INNOVATION TO INCREASE PROFITABILITY OF STEEP TERRAIN HARVESTING IN NEW ZEALAND

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Summary

The challenges to improved profitability of forestry are summarised and innovative solutions to improve profitability primarily through reducing the cost of steep terrain forest harvesting are discussed.

Introduction

Different Perspectives of a Problem

A Forest Manager went up in a hot air balloon to survey the forest and after a while he realized he was lost. He reduced altitude and spotted a guy with a hi-viz vest and a yellow helmet below and shouted, "Excuse me, can you help me? I promised to meet someone half an hour ago, but I don't know where I am". The man below looked at his GPS and replied, "You are in a hot air balloon hovering approximately 10 metres above the ground. You are at 38 degrees, 20 minutes, 16 seconds South latitude and Longitude 176 degrees 20 minutes and 5 seconds East longitude". "You must be a Forest Engineer," said the balloonist. "I am," replied the man, "How did you know?" "Well," said the Forest Manager, "everything you told me is technically correct, but I have no idea what to make of your information, and the fact is, I am still lost. You haven't been much help." The logger responded, "You must be a Manager". "How did you know?" replied the balloonist. "Well," he said, "you don't know where you are or where you're going. You have risen to where you are due to a large quantity of hot air. You have made a promise, which you have no idea how to keep, and you expect me to solve your problem. The fact is you are in exactly the same position you were before we met, but now, somehow, it's my fault!"

The Problem: Low Profitability of Forestry

The above story illustrates the situation and to some extent the relationships prevalent in the forestry value chain today. There are many challenges facing the forest industry, as a result of decisions taken in the past. In the 1980's and 1990's the plantation forest industry in New Zealand experienced significant growth and many areas of marginal pastoral terrain throughout New Zealand were planted in pine trees in places that sheep and goats had difficulty staying upright, far distant from towns and cities, sawmills and ports. Some additional 300,000 hectares were planted over a 7 year period from 1992-1998. Many of these forests were established by forestry syndicates, partnerships and small landowners. These small owners (<10,000 hectares) own almost 40% of the national forest estate and include some 15,000 owners with a wide geographical spread, a wide range of forest sizes and forest ages which largely fall into the post-1989 forest

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category, commonly known as “Kyoto forest” owners [1]. Although some small forest owners will commence harvesting their post-1989 forests from about 2015 onwards, the large scale forest owners who own 77% of the pre-1990 forest (age class 21+ as at April 2010) will dominate the harvesting scene until around 2020 (Table 1). Therefore this analysis will focus on harvesting undertaken by large forest owners, represented by the New Zealand Forest Owners Association (FOA).

Table 1: Plantation ownership by age class (hectares)

Forest Type	**Harvest ready**	**Age Class**	**Large Owners (>10,000ha)**	**Small Owners (<10,000ha)**	**Total**
Post 1989	>15 years	1 – 10	322,402	157,284	479,686
	11-15 years	11 – 15	220,515	215,559	436,074
	6-10 years	16 – 20	137,192	200,518	337,710
Sub-Total			**680,109**	**573,361**	**1,253,470**
Pre 1990	< 5 years	21 – 25	182,232	48,532	230,764
	Now	26+	189,672	63,685	253,357
Sub-Total			**371,904**	**112,217**	**484,121**
Total			**1,052,013**	**685,578**	**1,737,591**

Source: A National Exotic Forest Description, April 2010, MAF.

So in the traditional wood products market, the forest estate models of the large forest owners are telling their Forest Managers that these forests are almost ready for harvest and the Forest Managers are turning to the loggers and saying “Excuse me, I need some help”. The challenges for profitability in these forests are many, including harvest planning, roading, harvesting, log processing/value recovery and log transportation.

Harvest planning and roading challenges

According to the 2011 National Exotic Forest Description [2] 56% of the estate is first rotation forest. Of the identified first rotation forest, 64 percent is aged 16+ years, which is available for harvest within the next ten years. Deducting the area of the next two years’ harvest (approx 100,000ha) which is probably roaded and harvest ready, of the forest that is due to be harvested in the next 10 years there is approx 500,000ha that has few logging roads (apart from the original planting tracks) built in these forests. This situation is exacerbated by their relative isolation, steep terrain and small forest size (lower harvest volume to offset against roading expenditure). Not only will significant expenditure be required to build roads for harvest access in these forests, but it is doubtful that the forest industry has the skilled harvest planning and engineering resources for this task.

Harvesting challenges

The steep terrain and fragile soils of New Zealand and our environmental constraints demand harvesting by cable haulers. The cost of mainly manual steep terrain harvesting methods exceeds that of the more cost-effective mechanised ground-based systems by 50-100% (minimum $10.00/m3), although in most places there is no choice of system. Over the last 35 years cable logging has tripled from 15-16% of harvested volume [3] to currently 45-50%. Cable operations are almost exclusively done by contracting firms.

Based on 2010 benchmarking data, the average crew size is 9 workers with four machines cutting 200 tonnes per day (23 tonnes/PMH) for about $32.00 per tonne logging rate [4]. Extraction is commonly done with tower haulers (70%) or swing yarder (30%). The most common hauler is the 70 foot tower (ranging from 50-105ft). Most operations (90%) extract to a primary landing (single stage extraction). The most common rigging systems are scab skyline and North Bend. Methods have not changed much in the last 35 years. The last major innovation was the introduction in 1987 of the swing yarder which can operate on small log landings and the widespread conversion to knuckle boom loaders in the early 1990's.

Log processing/value recovery challenges

The intensive silvicultural management practiced over the last 30 years in many of these forests (pruning and early thinning to wide final crop spacing) was such that the final tree crop is now large (2.5 – 4.0 tonnes per tree) and heavily branched above the pruned log, a tree not conducive to efficient mechanised harvesting systems. Tree felling is still mostly manual by chainsaw (77%) and processing in harvesting operations is 56% motor-manual. Despite the relatively slow uptake of mechanised processing, this is the area where most innovations have occurred over the last 25 years. These innovations in log processing in New Zealand include the AVIS optimal crosscutting algorithm (1984), the Waratah processor (1986), the Interpine Computer Optimiser (ICO) in 1994, large scale log value optimisation and centralized processing such as the Kaingaroa Processing Plant (1995), the TimberTech digital caliper (1998), the Logrite® on-board computer control system for the Waratah and the Logmaister mobile optimising plant (2003).

From the early days of log grade segregation (primarily pulp and saw logs, with one or two long length export grades) there has been an explosion of log grade complexity. The average number of log sorts (grades/lengths) cut in New Zealand based on 2010 benchmarking data is twelve, but examples of more than 20 log sorts can be found. This must be at the upper end of manual log making ability and presents a challenge in terms of log processing productivity and cost, landing space, and loader operator workload.

Despite issues with measurement error on volume estimates and value recovery of harvesters, the single-grip harvester or processor is the dominant method for log processing used in most parts of the world. Moving on from simple length, diameter and branch size attributes, more sophisticated wood quality parameters are now starting to be used in harvesting operations, pre-harvest assessment and in design of log product specifications, such as acoustic velocity. Measurement of this parameter has already been solved for the harvester [5], but how to build these parameters into yield prediction models and log allocation optimisation models that accurately account for these wood qualities to provide the best match of log supply to customer demands remains a challenge.

Log transport challenges

The new forests are remote from the existing infrastructure of arterial highways, customers (both domestic and export), and sources of labour and maintenance services.

There are also a lot of constraints on trucking such as opening hours of mill yards and ports, local council roads and bridge standards. Opportunities for increasing gross vehicle mass and back loading need to be found to reduce log transport costs.

So from a traditional wood product point of view, high forest production costs are driven by steep terrain, challenges to mechanisation, and long transport hauls to market, resulting in lower than desirable profitability. The situational analysis in Table 2 summarises the characteristics of many wood supply regions in New Zealand.

Table 2: Challenges and opportunities for forestry in New Zealand

Strength	**Opportunity (Competitive Advantage)**
Large volumes of uncommitted wood coming available	Availability of volume for processing or export
Improving infrastructure	Provision of funds by central government.
Deep water ports	Single port loading
Established training system within industry and broadening career development opportunities within the harvesting sector	Potential for widespread adoption of new technology
Weakness	**External Threat**
Relatively low basic density of wood	Competitive disadvantage in structural products over other countries
Poor log storage capacity at ports	Little opportunity to take advantage of rail / Dependence on short term trucking capacity
Poor availability and range of harvesting crews in many regions	Poor alignment with harvesting constraints, high exposure to safety hazards.
Unreliable transmission of electricity	Risk to expansion of processing facilities
Vulnerable domestic processing sector	Low volume, ageing capital equipment, unable to source processing investment required for expansion. Leading to lack of utilisation of lower grade saw logs and residues.
Combination of topography, soils and underdeveloped in-forest roading networks results in comparatively high production costs than other, more established forestry countries.	Threat to existing markets for all log grades and to the whole-of-tree solution.
Log market volatility (Boom/bust cycle)	Loss of skilled labour due to harvesting labour force instability and attractiveness of other industries

These challenges and uncertainties are exacerbated by the Emissions Trading Scheme (ETS). Being able to generate pre-harvest income from selling the NZUs allocated for each eligible post-1989 forest area is a major improvement to the economics of forestry. However, the obligation to also surrender NZUs earned, upon harvest or a carbon stock decrease (such as from a catastrophic wind throw or fire) tempers the attraction of the

ETS. But if the stumpage returns from roading and harvesting these forests is so poor, the forests may in fact not even be harvested and the forests grown on to accumulate NZUs.

Initial economic studies point to the positive economic impact of delaying a forest's harvest. Even though the risk of fire and wind would increase considerably due to older forests, in terms of overall value, this has been shown to be a particularly lucrative scenario in a flat carbon price environment [6]. The net present value of a delayed harvest scenario could increase by over 75% against the base case scenario (no harvest delay) as the forest has more years in the near term earning units, whilst also delaying the surrender obligations. The attraction of the ETS will be greater to growers who have marginal land without alternative land use (HBU) but also may have sub-economic timber crops, perhaps because the stumpage returns are too low, due to poor timber yields or high roading and harvesting costs.

Solutions to Low Profitability of Forestry

As discussed above, the economics of forestry are affected by a large number of factors, not least the major uncertainty regarding the future of the ETS. The solution is to improve the sustainability of forestry. Unfortunately from the logger's point of view (who has now inherited the problem), delaying the forest harvest would only make the harvesting operation more problematic, and deciding not to harvest at all would have a devastating effect on the sustainability of the harvesting workforce. Extending the harvest age beyond where the tree size is manageable by current mechanised harvesting equipment will only result in a return to manual harvesting methods with attendant labour, skills and safety issues. There are only two mitigating factors against a change in harvesting intention to either delay harvest or not harvest at all:

1. The effect of the carbon price increasing over time.
2. A major increase in the profitability of traditional forestry (wood products).

Increased Carbon Price

In the first case, looking at the effect on the national estate of an increasing carbon price, the value of carbon forestry is substantially eroded. Ironically, in any other market, producers benefit with price increases. If the price of carbon increases it creates a significantly more expensive harvest liability to be met (assuming the forest owner is buying off the market to meet its harvest liability) and accentuates the benefit of carbon sequestration at that time. In a high carbon price scenario net present value is significantly reduced and it is doubtful if timber returns would cover harvest liability.

It was concluded that the high-price scenario holds considerable peril if an existing forest landowner (representative of the national estate) considers themselves to be a timber producer seeking to gain incremental benefit from the carbon market. Therefore a high carbon price may keep the forest owner in the timber market rather than the carbon market. Forest owners have the option of being in either market. If the value from timber is likely to meet the cost of buying the harvest liability off the carbon market, then these forest owners have the ability to make decisions nearer to the time of harvesting based on the prices in both the carbon market and the timber market.

Increase in profitability of traditional forestry

Little can be done about the forests maturing quietly on those marginal hillsides, or about their sub-economic timber crops or about the domestic or FOB export log prices (that are too low either way!). Add to those ongoing increases in fuel costs, steel costs and the likely fall in the NZ dollar exchange rate back to historic levels which will drive up new equipment costs. For example, the recent drop in NZD value from 0.81 to 0.76 USD results in a 6.6% increase in the cost of a machine worth USD 500,000. Owning costs (driven by capital costs, resale and machine life) comprise almost half of the machine rate in cable logging. But little can be done about the NZD: USD exchange rate, or international shipping rates (which are driven more by the steel market than the wood market). It is our problem. So what can be affected and controlled by the forest management company?

The profitability of forestry can be improved significantly through reducing the cost of forest harvesting. This is a significant value proposition as harvesting cost makes up approximately 20% of the free on board value of log exports. For the year ended 31 December 2011 log export value was $1.655 billion FOB, giving a harvesting value of $330 million for export alone. About 47% of New Zealand's harvesting volume is from steep terrain and cable logging costs comprise 60% of average harvesting cost (ground-based plus cable). By 2020 cable logging will increase to 58% of harvesting volume (and 70% of average harvesting cost) and to 66% by volume and 77% of cost by 2030. This annual increase in the proportion of cable logging alone will drive average harvesting costs up by almost 1% p.a. with no change to logging rates. Therefore cable logging costs will have to be reduced just to keep pace with current average harvesting cost.

The good news is that cable yarding is a commonly used and well known harvesting method in New Zealand. With almost half of the harvesting currently being done by cable logging systems there is a core of innovative entrepreneurial contracting firms in the cable logging sector. How to reduce cable harvesting costs is literally a 90 million dollar question. Innovations in steep terrain harvesting can reduce cable logging costs by 25% on the average cost of $30.00/tonne. Given the current annual harvest of 26.12 million cubic metres (year ended 31 Dec 2011) and current cable logging proportion of 47% this will give benefits to the industry of over $90 million.

There is no "silver bullet" but the vision to achieving these savings is "no worker on the slope, no hand on the chainsaw". To achieve this vision Future Forests Research Ltd (FFR), a partnership between the New Zealand forest industry, Scion, University of Canterbury and local engineering firms, in conjunction with the Ministry of Primary Industries (MPI), through the Primary Growth Partnership (PGP) has commenced a robust research and development programme. It has developed a strategy through strong engagement with the forest industry (co-owned strategic goals) aimed at improving productivity, reducing harvesting costs by at least 25%, lowering the cost and social impact of accidents and making harvesting jobs safer and more desirable for workers. As part of this programme the harvesting machinery industry in New Zealand has been given support to grow substantially in order to future-proof the growth of the forest industry.

The FOA has recognised the challenges facing the forest industry and its Science and Innovation Plan strongly supports priorities on harvesting and logistics [7]. The FFR programme emphasises outcomes as measured by sector impacts (primarily through uptake of the development programme's outputs). So how can we achieve a 25% reduction in steep country harvesting costs? Integrated process improvement is key! Innovations are occurring in all phases of the forest value chain from forestry planning to harvest planning, roading construction operations, tree felling, cable extraction and log processing.

Forest Planning

The forester can help a lot in maintaining or allowing economics of scale in harvesting operations. One example is in planning harvest areas to be as large as possible. Many independent logging contractors have between 2 and 5 harvesting crews whose operations include feller bunchers, cut-to-length processors and knuckle boom loaders. When they move harvest settings they may shift 2 km or 25 km which results in a minimum half day of downtime. Costs of moving include the fixed costs of idle equipment (25% of total daily costs), wages paid for non-productive employees (25% of total daily costs) plus direct costs of transporting equipment (if this is not paid by the forestry company). Because of the lost time there is a lower production volume over which to spread fixed costs.

One of the limitations on volume production may be the size of the contract area and the time lost in moving the location of operations [8]. In his study, Fraser concluded…"The implications of a high level of production and the benefits of economies of scale are clear….Even if the contractor has the right machinery and he has done his financial homework, market constraints or other factors beyond his control may force him to operate at a less than desirable target level of output. In this situation economies of scale are unattainable and costs per unit are higher than they otherwise might have been." More recent research has shown that maintaining large harvest setting areas is a positive factor in improved productivity [4]. The FFR benchmarking database which commenced in 2008 is now producing useful data that relates productivity to various harvesting attributes:

$$\textit{Yarder Prod (t/hr)} = \mathbf{-3.3 + 1.44\,W + 1.14\,M + 3.2\,MP + 0.021\,V + 0.15\,HA - 0.065\,S - 3.2\,DF}\ (r^2=0.54);$$

Where:

W = number of workers
M = number of machines
MP = 1 if mechanised processing, 0 if not
V = volume per hectare (m^3/ha)
HA = size of harvest area (ha)
S = average slope (%)
DF = difficulty factor: easy=0, medium=1, hard=2

For 2010 data the average harvest area size was 14.9ha (ranging from 4.6ha to 38.1ha). The underlying principle is that it is more economical to keep the harvest areas as large as possible to allow the maximum production harvesting crew to work (due to the high daily cost) than to try and put a large crew into a small harvest area. Other factors being equal, a reduction in harvest area size of 5 ha results in reduced daily production by about $6m^3$ per day.

In the southern states of USA harvest blocks are about the same size as in New Zealand (usually in the range of 16-20 hectares). Cubbage analysed the effects of moving costs on eight different southern harvesting systems ranging from the "bobtail" system of 3 men and a truck producing short wood pulp to a fully mechanised whole-tree chipping operation [9, 10].

All but one of the systems studied showed a reduction in average harvesting costs as tract size increased. As expected, the analysis indicated that lower capitalised systems cost less to move, because there were fewer machines and lower fixed costs, and larger highly mechanised systems cost more. Therefore the importance of scale of harvest area and reduced frequency of moving becomes more important with mechanised systems.

Harvest Planning

Harvest planning is undertaken on the following principles:

1. The harvest system selected must be physically capable of accomplishing the silvicultural and other resource management (environmental) objectives
2. The harvest system selected must be economically efficient and feasible.
3. The harvest system selected must be socially acceptable (including safe operating practices) and meet all forestry regulations and best management practices.

Cable systems where the stems are at least partially suspended during the haul to the landing are generally the preferred harvesting practice in steep terrain around the world. This can be accomplished with skyline systems. The flexibility of skyline yarding and the ability to suspend one or both ends of the payload make it well suited over a broad range of conditions, both economically and environmentally. The economic and environmental success of skyline harvesting operations is strongly influenced by the type of skyline selected for an operation and by how well the skyline is positioned on the terrain. Good planning is needed to develop well-positioned skyline spans.

Good positioning of skyline spans permit hauling an optimal volume (payload) of logs in each yarding cycle. Poor positioning of the skyline spans can result in little suspension, excessive soil disturbance; hang-ups on obstacles, reduced production, rope failure, equipment breakdowns, unsafe operations and unworkable harvest areas where tree stems cannot be extracted. Payload is constrained by the maximum load (or tension) in the cable and consequently the available sag in the cable (known as deflection). Deflection is the vertical distance between the chord slope and the skyline, measured at mid-span and expressed as a percentage of the span (Figure 1).

The more deflection, the less tension in the cable, the more payload can be hauled and the less suspension is achieved. There is therefore an optimal payload which results in the best solution for production, rope wear, suspension and hence soil disturbance. Deflection measures most often observed in skyline planning are in the range of 5-10 percent.

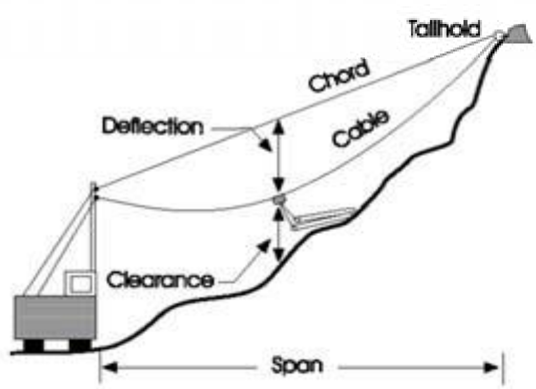

Figure 1: Deflection and horizontal span

To maintain a consistent volume and provide a balance between harvesting production and road construction, planning must be supported by an analytical planning process where a full range of alternatives is considered for each area. Computer software tools for cable harvest planning have been available for many years (e.g. LOGGERPC, PLANS, and CYANZ). These tools for harvest planning use either specific terrain profiles surveyed in the field or plotted from contour lines on topographic maps, or use the digital terrain model (DTM) to fit the harvest and roading design to the specific terrain. In addition to the ground profile the following data on yarding equipment is required to analyse payloads for a specific profile:

- System type (standing, live or running skyline)
- Maximum slope yarding distance (m)
- Tower height (m)
- Tail hold height (m)
- Desired payload (kg)
- Minimum required ground clearance for the carriage (m)
- Carriage height (m) where logs are fully suspended
- Carriage weight (kg)
- Rope characteristics (Skyline, main line and tail line diameter, unit weight and maximum tension)

The payload capacity is evaluated for any given span (terrain profile) extracted from the DTM for the planning area, or the maximum span for a given payload is determined for the cable system. In these earlier models, calculations of maximum span, deflection and payload were necessarily done separately then the setting boundaries and hauler positions and skyline spans were manually transferred onto the topographic logging plan. The level of convenience provided by these early computer methods was insufficient to encourage planners to thoroughly analyse full-rotation, total catchment area harvest plans. Considerable effort was required to digitize profiles needed to develop thorough plans for large areas. Because the planning algorithms required exhaustive calculations of payload and load path for many spans on many profiles, often fewer profiles were analysed or these calculations were done by approximation [11].

One innovation in cable harvesting planning is the recent development of CHPS (Cable Hauler Planning System), an extension for the ArcGIS desktop. This integrates the computer software planning package CYANZ with a geographic information system (GIS). When using the cable planning package in the GIS environment, harvest planners can sketch an intuitive network of skyline harvest settings directly onto the topographic map layer including such detail as proposed roads, landings, and rough hauler setting boundaries, and directly calculate payloads for proposed hauler spans. Such a first cut plan will only be a starting point for an interactive process of computer-aided design which encourages the logging planner to analyse a trial design, alter its parameters, and reanalyse it to converge on a better feasible solution rather than just accepting the first feasible solution found. Planners will be aided by repeated graphic displays on the computer screen showing the progress of a design and the associated calculations of payload and deflection.

One cause of payload analysis algorithm errors involves the accuracy of the profiles extracted from DTMs derived from topographic maps. When terrain break points (where the slope of the ground changes) are extrapolated from contour lines, some of the breaks are between the contour lines. If the slope at the terrain break point is convex, then the true ground line, at the terrain break, will be higher than the profile indicates. This source of ground-profile error is best constrained by using more accurate DTMs that are derived from high resolution LiDAR datasets. These LiDAR data can provide close contour interval mapping and sub-metre DTM grid spacings to substantially improve the quality of topographic mapping for harvest planning. The use of high quality DTMs, in harvest planning can have a number of benefits such as an improved identification of the landing locations, and difficult areas and exclusion zones such as streams and wetlands.

Other tools such as simple hand-held GPS have also been used to measure landing size and location to improve harvest planning [12]. The GPS was also used to collect position points inside the landing to separate the functional areas. These position points were then downloaded into a laptop computer and used to calculate the perimeter, surface area, length and width of each landing, and of each functional area. The significant factors influencing landing size were then identified to be the daily crew production, the number of log sorts produced and whether the landing was unused (new), in use or harvesting had been completed:

Landing Size (m2) **= 390 + 560 x Landing Age + 173 x #Log Sort + 3.5 x Daily Prod.**

Where Landing Age =0 when new; =1 when in use; and =2 when complete.

From the above relationship the landing size required will increase by almost 700m2 for every 4 log sorts added to the cut plan. At average production of 200 tonnes per day, a crew with a cut plan of 7 log sorts requires a planned landing size of 2300m^2, whereas the same crew with a cut plan of 11 log sorts requires a landing of 3000m^2, and if the cut plan is expanded to 15 log sorts the landing size must be planned to be 3700m^2. This equates to an increase in landing density (loss of forest production) of 1%.

Roading Operations

Innovations can occur by questioning the "status quo". Is it more economical to keep the investment in roads as low as possible and shift the logging crew when the conditions worsen or to build all-weather roads and keep the logging crew working? In the past in New Zealand, with permanent forest ownership and stumpage sales the exception rather than the rule, roads were considered as an asset to the forest and capitalised. With the shift to forest lands changing ownership, at the conclusion of current rotations, expenditure on harvest access becomes a sunk cost (similar to the stumpage sales scenario) unless the new land owner gives some sort of credit for road construction.

One alternative is to build roads as low a standard as possible and when it rains and the water table rises and skid trails start rutting and haul roads start to collapse, shift the harvesting crew to the next harvest block. This is the scenario used in the east coast of the USA (swamp loggers!). This is because timber in these areas is commonly purchased on a lump sum stumpage basis. Any expenditure on roading is a sunk cost and consequently there is a tendency to avoid large expenditures on roading [13]. The underlying principle in New Zealand is that it is more economical to undertake a good standard of roading to keep the harvesting crews working (due to the high daily cost) and keep the trucks rolling, than it is to shift. Increasing environmental pressure and the fact that roading costs in some parts of New Zealand (such as the East Coast) are much higher than the New Zealand average may stimulate a review of these principles in these areas.

Tree Felling

The aim of tree felling is to aid the subsequent extraction phase. While it may be self evident what the goal of tree felling is, it is useful to reflect, as common practice will show this is often overlooked. In the 1984 LIRA Seminar on Human Resources in Logging it was defined: *"The goal of tree felling is to fell the tree in such a direction that the following operations (delimbing, extraction etc) are helped as much as possible. A pre-requisite is that the work is performed in a safe way*" [14]. In another LIRA Seminar (Limited Scale Logging 1985) the principle was expressed in much simpler terms *"Cut the wood to suit the hauler. After all there is no capital outlay involved and you will be able to use the same hauler over a wide piece size range"* [15].

The safety and productivity benefits of mechanical felling are well known and often quoted but the value recovery benefits of mechanised felling are often overlooked. Reduction in stump height through mechanised felling is a significant saving. In the average radiata pine clearfell block a 10cm reduction in stump height will recover about 6m3/ha of pruned log volume worth $700/ha. As is well known and understood large radiata pine trees break during felling (often at relatively short tree lengths). The stem volume of the broken stem is therefore low relative to its diameter, reducing the potential value able to be produced from these broken stems [16]. Many studies have indicated that with manual tree felling (current practice) considerable value is being lost. In the past a lot of emphasis has been placed on trying to improve manual tree felling practice to achieve satisfactory conversion into the desired log grades. However with the high physical workload associated with good practice, labour turnover and shortage of skilled workers, harvesting practices that maximise value recovery such as low stump heights and cross-slope felling are not common. Mechanised felling is the only practical way to consistently perform cross-slope felling and hence gain a reduction in felling breakage.

Current levels of mechanisation are still quite low with only 23% of all harvesting operations using mechanical felling (the balance of operations use manual felling by chainsaw). Even on flat and rolling terrain only 57% of trees are mechanically felled. New machines and systems are being developed to mechanise the felling and pre-bunching on the slopes with the aim of eliminating manual chainsaw felling in cable operations. Successful operations are using excavator-type loaders bunching on slopes, and two of the more innovative approaches involve cable-assisted feller bunchers either tethered to a bulldozer with a winch, as well as a steep country feller buncher with an advanced built-in winch to aid traction (the Trinder ClimbMax).

To assist operators with real-time information about the ground surface that the feller buncher is working on, FFR is developing an interface that deploys a LiDAR-derived digital terrain model onto an on-board computer on a feller buncher. When combined with GPS technology it will provide the operator with information on location and terrain, and assist with felling layout, optimal load accumulation and extraction corridor layout.

Cable Extraction

A recent survey of current yarder operations showed that very few cable logging crews use rigging configurations that are higher productivity such as motorised carriages and grapples. Two-stage extraction, although more productive, is also not a common practice in New Zealand cable logging.

Improved Grapple Control

A new grapple restraint has been developed by Scion to improve grapple control. This cost-effective solution to the uncontrolled movement of rope grapples has undergone extensive testing in the field and has now been released to logging contractors across the industry. The benefit of using time and motion studies was highlighted in the evaluation. It was found that the time saved through better control of the grapple was only 3-4 seconds per cycle but added to the small increase in average turn volume associated with the improved ease of loading the grapple resulted in a payback on the grapple restraint of less than 2 months. Innovations in the use of improved radio controlled hydraulic grapple carriages such as the Alpine Logging grapple [17], or the Falcon Forestry Claw [18] for either two-drum or three-drum uphill and downhill yarding will also increase productivity of cable logging, through reduced grapple loading times.

Two-Staging

Swing yarders and their ability to operate on smaller landings or at roadside, often coupled with two-stage extraction to de-phase extraction and log making functions, have the potential to increase cost-effectiveness. Two-staging involves an extra machine (usually a skidder) and an operator to extract from the primary extraction machine to the processing area (which is an extra cost to the contractor). Only 10% of all harvest areas in the 2010 benchmarking survey were two-stage operations. The average two-stage distance recorded was 320 metres (ranging from 50-1200m) which at an average roading cost of $20,000/km is worth $6,400 or over $0.50 per tonne over the average setting volume of 11,500 tonnes. Two stage operations tended to be in larger harvest areas and resulted in shorter average haul distances. When all other factors were taken into consideration two-staging was 13% more productive and resulted in a lower average harvesting cost (by $1.40/m3) over single stage extraction.

Log Processing

In the 2010 benchmarking survey over 90% of harvesting operations processing was done at the primary landing (96% in 2010, 92% in 2009) as opposed to cut-to-length at the stump, or processing at a secondary landing or at a log yard. Processing is still mainly done motor-manually (56%), although this represents a decrease from 67% in 2009. The average number of log sorts in 2010 was 12 ranging from 7 to 16 [4]. Putting all these factors together (manual processing a large number of log sorts on the primary extraction landing) it is timely to consider whether as an industry we are sacrificing productivity and cost advantages due to this complexity. Since the last economic analysis of this problem was over 20 years ago [19], maybe it is time to reconsider the optimal location of processing operations?

Most modern harvesters do not completely delimb and scan the stem before bucking the stem into logs. Many have a taper equation prediction system so that a "near optimal" solution can be generated without scanning the full stem. However, studies have shown that it is more economic to do a complete pre-scan than to use the partial scan and diameter prediction technique [20, 21]. Full stem optimisation and high productivity accurate cut-to-log length merchandising on slopes is still in development.

Conclusion

So what does the future of cable harvesting look like and what will it change into? Mechanical felling and bunching using the Trinder ClimbMax and grapple yarding using the Alpine or Falcon radio controlled hydraulic grapple carriage is the solution for difficult terrain harvesting. The ability to mechanically fell and bunch safely on all steep slopes opens up the opportunity to delimb on steep slopes, to cut-to-log length, bunch logs and extract bunches with smaller faster cable yarders. In the past, extraction of logs by cable hauler rather than tree stems was tried but due to the reduction in payload, productivity was low and costs were high [22]. This paradigm has now changed and high speed extraction of log bunches to roadside is a real option.

Imagine a system where there are no landings, where innovative low-ground pressure high speed cable yarders walk down ridge lines and perch out as far as necessary (without guy lines) to access all the wood in a setting, without having to build a road to the yarder (or a landing). Bunched logs are extracted by grapple to the nearest ridge line and then two-staged to roadside with an all-terrain forwarder and loaded directly to truck. No hand will touch the wood and no worker will be on the slope. This vision will put steep terrain harvesting on a pathway to growth, with reduced costs, continuing record harvest levels and total elimination of lost time accidents in felling, breaking out and extraction. New investments in machinery and new employment opportunities in safer, higher skilled jobs will result. In this vision the government will also continue to make new investments in harvesting research and development to support the forest industry at large to become not only a cornerstone of government policy in carbon reduction, but also a bigger earner of export revenue for NZ.

This future would be assured long term if we could improve the profitability of forestry. Improvements can be made through a concerted effort from foresters, loggers and engineers to implement these innovations in steep terrain harvesting. Industry members who are not already involved in the FFR PGP Harvesting development programme are encouraged to become a stakeholder in this harvesting research programme to address the issues that are draining the lifeblood of forestry profitability: high cost harvesting of our steep terrain forests.

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