Optimising a Yarders Economic Productivity: Effect of Timber Recovery Specifications and Strop and Choker-setter Combinations.

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SUMMARY

Liro completed two studies focussing on increasing yarder extraction efficiency: (a) the effect of changing minimum piece size extraction specification and (b) the appropriate strop and choker-setter combination selection for a given system.

The first study used three treatments, increasing the minimum extraction piece size diameter specification from the current common standard of (1) greater10 cm SED, 3.7m length; to (2) >20cm SED; and finally (3): 30cm LED containing sawlog material. Key findings from this work included:

- Productivity increased by 9% and 26% by applying Treatments 2 and 3, respectively. Increased productivity was achieved through larger average drag volumes.
- Potential net savings to the forest owner (including opportunity costs) by increasing minimum specification were estimated at NZ$1,130/ha for Treatment 2 and NZ$3,100/ha for Treatment 3. Logging costs were assumed at NZ$21/m^3 and pulp value was assumed at NZ$20/ton.
- Margin on pulp values needed to exceed NZ$470/m^3 and NZ$160/m^3 before Treatment 1 and Treatment 2, respectively were more cost-effective than Treatment 3.

The second set of field trials used all possible combinations of 1,2 or 3 choker-setters with 2,3 or 4 strops on two systems (Northbend and motorised slack-pulling carriage). The only logical exception was 3 choker-setters with 2 strops. Key findings from this work included:

- Increasing the number of strops used increases drag volume by approximately 33% each strop.
- Increased drag volume did not always result in increased productivity due to increased hook-on and in-haul times, as well as yarder limitations.
- On average, a 10% increase in productivity was recorded for each additional choker-setter when the number of strops used remained constant.
- Specific combination features, such as the limited benefit of adding a third choker-setter when operating with four strops, were recorded.
- The motorised slack-pulling carriages reduces hook-on time significantly for all combinations.
- Each head pull increased hook-on time by an average 10 seconds.

INTRODUCTION

Cable logging operations have high daily costs and correspondingly unit logging costs ($/m^3) are also high. Liro is undertaking a series of research projects aimed at improving current cable harvesting systems. By reviewing current practices and looking for opportunities to

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improve productivity or reduce costs, some key decision variables were identified that could greatly affect productivity and therefore extraction costs.

Many previous productivity studies have focused on individual machinery or a particular combination of machinery (Harper, 1992). There are a large number of logging variables that directly affect productivity that can not readily be influenced. These include timber size, breakage, site slope, and the machinery available to the contractor to complete the job.

The overall goal for the forest owner is to maximise value recovery, which is maximising the value of the logs relative to the extraction costs. Since no-log-making decisions are made during the whole-tree length extraction phase, the simple goal is to minimise extraction-cost. One decision that can potentially greatly influence productivity, typically made by the forest owner, is the minimum extracted piece size specification. Another key decision, typically made by the logging contractor, is what combination of strops and choker-setters to use.

Cable logging productivity and subsequent unit costs are sensitive to minimum extracted piece size specifications (McMahon *et al*, 1998). For example consider an average New Zealand cable logging operation which costs NZ$4,200/day, with an average day comprising 7.5 PMH. This equates to a cost of approximately NZ$0.15/productive second. When considering a typical minimum extracted pulp log to be greater than 10cm SED, 3.7m length, depending on transport costs and mill door prices, the profit on such a log may range from approximately NZ$0.60 to NZ$1.20. It follows that, if extraction of this log delays the cable operation for more than four to eight seconds, the extraction cost outweighs the value of the log to the forest owner.

The effect of piece size on yarder productivity has been investigated in the past. Larsen (1985) found productivity could be increased by 5% if the minimum length was increased from 2.4m to 3.7m. If this was further increased to 5.7m, a productivity gain of 23% could be achieved.

Similarly, cable logging unit costs are sensitive to average drag volume and breaking out efficiency (Visser *et al*, 1999). This is directly influenced by the system used as well as the strop and choker-setter combination. Increasing the number of strops obviously provides greater drag volume potential, although this should be balanced with risk of overloading and the tangling of strops. A number of studies have shown that increasing the number of choker-setters also increases productivity through reduced cycle time (e.g. Murphy, 1992). However, the increase in productivity benefit must be greater than the cost of an additional labour unit.

Given the current market pressures and the emphasis on value realisation, it is considered timely to define both the effect of minimum piece size specification and strop - choker-setter combination on extraction productivity. This report details the findings of these two studies.

STUDY METHODS

Minimum Piece Size Study

Three minimum extracted piece size specifications were applied across the setting, with a minimum of three extraction corridors per treatment area. These specifications were as follows:

Treatment 1: >10 cm SED, 3.7m length

Treatment 2: >20cm SED, 3.7m length
Treatment 3: >30cm LED, 3.7m length, containing sawlog material

The operation was time-studied over a period of seven days, and data collected on drag volumes and composition. Extracted material was classified as follows:

Butt piece	- stem with butt log attached
Sawlog top piece	- broken stem containing sawlog >30cm LED, 3.7m length
Pulp top piece	- broken stem containing pulp only

The volumes of the butt pieces were calculated using a butt-diameter regression equation derived from the scale measurement of stems extracted during the study. The volumes of the sawlog and pulp top pieces were calculated using a three-dimensional log volume formula (Ellis, 1982).

After the operation was completed, the cutover was 100% assessed to determine the volume and size of residual merchantable material. Walk and planting hindrances were also assessed. Activity sampling of the processing site was also carried out.

Potential net savings ($/ha) to the forest owner through changing the minimum specification were estimated by subtracting opportunity costs from the potential decrease in harvesting costs;

$$\textit{Net saving} = \textit{Prod.increase.} \times \textit{LoggingRate} \times \textit{TotalVol} - \textit{VolWaste} \times \textit{PulpMargin}$$

To complete the calculation it was assumed that the percentage increase in productivity equalled the percentage decrease in unit logging costs, that the recoverable volume was $600m^3$/ha and the logging rate $\$21/m^3$ at >10cm SED, 3.7m length specification.

Choker Study Design

The key dependant variables needed to describe the effect of changing strop and choker setter combinations were determined to be the 'Hook On' (c.min) time element and Productivity (Cycle Time / Drag Volume - m^3/c.min).

The strop - choker-setter combination effect was trialed on two separate cable systems; North-Bend and a standing skyline system using a motorised slackpulling (MSP) carriage. All combinations of 1,2 and 3 choker-setters and 2,3 and 4 strops were trialed, with the logical exception of 3 choker-setters and 2 strops. The goal was to record 30 drags for each combination, in either 2 or 3 sets at different locations in the span and on different corridors. Skyline tension limited drag size in both settings in the last third of span and therefore 4 strop combinations were carried out only in the front and mid span sections.

The extraction variables recorded for each drag were: extraction distance (m); butt pieces (#); top pieces (#); pieces lost during inhaul (#). To take into account the increased difficulty of hooking at the top instead of a butt, the number of 'head-pulled' stems in a drag were also recorded.

The following key cycle time elements (along with their respective start features) were recorded to describe the differences between treatments:

<u>Time Element</u> <u>Start feature</u>

Carriage out	Carriage starts to move away from tower
Lower rigging	Carriage stops or rigging starts to be lowered
Untangle	*Touch the strops*
Hook-on	Strop pulled out (or touch the strop if no untangle)
Walk out	Last choker-setter starts to move away
Breaking out	Signal is given to start breaking-out the load
In haul	Load starts moving towards the tower (v - rider block)
Lower-unhook	Rider and fall block stop (and load is lowered.)
Delay	*All delays except untangling*

All elements were expected to occur at least once during each cycle with the exception of untangle or delays. No effort was made to differentiate between delays.

FIELD STUDY SITES

Minimum Piece Size Study

The minimum piece size specification study was carried out on a cable logging operation in Kaingaroa Forest. The extraction machine was a Madill 171 operating the Northbend system. The setting comprised a deep gully with concave sides, devoid of any terrain features that constrained payloads. Two choker-setters were used during the study. The processing site was separated from the yarder landing by approximately 200m, requiring two-staging of stems with a grapple skidder.

Strop/Chokersetter - Northbend System

The machine and crew used was the same as for the minimum piece size study but in a different compartment. The total extraction distance was 495 meters, comprising of a steeper front face going down into a small gully at the 105 metre mark and then a more gradual upward gradient for the remaining 390 metres up to the road where a bulldozer was used as a mobile tailhold. Maximum possible mid-span deflection is 8.5 % which equates to 6.8 ton maximum payload at mid-span (assuming suspension).

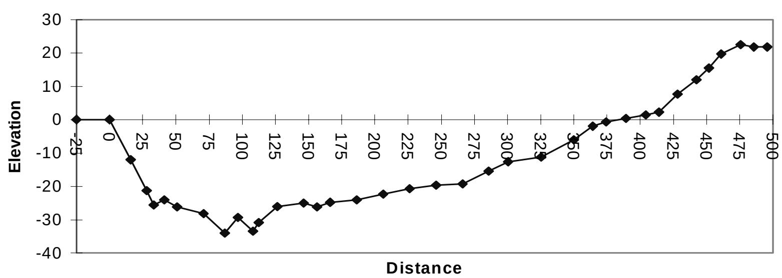

Figure 1: Cross-section of northbend study site, yarder at far left

The stand itself was 28 year old unpruned Radiata pine with a predominant lean down-slope. The timber was therefore felled across and slightly down-slope. The disadvantage of this felling pattern meant that the stems needed to be turned when broken out, whereby one could expect longer times for the initial in-haul, and more gut or head pulls.

The amount of breakage on site was relatvely high, with only 63 % of all pieces coming up to the landing as butts. Average butt diameter was 50 cm - average butt volume was 2.33 m^3.

Average top LED was 25 cm - average top volume was 0.35 m^3. Therefore, average piece volume was 1.52 m^3.

Strop/Chokersetter Study - MSP System

The second choker study site was in Maramarua Forest using a Madill 071 yarder rigged with a Maki II MSP carriage. The total extraction distance at the study site was 450 meters. It comprised of a mild grade front face going down into a small gully at the 330 metre mark and then a steeper upward gradient for the remaining 120 metres up to the road where stumps were used as a tailholds. Maximum possible mid-span deflection was about 9% which equates to 7 ton maximum drag size.

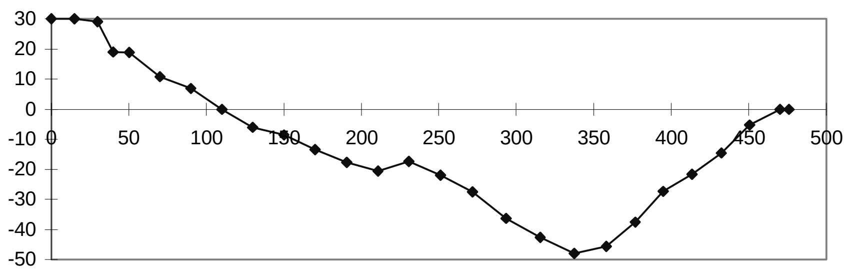

Figure 2: Cross-section of MSP carriage study site

The stand itself was radiata pine with an average butt piece size of approximately 1.7 m^3. The timber was felled primarily across and slightly away from the yarder - ideal for breaking-out. Only one patch of timber in the middle of the cutover had been felled against the predominant felling direction due to adverse wind conditions at the time.

This site had low breakage with 87 % of all pieces coming up to the landing as butts with an average butt diameter of 42 cm. This equates to an average butt volume of 1.75 m^3. The average top LED was 24 cm with volume of 0.31 m^3. Therefore, average piece volume was 1.56 m^3.

RESULTS - MINIMUM PIECE SIZE STUDY

Drag volume and composition

The average drag volume and composition changed as the minimum specification was increased. Mean drag volumes increased by 12% between Treatments 1 and 2, and 37% between Treatments 1 and 3 (Table 1). These changes coincided with changes in the drag composition. The proportion of butt pieces increased and the proportion of pulp top pieces decreased with increasing specification. The change in drag composition also resulted in a successive increase in mean extracted piece size; 1.94m^3, 2.08m^3, and 2.58m^3.

Table 1: Mean drag volume and composition. Mean values followed by the same letter were not significantly different ($p<0.05$).

Treat-ment	Specification (all 3.7m)	Mean drag volume (m^3)	Drag composition (% of total pieces)		
			Butt pieces	Sawlog top pieces	Pulp top pieces

1	>10cm SED	5.79 a	54	34	12
2	>20cm SED	6.49 a	55	31	14
3	>30cm LED (sawlog)	7.93 b	83	11	6

The presence of pulp top pieces in Treatment 3 relates to pieces which the choker-setters thought may have produced sawlog, but actually did not. The smaller proportion of sawlog top pieces in Treatment 3, relative to the other treatments, reflects a difference in breakage. The reason for this difference was unable to be identified.

In volume terms, butt pieces contributed between 89% and 98% of the mean drag volume across the three specifications. Mean butt piece volumes for each treatment area were not significantly different ($p<0.05$).

Cycle times & Yarder productivity

A total of 426 extraction cycles were observed over the seven days. Productive time only was analysed to determine average cycle times. Underlying differences between cycle times for each treatment were analysed by excluding inhaul and outhaul variation which was predominantly due to haul distance. Standardised inhaul and outhaul times, based on an average haul distance of 200m, were then substituted to give "complete" production cycle time values.

Mean cycle times increased with increasing specification (Table 3). The two main factors contributing to this were increased hook on and breakout times. These trends probably reflect the proportionally greater time required to locate and hook-on extra butt pieces, and slower breakout times for the heavier drags.

For a given haul distance, productivity is a function of drag volume and cycle time. Productivity increased with increasing specification (Table 2), from Treatment 1 to Treatment 2 resulted in a 9% increase in productivity. Increasing the specification from Treatment 1 to Treatment 3 increased yarder productivity by 26%.

Table 2: Mean cycle time composition and the resulting productivity increase relative to treatment 1. Mean cycle time values followed by the same letter were not significantly different ($p<0.05$).

Trt	Specification (all 3.7m)	Number Cycles	Mean Cycle (min)	Drags per PMH	Extracted vol/PMH	Prod. increase (%)
1	>10cm SED	168	6.60 a	9.1	52.5	-
2	>20cm SED	184	6.71 b	8.9	57.7	9
3	>30cm LED (sawlog)	74	7.12 b	8.4	66.6	26

The cutover within each treatment area was 100% assessed to determine the volume of merchantable waste >10cm SED and 3.7m length. The cutover assessment showed that the volume of merchantable waste was substantially greater in Treatment 3 compared to Treatments 1 and 2. One of the merchantable pieces in Treatment 1 was a small, but complete, stem that had not been extracted. This stem comprised 0.75 m^3, or 11%, of the merchantable volume.

Calculation of Net Savings

The potential net savings to the forest owner through increasing the minimum specification from >10cm to >20cm SED can be calculated relative to productivity increases. In this case, changing the minimum specification did not result in a change in merchantable waste, and hence opportunity cost. Therefore, savings to the forest owner reflect the increased productivity alone. In this case the productivity increase was 9% and the potential net saving was therefore NZ$1,134.

When the minimum specification was increased from >10cm SED to >30cm LED (sawlog), there was a 7m^3/ha increase in merchantable waste. This meant that the potential net saving to the forest owner would vary with the margin on pulp value (Table 3).

Table 3: Estimated potential net saving (NZ$/ha) to the forest owner by increasing the minimum specification from >10cm SED to >30cm LED (sawlog only), 3.7m length. A 26% increase in productivity was recorded in this study.

% prod.	Margin on pulp			
increase	NZ$30	NZ$20	NZ$10	NZ$0
5	420	490	560	630
10	1,050	1,120	1,190	1,260
15	1,680	1,750	1,820	1,890
20	2,310	2,380	2,450	2,520
26	3,070	3,140	3,210	3,280

An alternative way of viewing these potential net savings is to determine the margin on pulp (NZ$) required before extraction of pulp top pieces becomes economic. Based on the productivity increase mentioned above, the margin on pulp needed to exceed NZ$470/m^3 before Treatment 1, and NZ$162/m^3 before Treatment 2 became more cost-effective than Treatment 3. Thus, in some cases, the margin on pulp may have to increase from 6 to 20 times above present values before extraction of pulp top pieces becomes economic.

Note, that the potential net savings calculated here do not include any added costs associated with slightly increased planting hindrance, and costs associated with changing demands on the processing and uplifting of logs.

Activity sampling of processing activities

During the minimum piece size specification field study activity sampling was carried out on the processing landing. The skidder was subjected to fewer delays on the landing and the excavator and rubber-tyred front-end loader spent less time sorting and stacking when Treatment 3 was applied. The skid workers spent more time trimming for Treatment 1, than for the other two treatments. All of the system components in the activity sampling study had idle time present during all treatments, suggesting that even with the increase in productivity, the system was not necessarily limited by the processing operations.

RESULTS - STROP AND CHOKER-SETTER STUDY

The low breakage rate at the Maramarua Forest site (MSP carriage system) and the limited amount of deflection available within the spans meant that 4 strops could only be utilised in selected areas. In most locations hooking on 4 butt logs overloaded the skyline and significantly reduced the inhaul cycle time. Regularly running 4 strops when only 3 could realistically be used would have biased the results. Therefore only one treatment with four strops (with two choker-setters) was safely carried out.

Statistical analyses showed that each head pulls increase hook-on time by almost 10 seconds. Since the distribution of head-pulls was uneven across the treatment combinations, this effect was removed from the average data presented. The time element 'landing and unhooking' the timber had a great variation caused by situations such as failure to keep the chute clear at all times and requiring the assistance of the excavator to unhook. Although most of these operational delays were successfully isolated by the time-keeper, a simple statistical regression was generated for the landing and unhooking time element using the variables number of strops and drag volume. These regression times were then used to complete the total drag cycle times.

The following three graphics shows the main results in terms of untangle and hook-on times, increase in drag volume and change in productivity.

Untangle and Hook-on Time (c.min)

In general, as expected, using more strops resulted in longer hook-on time and increasing number of choker-setters decreases hook-on time (Figure 3). Hooking on using the MSP system was also clearly faster compared to the Northbend system in all combination alternatives.

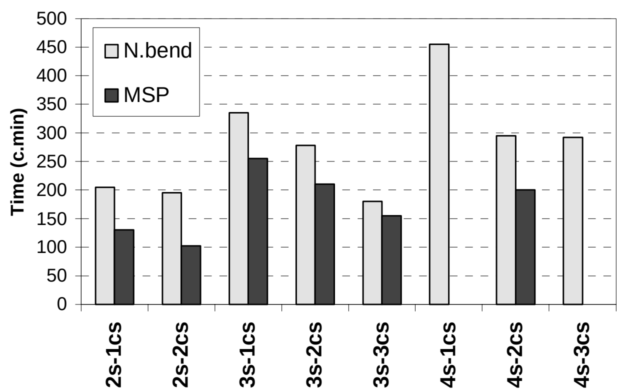

Figure 3: Untangle and breaking-out time (c.min) for strop - choker-setter combinations

Specific comparisons can be made, for example comparing 4s-2cs and 4s-3cs indicates that little is gained by adding a third choker-setter. This can be explained in that one choker-setter still has to hook up two logs in the three person scenario, whereas both have to hook up two logs in the two person scenario. In the 4s-1cs combination the untangle and hook-on phase took on average just over 4.5 minutes. From field observation, the choker-setter struggled to untangle 4 strops and struggled to pull out the butt rigging to the stems.

Total Drag Volume (m3)

Increasing the number of strops resulted in a greater drag volume as would be expected (Figure 4). Increasing from 2 to 3 strops and 3 to 4 strops increased average drag volume by 32% and 35% respectively. However, other clear trends were also apparent. Increasing the number of choker-setters also increases drag volume by an average of 12% per choker-setter. From field observation this was due to the increased ability to double stems logs and by one choker-setter aiding the other with the rigging reaching stems that would otherwise have been considered out of reach.

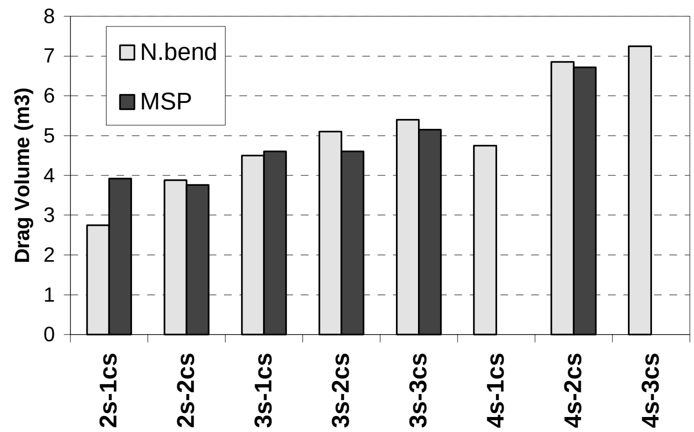

Figure 4: Drag volume (m3) for strop - choker-setter combinations

The 4s-1cs combination struggled to utilise strops capacity, with over 30% of drags returning with one or more strops unused. In this treatment the hook-on time took 1.3 minutes longer on average, the increase in volume per drag was a mere 0.2 m^3.

Figure 5 shows the effect of number of strops on drag volume as a frequency distribution. If for example the maximum allowable drag volume to avoid overloading the skyline is 7.5 m^3, then it is possible to see that for the two strop option the average load would only be half of the maximum load.

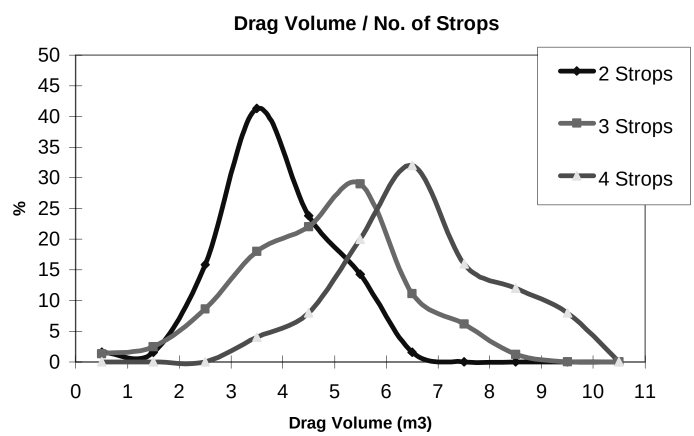

Figure 5: Drag volume (m^3) frequency distribution for 2,3 or 4 strops.

For the 4 strop option, almost a quarter of the drags will exceed the limit. If this can be avoided through 'intelligent' breaking-out, that is the choker-setter building an optimum drag by estimating each piece volume, then the average drag volume should be closer to the maximum allowable.

Treatment Productivity (%)

Figure 6 shows the relative productivity for each system combination. The chart is organised so that the 3 strop and 2 choker-setter combination is set at 100% and the alternatives should be viewed relative to that. All data was standardised to 200m extraction distance using the appropriate regressions for both the carriage-out and inhaul time elements.

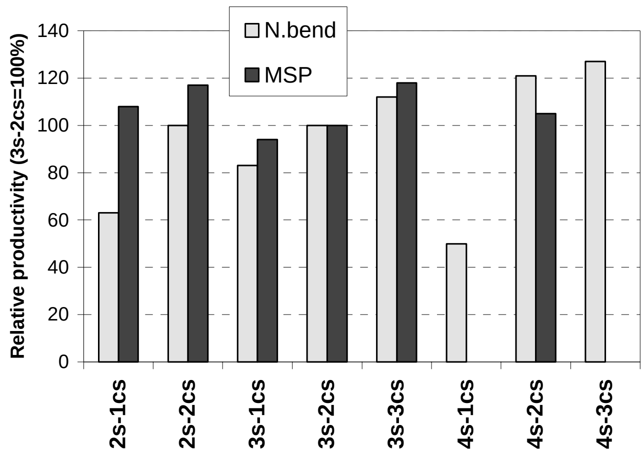

Figure 6: Relative (3s-2cs is set at 100%) productivity for strop - choker-setter combinations.

For the Northbend system at the higher breakage site running the more powerful Madill 171, the system could easily cope with the drag volumes provided by the 4 strop alternative. This also provided for the greatest productivity, a significant 21% increase relative to the 3 strop option when using two choker-setters.

For the MSP carriage system at a site where the less powerful Madill 071 was used, using just 2 strops provided the best solution. Although drag volume was increased with 3 strops, the increase in hook-on and in-haul times reduced the effective productivity. Running only one choker-setter reduced the productivity by just 8%. The results for the MSP system were non-linear and indicated the yarder mainline capability limits were reached when pulling loads larger than 6 tonnes.

DISCUSSION

These studies demonstrated the potential for increasing cable logging productivity by increasing the minimum extracted piece size specification and correct selection of strop and choker-setter combination. The levels of productivity increases found in this study reflect the setting and stand characteristics and the level of breakage. In situations where the terrain is more limiting on payloads, the potential for increased productivity gains is likely to be less.

The potential for increased productivity can be gauged by having the yarder operator monitor the drag composition (i.e., number of butt and top pieces). In particular, small drags comprising only pulp reduce potential yarder productivity. To a lesser extent, mixed drags (containing butt and pulp pieces) would also reduce productivity.

In some cases, potential gains by increasing the minimum piece size specification may be limited because of a requirement to extract the pulp pieces for non-economic reasons. For instance, riparian management policies may require the extraction of material smaller than the minimum pulp specification from some sections of the extraction corridor.

The net affect of changing the specification, was the increase in extracted piece size. This could also be achieved by relaxing the cutover waste standard. For example, a current standard of 5m^3/ha merchantable waste could be relaxed to for example, to 15m^3/ha. The relative difference in butt and pulp top piece volumes and values would ensure that butt pieces were extracted in preference to pulp top pieces. As a means of reducing costs, the adoption of an increased piece size specification has the advantage of providing a clearer guideline for choker-setters.

Correct strop and choker-setter combinations selection is dependant on knowing what the maximum allowable payload is in the various sections of the span. This requires profile analyses in the planning phase or the measurement of available deflection during operations. Yarder capability may also limit the maximum payload. When increasing the number of strops to increase average drag size, the choker-setter must estimate individual piece volume and ensure that the maximum allowable drag volume is not exceeded.

For many operations moving the timber across the skid limits the system productivity, not the yarder. However, a yarder's potential efficiency should not be reduced to suit skid operations. Running a yarder efficiently for a shorter period of the day, or increasing the processing capacity of the skid are two logical options. Finding solutions to increasing processing capacity on the landing will be the next main project.

CONCLUSIONS

Two specific studies have been carried out with the aim of improving extraction efficiency. In the first study three treatments with increasing minimum piece size specification were extracted. In the second study 8 strop and choker-setter combinations were trialed on two cable extraction systems.

It was shown that both increasing the minimum extraction piece size specification and the correct selection of strop and choker-setter combination can increase extraction productivity markedly. These key variables can readily be influenced by the forest owner and the logging contractor.

ACKNOWLEDGEMENTS

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