per PMH for the processor (12.5 tonnes/PMH). Forwarder productivity, given payloads of 10.9 tonnes, averaged 12.7 tonnes/PMH. The most significant factor influencing forwarder productivity was extraction haul distance. Productivity ranged from 15.9 tonnes/PMH at 100m haul to 11.9 tonnes/PMH at 900m.

ACKNOWLEDGEMENTS

LIRA acknowledges the assistance of United Logging Limited, and Northern Pulp Limited, Kaitaia in this study.

STUDY AREA

The study was conducted in a "Board" regime stand of 12 year old Radiata pine in Aupouri Forest (Table 1). The stand had previously been thinned to waste to approximately 830 stems per hectare, of which 250 stems had been high pruned to 6.0m.

Table 1 : Stand Details

Total stocking (sph)	*830*
Crop stocking (sph)	*275*
Thinnings :	
Mean merch. length (m)	*10.1*
Mean merch. LED (cm)	*20.4*
Mean merch. volume (m^3)	*0.17*

The operation consisted of thinning the stand down to approximately 275 sph. The stocking prior to thinning was such that an outrow system was not required. The DFB and processor worked through the stand roughly in the direction of the planting rows, minimising the removal of crop trees. Merchantable tree size was $0.17m^3$. This was calculated from the mean number of log lengths processed from each tree and the measured piece weight (tonnes). This was converted to volume using a conversion factor of $0.9m^3$/tonne.

STUDY METHOD

Cycle time data was collected on the DFB, the Waratah processor and the Volvo forwarder to enable calculation of machine productivity.

(1) Waratah DFB Harvester

The elements of the DFB work cycle in the first study were:

- Position head on the tree
- Delimb the tree by moving head up and down several times
- Fell the tree
- Bunch (including move to bunch)
- Clear slash.

Detailed timing of the DFB operation was undertaken for one day during which time 277 work cycles were recorded. The operator had approximately six months experience on the machine and appeared to have reached a competent standard.

Delays involving mechanical breakdown or other major stoppages were not recorded due to the short term of the study. Operational delays (i.e. those occurring during periods of machine operation) were recorded during the study.

(2) Waratah grapple processor

The time to process 476 trees into 75 bunches was measured (6 to 7 trees per bunch average).

The work cycle of the processor comprised the following elements:

- Pick up tree
- Process (delimb and cut to length)
- Move between bunches
- Clear slash.

Operational delays such as resetting the length measuring computer, interference from the manual trimmer, and mechanical delays such as sharpening the chainsaw were recorded.

(3) Volvo Forwarder

The elements of the forwarder work cycle were:

- Run empty (return to bush on sand track)
- Travel empty (in-bush travel)
- Load forwarder
- Move while loading (between bunches)
- Travel loaded (in-bush)
- Run loaded (on sand track)
- Unload (either to truck or stockpile)
- Delays (mechanical, operational, and personal).

The forwarder operator worked a systematic pattern, extracting each line of processed wood prior to commencing the next one (Figure 3). The forwarder loaded on the way into the bush. Once loaded, the forwarder turned and travelled by the most direct route either straight onto the truck road, or onto the sand track and then out to the road. The normal work method involved unloading direct to truck or trailer. There was direct radio communication between the forwarder and the trucks and efforts were made to ensure that trucks were scheduled into the operation regularly in order to minimise forwarder unloading to stockpile. This was because loading trucks from the stockpile constituted a delay to the extraction function of the forwarder, hence reducing its productivity.

RESULTS AND DISCUSSION

Mechanical availability was not quantified in this study. Experience from Australia suggests that machine availability of 80% is achievable for the DFB (O. Raymond pers. comm.). A utilisation figure of 70% has been adopted for the DFB and the processor and 75% for the forwarder.

(1) Waratah DFB Harvester

Results of a previous study of the Mark 5B DFB working in 0.11m³ tree size are given in Table 2 (Raymond, 1989). Total cycle time, excluding mechanical delays, totalled 0.719 min or 83 trees per productive machine hour (PMH). In 0.17m³ tree size this equates to 15.8 tonnes/PMH.

The harvester was capable of high quality delimbing of the bottom 7 m of the trees and high felling productivity. The productivity of the DFB is higher than studies of earlier DFB models (Wells, 1981a).

In the previous study (Raymond, 1989) the DFB had built larger bunches of trees (13 trees per bunch). This meant that a lot of DFB time was spent moving back and forth to build these large bunches that otherwise would have been spent felling and delimbing. In this study,

Table 2 : Waratah DFB Work Cycle

Element	*No. of Observations*	*Mean per Cycle (min)*	*±95% Confidence Limits*	*% of Total Cycle*
Position head	*277*	*0.173*	*0.009*	*24.1*
Delimb	*244*	*0.127*	*0.014*	*17.7*
Fell	*277*	*0.059*	*0.003*	*8.2*
Bunch (including move)	*277*	*0.280*	*0.020*	*38.9*
Total process	*277*	*0.639*	*0.029*	*88.9*
Clear Slash	*46*	*0.080*	*0.016*	*11.1*
Total Cycle	*277*	*0.719*	*0.181*	*100.0*
Productivity :				
Trees per PMH		*83.4*		
Tonnes per PMH		*15.8*		
Daily Production (Tonnes)		*105*		

Table 3 : Waratah Processor Work Cycle

Element	*No. of Observations*	*Mean per Cycle (min)*	*±95% Confidence Limits*	*% of Total Cycle*
Pickup tree	*476*	*0.165*	*0.005*	*18.1*
Delimb & Cut	*476*	*0.588*	*0.028*	*64.8*
Total process	*476*	*0.753*	*0.027*	*82.9*
Move	*75*	*0.091*	*0.027*	*10.0*
Clear	*56*	*0.031*	*0.003*	*3.4*
Op. Delay	*17*	*0.034*	*0.034*	*3.7*
Total Cycle	*476*	*0.909*	*0.043*	*100.0*
Productivity :				
Trees per PMH		*66.0*		
Tonnes per PMH		*12.5*		

felled trees were accumulated into bunches averaging 6.5 trees per bunch (1.24 tonnes) for processing into 2.6m lengths by the Waratah processor. Building smaller bunches of trees improved pick-up times for the following processor, resulting in stacks of processed wood which better matched the capacity of the forwarder grapple.

(2) Waratah Grapple Processor

Table 3 gives the results of the measurement of the processor work cycle. The total cycle time of 0.91 minutes gives hourly machine productivity of 66 trees per PMH (12.5 tonnes per PMH). From observation, it was apparent that the DFB had delimbed almost all trees to a sufficient length to allow three 2.6 metre lengths to be cut prior to further delimbing. The average length of DFB delimbing was estimated to be 7.8 metres. On average 3.9 processed lengths were cut from each tree (range 1-8).

Mean delimbing speed as a function of tree length was calculated at 0.28m/sec. This figure includes cutting to 2.6 m lengths.

The mean delimbing time was predicted by linear regression:

Delimb time (min) = 0.182 x No. of pieces - 0.104

This relationship was highly variable ($r^2 = 0.35$). Sources of variation in delimbing time include individual tree volume, branch size and degree of nodal swelling.

(3) Volvo 861 Forwarder

Forwarder work cycle measurements are given in Table 4. Eleven forwarder cycles were measured, eight of which were full loads. A mean total cycle time of 51.36 mins and mean payload of 10.9 tonnes resulted in forwarder extraction productivity of 12.7 tonnes per PMH. Average haul distance per cycle was 658 metres, with a maximum of over 900m. On 4 occasions, the forwarder loaded the truck from the roadside stockpile. The mean "load from stack" time was 15.33 minutes, increasing mean forwarder cycle time by 5.57 minutes. The effect of this delay to the extraction cycle was to reduce forwarder productivity to 11.5 tonnes/PMH (-10%). Obviously if truck scheduling could be improved or one stake-out trailer provided on the roadside at all times, total forwarder productivity would increase to 12.7 tonnes/PMH.

Table 4 : Volvo Forwarder Work Cycle

Element	*No. of Observations*	*Mean per Cycle (min)*	*±95% Confidence Limits*	*% of Total Cycle*
Return empty	*7*	*5.76*	*3.41*	*10.1*
Load	*7*	*23.60*	*2.87*	*41.5*
Move to load	*7*	*3.29*	*1.64*	*5.8*
Travel Loaded	*7*	*3.55*	*1.65*	*6.2*
Run Loaded	*7*	*2.74*	*1.30*	*4.8*
Unload	*8*	*12.42*	*2.06*	*21.8*
Total Extraction Cycle (mins)	*8*	*51.36*	*7.26*	*90.2*
Load truck from stack (mins)	*4*	*5.57*	*6.48*	*9.8*
Haul Distances (m)		***Mean***	***Range***	***% of Total Distance***
Return Empty	*7*	*575*	*10-916*	*44%*
Move while loading	*7*	*120*	*63-212*	*9%*
Travel Loaded	*7*	*235*	*40-458*	*18%*
Run Loaded	*7*	*386*	*40-816*	*29%*
Total Distance (m)	*7*	*1316*	*191-1836*	*100%*
Forwarder Payload				
No of Pieces		*222*	*195-261*	
Tonnes		*10.9*	*9.7-12.3*	

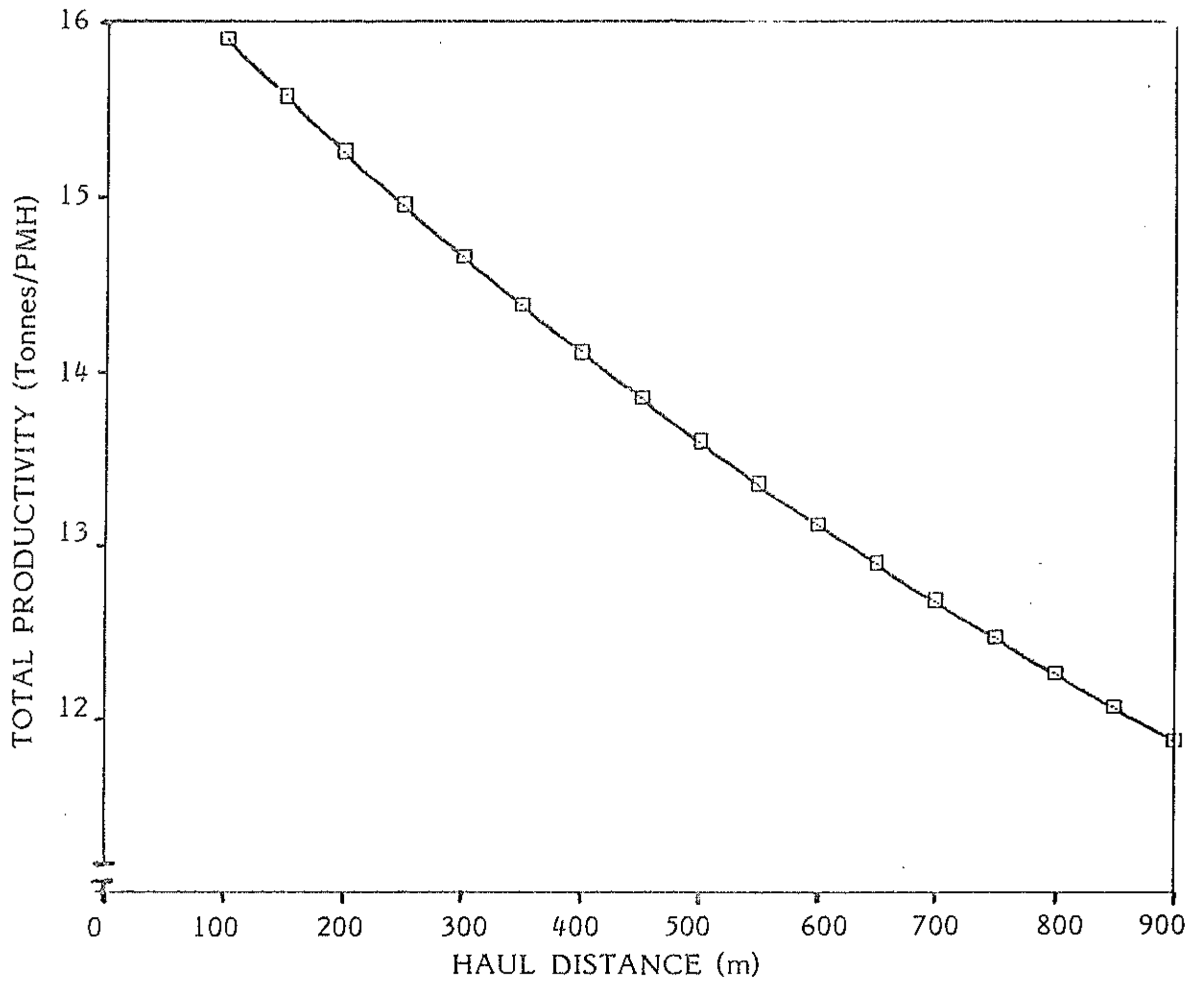

Figure 4 : Forwarder Productivity vs Haul Distance

Forwarder extraction cycle times can be predicted from total haul distance and forwarder payload.

Total cycle (min)
= 0.017 x Haul Distance (m)
+ 3.57 x Payload (tonnes)
+ 0.49 (r^2 = 0.95)

Haul distance had a more significant effect on forwarder productivity (tonnes per PMH) than payload. Given a constant average payload of 10.9 tonnes, extraction productivity dropped from 15.9 tonnes per PMH to 11.9 tonnes per PMH as haul distance increased from 100 m to 900 m (-25%). Figure 4 shows the effect of increasing haul distance on forwarder productivity.

If average payload was increased by 0.5 tonne (10 pieces) for each 100 m increase in haul distance up to a maximum capacity of 13.5 tonnes, productivity would still fall by around 20% from 100-900m haul distance. This reduction in productivity was calculated at 2-3% per 100m of haul distance increase. Given a constant haul distance of 300 m the effect on forwarder productivity of increasing forwarder payload was also minimal. By increasing payload from 10.9 to 13.06 tonnes per cycle (+20%) productivity only increased from 14.7 tonnes per PMH to 15.0 tonnes per PMH (+2%).

Analysis of forwarder loading is given in Table 5.

The bunch size of processed wood averaged 25.3 pieces per bunch. The forwarder loaded an average of 7.2 pieces per grapple (0.35 tonnes) requiring 3 - 4 grapple swings to load each bunch. Loading productivity (pieces/min) increased as the number of pieces in the grapple increased (Figure 5). Hence to maximise productivity the forwarder operator must load as many pieces per grapple as possible, hence minimising the number of grapple swings per bunch. Forwarder loading time per cycle was predicted by linear regression:

Table 5 : Forwarder Loading Analysis

		Mean	Range
Mean Total Load Time (min/load)		*23.60*	*19.97 - 28.78*
No. of grapple loads		*31.3*	*27 - 36*
Mean grapple load (pieces)		*7.2*	*1 - 9*
Mean grapple load (tonnes)		*0.35*	*0.32 - 0.40*
Loading Productivity:	*(pieces/min)*	*9.6*	*8.4 - 11.1*
	(tonnes/min)	*0.47*	*0.41 - 0.54*
Unloading Productivity:	*(pieces/min)*	*18.5*	*13.7 - 22.9*
(direct to truck)	*(tonnes/min)*	*0.90*	*0.67 - 1.12*

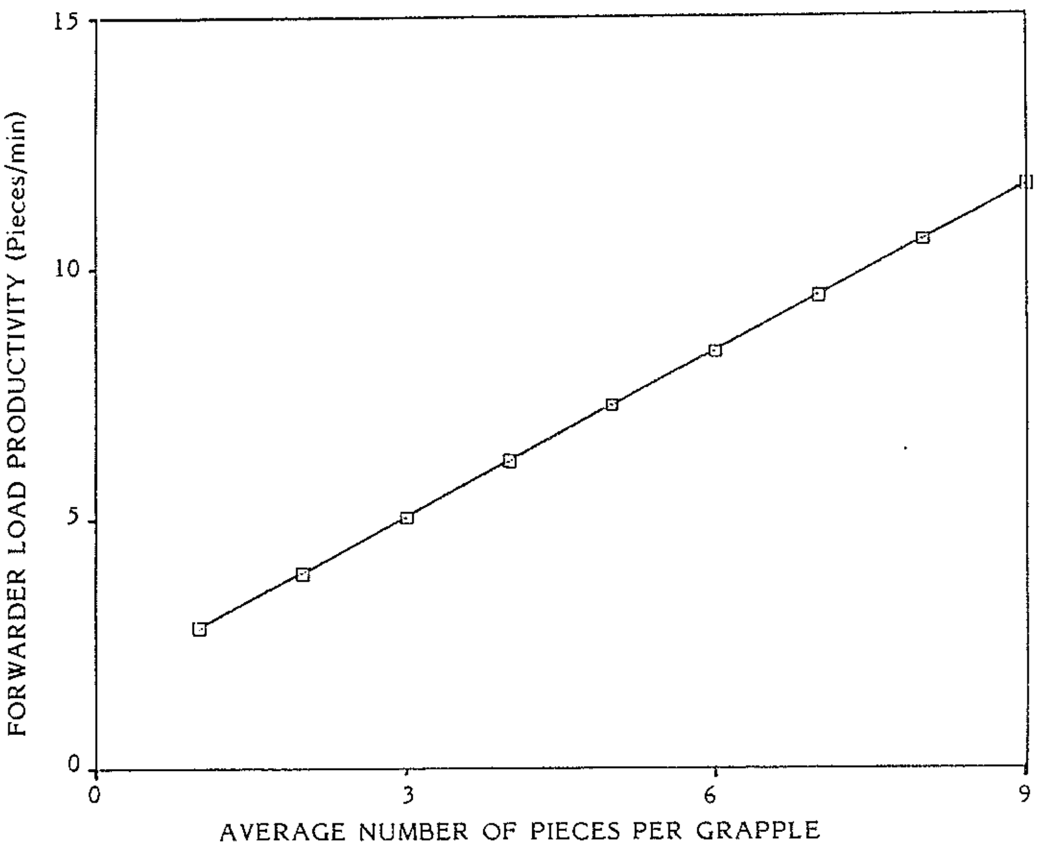

Figure 5 : Loading Productivity vs Grapple Load Size

Table 6 : Forwarder Travel Speed

Element	*m/min*	*Km/h*
Run Empty (track)	*149*	*8.9*
Travel Empty (bush)	*87*	*5.2*
Move while loading	*36*	*2.2*
Travel Loaded (bush)	*66*	*4.0*
Run Loaded (track)	*141*	*8.5*
Mean Empty	*100*	*6.0*
Mean Loaded	*99*	*5.9*

Load time (mins)
= 0.90 x No. of grapple swings
+ 0.22 x No. of pieces per grapple
- 6.02 (r^2 = 0.97)

Load time (min)
= 0.009 x No. of pieces per load
+ 0.84 x No. of grapple swings
- 4.65 (r^2 = 0.97)

The forwarder took an average of 0.42 min to move between bunches. The average distance moved was 15 m giving a mean speed moving between bunches of 36 m/min. An analysis of forwarder movement is given in Table 6.

(4) <u>System Costing</u>

Machine daily costs were calculated using the LIRA format (Wells, 1981b). All machines were costed on both a single shift and double shift basis.

For the Waratah DFB, capital cost of the boom and head was $191,300 (including fitting). Repairs and maintenance costs on the head and boom were estimated to be quite low due to the robustness of the construction.

The capital cost of the Waratah processor head was $141,500. This includes fitting and the optional length measuring system. The life of the processor head was estimated at 3 years, with a high R & M factor.

For the excavator bases of both the DFB and processor it was expected that R & M would be high due to the effect of in-bush travel on track maintenance and also the effect of double shifting. A capital cost of $120,000 for the excavator bases was used. The Volvo forwarder was secondhand and was costed at a capital cost of $200,000 with a 5 year life.

Productivity and cost was calculated given a three machine system of 1 DFB, 1 processor and 1 forwarder producing 2.6m lengths of shortwood to the existing specifications. Shift length was set at 9.0 hours per day (7.00 am - 4.00 pm). System productivity, determined by the forwarder, was calculated at 78 tonnes per day (11.5 tonnes/PMH x 9.0 SMH x 75% utilisation). This gives a unit cost loaded on truck of $32.00/tonne on a single shift basis (Table 7). Double shifting gives a unit cost of $30.00/tonne.

The unit cost of shortwood loaded on truck was equivalent to the cost of a conventional manual tree length operation. The productivity of a manual operation with 4 cutters, and a double drum skidder extracting over an average haul distance of 300m, would be approximately 40 tonnes per day (single shift). This gives a wood cost (including loading) of approximately $31.50 per tonne. On a double shift basis, the unit cost of the

Table 7 : Total System Costing

	SINGLE SHIFT	DOUBLE SHIFT
DFB	574.00	955.00
Processor	610.00	1053.00
Forwarder	472.00	843.00
3 machine operators	424.00	943.00
1 manual trimmer and chainsaw	166.00	347.00
1 mechanic/foreman	150.00	315.00
Vehicle (2.0 L)	50.00	100.00
Overheads	60.00	130.00
Total Daily Cost ($)	2506.00	4686.00
Unit Cost ($/tonne) (at 78 tonnes/shift)	32.00	30.00

mechanised operation is lower than that of the conventional manual system. Increases in system productivity could be achieved by:

(1) working the processor longer hours to match the daily production of the DFB;
(2) reducing the haul distance of the forwarder;
(3) minimising the amount of truck loading from roadside stockpiles.

By extending the processor shift to 11.5 hours, eliminating the "load from stack" delays and restricting the forwarder haul distance to 280 m, a production rate of 100 tonnes/day is achievable.

Reworking the costing for the extended processor shift and the increased production, gives a unit wood cost of $26.50/tonne. On a double shift basis, unit cost would reduce to $23.00/tonne.

If the requirement for measured lengths could have been removed, and the operation allowed to pro-duce random short lengths, then the processor could be eliminated from the system. This would reduce daily gang cost by $933.00. The productivity of the DFB cutting random 5-6 m lengths is estimated at 74 trees per PMH or 14.1 tonnes/PMH (Raymond, 1989). Assuming the same haul distance and payload, forwarder productivity would increase due to the larger grapple load (0.7 tonne), and shorter load and unload times (due to handling fewer pieces. From simulation, forwarder cycle time would decrease to 29.9 min giving hourly productivity of 21.8 tonnes/PMH. This forwarder productivity is similar to that reported in Australia (Raymond, 1988). The DFB would then become the limiting factor on system productivity at 14.1 tonnes/PMH. Daily production would be 89 tonnes and unit cost would fall to $17.70 per tonne (single shift). On a double shift basis, unit cost for the DFB/Forwarder system would be $16.30/tonne.

CONCLUSIONS

Thinning a "Board" regime stand had the advantages of:

- improved access to trees for the harvester and processor.
- the lower stocking resulted in fewer trees per bunch. This resulted in shorter tree pick-up times for the processor and more efficient forwarder loading (i.e. fewer grapple swings per bunch).

The Waratah DFB has shown to be capable of high productivity felling, delimbing and bunching for either further processing or forwarder extraction. It has the ability to alleviate both the high cost of delimbing small diameter stems and the difficulty of accumulating suitable payloads. Although subsequent extraction was by forwarder (due to processing into short lengths in the bush), the DFB would also be suitable in a conventional tree length skidder extraction operation. The further delimbing required (past 7 m length) could be done either manually in the bush or at the landing.

It was apparent given the amount of prior delimbing by the DFB, that the processor worked primarily as a merchandiser. It delimbed mostly one and sometimes two extra pieces from each tree, and measured and cut to length.

If the requirement for measured lengths was removed the operation could produce random short lengths, and the processor could be eliminated from the system. Unit wood cost would fall by approximately 40%.

Further increases in productivity could be made by either reducing total haul distance or increasing the proportion of total distance travelled on the sand track. The forwarder was extracting over very long haul distances (over 600m average) and forwarder productivity was found to be highly sensitive to haul distance. If haul distances were reduced to less than 300m forwarder productivity would increase significantly.

The other option for improving forwarder productivity would be to take advantage of the high forwarder travel speed on the sand track. Increasing the proportion of distance travelled on the sand track could be achieved by spacing tracks at regular intervals through the stand at right angles to the truck road.

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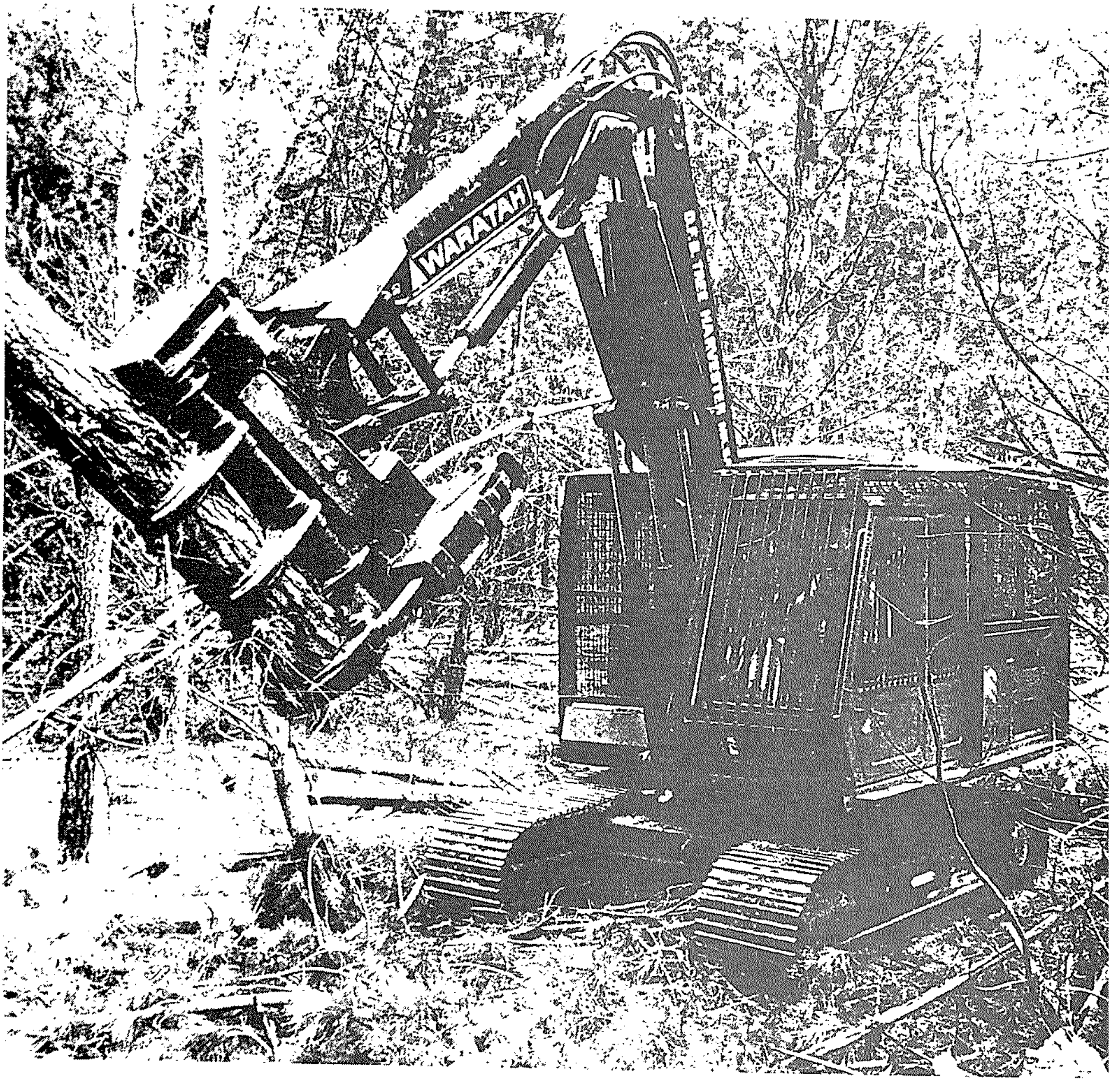
The costs stated in this Report have been derived using the procedure shown in the LIRA Costing Handbook for Logging Contractors. They are only an estimate and do not necessarily represent the actual costs for this operation.

THE WELL-TRIED HEAVY DUTY TREE HARVESTER FOR MECHANIZED EXTRACTION



Waratah Mk.5A tree harvester fitted with a 45cm shear.

The Waratah D.F.B. Tree Harvester is the lowest cost, most reliable multi-function machine available in the world today.
High durability uncomplicated design and simple mounting are contributing factors that make the Waratah Head sound replacement or additional tool for tree felling. The Waratah Harvester can be fitted to most excavators of 13 to 17 ton.

Max. felling diameter	18" - 45cm	Max. Tree diameter delimb	15"-38cm
Max. Topping shear diameter	6"- 15cm	Full tree length delimb in steps of	26ft (8m)

WARATAH FORESTRY EQUIPMENT

WARATAH PLACE • P.O. BOX 375 • PHONE (0814) 68-828 • TELEX NO. NZ21890 • TOKOROA • NEW ZEALAND • FAX (0814) 60054 •

The TREE HARVESTER brings performance, quality and simplicity of attachments to the woods. The DFB can handle the process multistem trees with ease. No limbs are a match for the Delimber Knives which require little or no sharpening.

The bottom shear knives have cam adjustment for wear. The Topping Knives cut unwanted tops and leave them on the forest floor with the delimbed limbs to act as a carpet to protect roots and soil when manoeuvering the machine. With specially built long reach booms, ~~bunching of~~ processed stems are bunched into large bundles for speeding up extraction time.

The DFB can operate in rain-snow-heat and successfully at night when other systems stop.

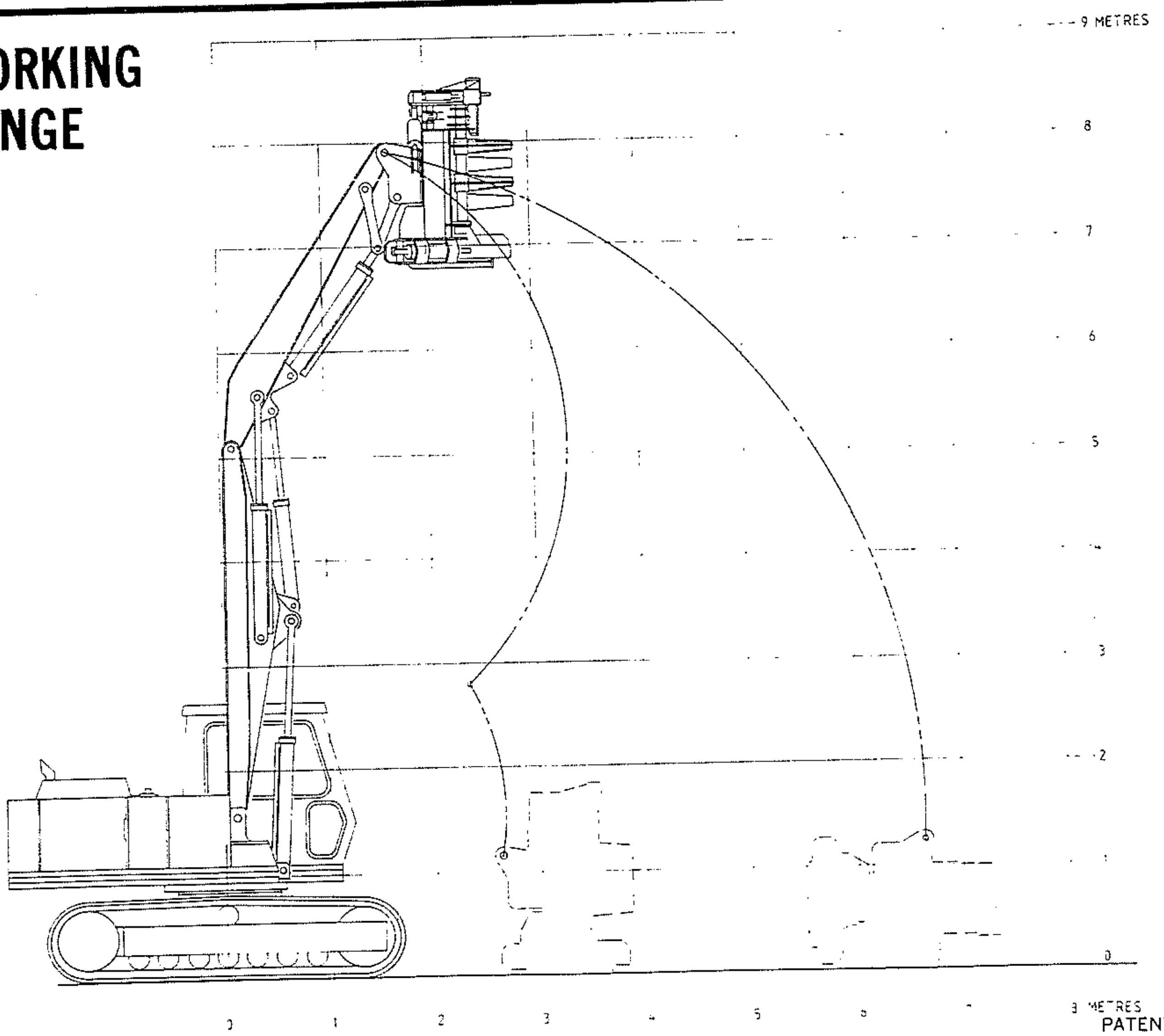
TECHNICAL DATA	18" Waratah		15" Waratah
Max. Felling diameter	458mm		381mm
Required Oil Flow	150-200L/min	33-44g/min	150-200L/min
Required Oil Pressure	175 Bar	2500 psi	175 Bar
Max. Oil Pressure	276 Bar	4000 psi	276 Bar
Height of Head	1580mm	62"	1580mm
Width of Head	1250mm	49"	1250mm
Length of Head	1510mm	59"	1435mm
Weight of Head	1500kg	3300lbs	1390kg

METHOD OF CONTROL

The electric/hydraulic control requires only one additional hydraulic circuit. Control switches are fitted to the lever handles to operate the ~~spool~~ valve fitted on the head.

Head tilt is operated through ~~by the~~ existing hydraulic ~~bucket~~ circuit.

WORKING RANGE



DELIMBER FELLER BUNCHER

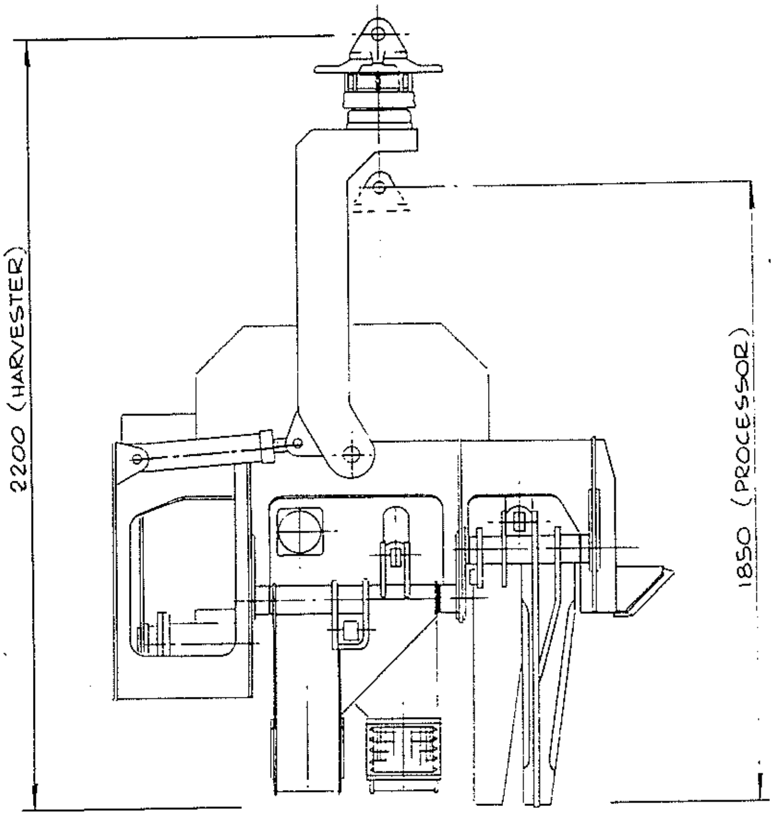
PATENT No.

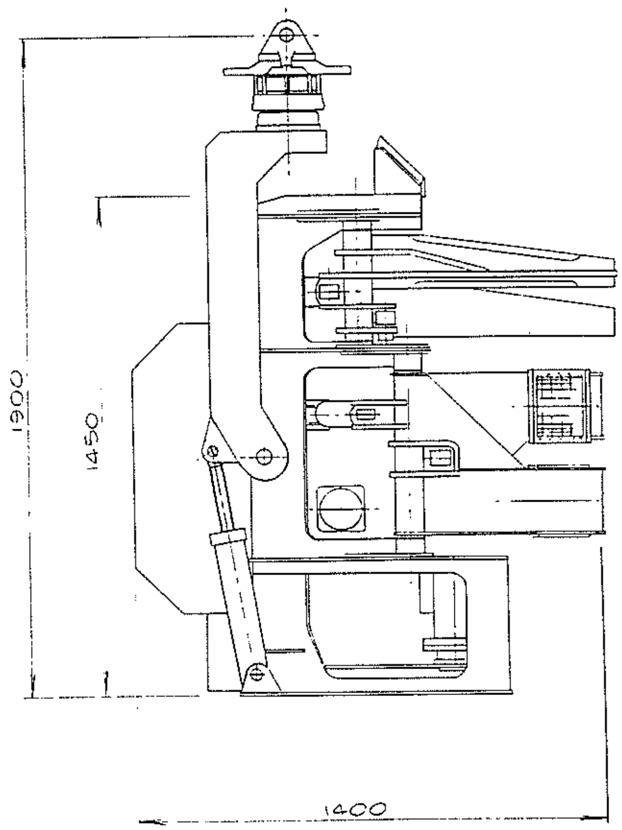
NZ No 191447 — AUSTRALIA 534473 — USA 4412569 — CAN. 359348 — S.A. 80/5424

We reserve the right to alter the specifications without prior notice.

WARATAH FORESTRY EQUIPMENT

HEAVY DUTY GRAPPLE PROCESSOR/HARVESTER





TECHNICAL DATA

FELLING – CROSS-CUTTING

Max Diameter	50cm	20"
Felling Power	40kw	54HP
Felling Saw	Hydraulic Driven	
Chain Dimension	½ inch or 404	
Shear (optional)	46cm	18"

FEED

Feed Type	2 Hydraulically Driven Steel Rollers and 1 Driven Chain. Option: 4 Hydraulically Driven Steel Rollers or 3 Rubber Drive Wheels.	
Feed Power	19kw @ 260 Bar P Start	1.9 Ton
	28kw @ 260 Bar P Run	2.8 Ton
Feed Speed	0-3.5m/s	0-11.5Ft/s
Clamping Power	Adjust to required pressure	

DELIMBING

Type	2 Moveable Delimbing Knife Arms Option: 2 Additional Delimbing Arms 1 Fixed Knife	
Delimbing Diameter	min – 75mm – 500 max	3in – 20"

HYDRAULIC SYSTEM

Required Oil	From 200 L/min	44 Gals/min UK
Maximum Pressure	260 Bar	3770 p.s.i.
Minimum Power	75kw	100HP

Open, Closed, Load Sensing, or Pressure Comp, Danfoss, Monsun Tison, GV 10 Rotator Indexators or Waratah Heavy Duty Gear Rotator.

WEIGHT

	1000kg depending on options	2200 lbs

We reserve the right to alter the specifications without prior noti