Session 2
Paper (c)

MECHANISED FELLING AND PROCESSING IN CABLE OPERATIONS

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ABSTRACT

A review of literature worldwide on the subjects of "Mechanised Felling on Steep Terrain" and "Mechanised Delimbing in Cable Operations" was undertaken in December 1988. It is intended as an annotated bibliography of all available literature in order to evaluate the "state of the art" in mechanised felling and processing in cable operations.

Developments in the technology of feller bunchers, delimbers and processors have provided alternatives to manual felling and trimming. Transferring this technology into restricted landing multiple logsort cable operations will require extensive operational trials.

INTRODUCTION

This paper is a review of literature found in a search of worldwide forestry databases on the subject of mechanical felling and delimbing in cable operations.

Mechanised felling on steep terrain has been reasonably well documented in the past. Steep country felling machines in use throughout the world include the Timbco feller buncher, the Allied Tree Harvester ATH-28, the Menzi-Muck and the Kaiser Spyder. Some of these machines are capable of felling and bunching full trees on slopes over 35° (70%) displaying obvious advantages for improving the felling productivity of NZ cable operations.

Mechanised processing in conjunction with cable logging is a subject that is not so well documented.

In this review, literature on the use of delimbers and processors has not been confined to cable landings in the interests of reviewing various applications of this kind of machinery. Literature on stroke delimbers in roadside operations and stroke-deck or bed delimbers operating on large landings and sortyards has been included.

The evidence of this literature is that technology is emerging that enables both steep slope felling and mechanical processing on roadsides and restricted landings. A case is presented for the introduction of this technology into New Zealand, in order to increase productivity, provide a safer working environment and ultimately reduce the cost of steep country logging.

STEEP SLOPE FELLING AND BUNCHING

In other parts of the world mechanised felling on flat-to-rolling terrain has proven competitive with motor-manual felling in both thinnings and clearfell of trees with butt diameters less than 60 cm.

There is a trend towards feller bunching on steeper ground in the Pacific Northwest of the US (Hemphill, 1988).

These steep slope felling machines are designed to operate on slopes of at least 17° (30%) although commonly they are pushed on to slopes up to 27° or 50% (Schuh and Kellogg, 1988).

Manufacturers are now designing and producing track-mounted feller bunchers that are self-levelling. These machines have a tilting turntable, which allows the boom and cab assembly to swing in a horizontal plane, and a very low centre of gravity for improved stability.

The Timbco feller buncher has been extensively studied and reported (Crawford, 1983; Gingras, 1988b; Gonsior, 1986; Gonsior and Mandzak, 1986; Hensel, 1980; Lanford and Stokes, 1984; McMorland, 1985; McMorland, 1986; Stokes and Lanford, 1985). Studies generally indicate that this machine has great potential for handling both steep slopes and rough ground conditions. One study showed that the productivity of the Timbco decreased with increasing slope although major productivity reductions did not occur unless grades exceeded 20° (Gingras, 1988b).

One manufacturer, Finning Allied Products Ltd, have built a feller buncher which they claim has a gradeability of 56° (150%) and is automatically self levelling to 35° (70%). Lift capacity with full 360° rotation is 4.6 tonnes at maximum 8.5 m reach, and maximum tree diameter is 71 cm.

On Vancouver Island a prototype feller buncher built with FERIC's assistance is equipped with a "rotosaw" capable of felling and bunching trees 70 cm in diameter and 60 metres tall (Wellburn, 1987).

Two models of climbing backhoes converted to feller bunchers (the Menzi-Muck EH3000 and the Kaiser-Spyder X5M) have been fully evaluated and reported (Arola et al, 1981; Arola, 1983; Deal, 1983; Hemphill, 1983; Schiess et al, 1983; Schiess et al, 1984; Schiess and Schuh, 1985).

Although the Kaiser Spyder has a more powerful engine capacity than the Menzi-Muck EH3000 and larger hydraulic system, the maximum tree capacity of the Spyder is only about 0.9 m^3 (Hemphill, 1983).

In clearfelling Red Alder (mean butt diameter of 24 cm) on slopes of 17 - 31° (30 - 60%), productivity averaged 40 trees/PMH. The largest tree cut had a butt diameter of 40 cm (Schiess et al, 1983). Gradeability was limited to about 33° (65%). Production was influenced more by stocking density than by slope. This agrees with the findings of Deal (1981), in his study of the Menzi-Muck. Both these machines however, require further development in order to be able to handle larger trees on steep country.

In current New Zealand cable operations, felling is usually undertaken ahead of the hauler by two manual fallers. Due to requirements for safety in felling on steep country, a greater number of fallers is usually not feasible. Faller productivity must be matched to the production rate of the hauler to avoid problems related to the rapid degrade of Radiata pine through fungal sapstain.

"New generation" haulers may be capable of higher productivity through improved system flexibility, faster line speeds and increased power. If these 4-drum, 400 HP, 70-foot tower haulers are indeed capable of producing over 400 m^3 of Radiata pine per day questions relating to system balancing arise. Can manual felling productivity be matched to hauler productivity? Are two fallers capable of maintaining a production rate of 400 m³ per day?

One option for increasing felling productivity is through the introduction of a steep slope feller buncher. The use of feller bunchers in smaller sized second crop Radiata pine (DBH range 40 - 60 cm) has great potential.

Mechanical felling can increase hauler productivity and reduce the cost of hauler extraction in three ways :

i By improving hauler payload through the elimination of breakage and by bunching felled trees.

ii By reducing hook on time through better wood presentation.

iii By reducing drag breakout time through improved alignment of felled stems.

Bunching and the use of grapple yarding systems has the potential to significantly increase hauler productivity (Carson et al, 1985; Sessions et al, 1986). Large payloads can be achieved by accumulating many stems into a bunch for efficient materials handling. Furthermore, simulation studies have indicated that yarding bunches with a large yarder is more cost effective than yarding scattered stems with a small yarder (Schiess and Martin, 1982).

On steep uniform terrain in BC, yarding cranes using running skylines and equipped with grapples haul logs directly to roadside. The larger cranes with 17 m booms can yard out to 300 m and when used with grapples and a mobile backspar, the hauling system is fully mechanised. On the Queen Charlotte Islands, a feller buncher and grapple crane system was used for logging small timber on wet, moderate slopes up to 45% (24°). The bunching increased the number of pieces hauler per cycle from 1.5 to 3.5 with no reduction in cycle time. It also directionally felled the trees for easier pick up and butt first hauling to roadside for easier processing (Wellburn, 1987).

Mechanical felling presents opportunities for improved value recovery. This occurs in two ways :

i ***Elimination of butt damage and reduction in stump height.***

A study of manual felling patterns in a 41-year old stand of Radiata pine on steep country indicated total stump heights ranging from 28 - 56 cm. The average total stump height (including butt damage exceeding 20 cm) was about 30 cm for both downhill and cross slope felling. The frequency of butt damage exceeding 20 cm in length ranged from 11% for cross slope felling to as high as 63% in the conventional downhill crossed felling pattern (Murphy and Gaskin, 1982).

Butt damage of less than 20 cm in length is usually ignored in manual felling studies due to the removal of the sloven after felling (Murphy, 1982). Another study indicated that butt damage ranging from 20 - 60 cm in length and averaging 24 cm) occurred in 19% of felled trees. This gave an average total stump height including damage of 21 cm (Murphy, 1984). A third study of nine manual fallers resulted in stump heights of 16 cm, draw wood averaging 13 cm in length in 75% of trees, and slabbing averaging 55 cm

Table 1 : Typical Second Crop Radiata Pine Resource Data
(Source : NZFS 1985)

Age Class (years)	*25 - 29*	*30 - 34*	*35 - 39*
Mean DBH (cm)	*42.6*	*46.1*	*50.9*
Mean Top Height (m)	*38.3*	*42.0*	*45.0*
Mean Recov Vol (m^3/ha)	*460*	*621*	*723*
Mean Stocking (sph)	*303*	*328*	*300*
Mean Tree Size (m^3)	*1.51*	*1.90*	*2.41*

in length occurring in 12% of trees felled. This gave an average total stump height including damage of 32 cm (Vaughan and Biddle, 1987).

A reduction to total stump height from the current industry average of about 30 cm to a maximum of 15 cm is achievable through mechanical felling. Total elimination of butt damage is also achievable. Hence if butt damage is eliminated the minimum saving with mechanical felling will be 15 cm. Using typical second crop Radiata pine resource data (Table 1) the effect of this reduction in stump height was calculated at about 0.03 m^3 per tree or 9 m^3/ha. This is a minimum increase in volume and will vary widely between operators, stand and terrain conditions.

ii *Elimination of tree breakage.*

Trees felled manually on steep country generally break. This results in damage to the felled tree, reduced volume utilisation, reduced wood value, and smaller piece size. A previous study has assumed a length of break of 1.0 m, which allows 0.5 m either side for fractures (Murphy, 1982). This study found the probability of a tree not breaking to be 8%. Another study indicated that the probability of no breakage was related to tree DBH (Murphy, 1984). The probability of a tree in the 40 - 50 cm DBH class not breaking was calculated at an average of 20%. Using the tree size data in Table 1, the calculation of average value savings with no breakage is possible. Given average tree diameter at the break point of 25 cm, the average length loss of 1.0 m per break and the probability of no breakage of 20%, the average volume loss through breakage is calculated at 0.04 m^3 per tree or 12 m^3/ha. This volume loss is similar to that attributable to butt damage and high stumps. Hence the combined saving in volume through mechanical felling is about 20 m^3/ha or 3 - 4% of merchantable stand volume.

MECHANISED PROCESSING IN CABLE OPERATIONS

In the largest private forest enterprise in Central Europe - the Mayr-Melnhof Estate in Austria - 40% of the annual cut is produced using a fully mechanised cable system (Vyplel, 1980). Full trees (0.5 - 1.25 m^3/tree) are yarded to roadside, cold decked for a MM800 two-grip processor which is capable of delimbing and cross cutting timber up to 80 cm in diameter.

After cutting to length, logs are stacked on roadside for loadout by self loading truck. After four years experience with the system, results indicated that mechanised logging was 35% cheaper than conventional motor-manual harvesting (Vyplel, 1979).

In the area of mechanised delimbing, FERIC is designing and building a processor attachment for a heel boom loader (Wellburn, 1987). It will be used on narrow roads primarily in cable operations where there is not enough room to process and restack logs. Large trees would be cut to length in the bush and small trees yarded tree length. The combination machine would then process the small trees and load all the logs.

The introduction of mechanical felling on steep country necessitates the introduction of mechanised processing technology to cable operations. This effectively means machines must be capable of operating on small landings or roadsides.

Mechanised delimbing of Radiata pine on intermediate terrain is well proven in Australia (Raymond K, 1988a, Raymond O, 1989). High volume mechanised logging operations on either landings or roadsides are also common in ground based operations in the US and Canada (Heidersdorf et al, 1986; Peterson, 1987; Schuh and Kellogg, 1988). However, transferring this technology to operate in New Zealand cable operations will require extensive trials.

The productivity of cable logging in New Zealand compares poorly with overseas operations (Galbraith, 1987; Williams, 1989). Reasons given include the adherance to tree length logging, inadequate loaders and limited use of different cable systems and carriages. In other words, for New Zealand hauler productivity to increase some radical changes in either systems or technology are necessary.

In conventional tree length cable logging, (manual processing and rubber-tyred loaders) there appears to be a tradeoff between the number of logsorts processed and the production rate. This is a function of the interference patterns between the extraction, processing and loading phases of the operation.

Although there is wide variation between the operations sampled to date (Donovan, 1988; Williams, 1989), it appears that the highest producing cable operations in both New Zealand and the Pacific Northwest (PNW) produce a minimum number of logsorts (3-5). Conversely, the productivity levels of PNW operations processing a large number of sorts (12-18) is on average lower than those producing few sorts. To increase New Zealand hauler productivity it may therefore be necessary to reduce the complexity of the log processing and sorting phases of cable operations in order to reduce interference with the extraction phase. The evidence of the overseas literature is that the introduction of mechanised processing technology will increase landing productivity. Attempting to mechanically process large numbers of logsorts in a high production cable operation may not however be feasible.

In single-stage, hot deck cable operations, the use of a hydraulic knuckleboom loader in conjunction with a processor is advocated. The ability of knuckleboom loaders to handle multiple log sorts on restricted landings is well documented (Donovan, 1988; Galbraith, 1987; Raymond, 1988b). In a two-stage operation, where space is not as critical, a rubber tyred loader may be adequate. However both systems require a loader matched to extraction capacity.

In the Pacific Northwest, only a few companies have been successful in mechanically processing on hauler landings (Hemphill, 1988; Schuh and Kellogg, 1988b). As with manual cable systems, the introduction of mechanisation of processing in order to handle increased hauler production may require a reduction in the number of log types produced. One machine with the potential to handle multiple logsorts is the Hahn Harvester. This tree length processor has a colour coding facility for marking different logsorts for easier loadout. The literature suggests however that this machine requires a large amount of available space to work most productively (Gonsior, 1986). Whether this machine can operate on small cable landings is unknown.

__FUTURE TRENDS IN CABLE LOGGING__

A seminar on the technology and mechanisation of logging operations in mountainous regions was held by the FAO/ILO in 1985. Papers described European logging operations with respect to the technology available for both complete and partial felling on slopes of various degrees of steepness (Besprozvanny and Kovalev, 1985; Bieberstein, 1985; Muhl, 1985; Olteanu and Stan, 1985; Zapotocky, 1985).

The seminar concluded that among other things, significant progress had been made over the past decade in techniques and equipment used in mountain harvesting. It was noted however that there is considerable scope and need for further development, particularly with the object of raising labour productivity and reducing the cost differential with operations on easier terrain.

Recommendations included :

- That wherever possible, operations such as delimbing and cross-cutting should be transferred to the roadside or landing where they can be undertaken under easier and safer working conditions, and where wood utilisation and labour productivity will be higher than at the felling site.
- That research and development is needed to improve the stability and ground pressure of wheeled machines. The use of high flotation tyres should be further studied and improved for use on steep slopes.
- More use should be made of the possibilities for remote control and automated processing systems to improve productivity in harvesting in mountain forests.

Mann et al (1985) predicted that changes in technology in the next few years will result from current research and development activity in :

- Methods to increase productivity by bunching log loads to approximate the capability of the yarding system.
- Innovations in vehicle designs to make them more suitable for operation on slopes.
- Practical substitute anchors for cable logging systems.

As New Zealand logging moves into the 1990's the average tree size harvested will decrease and more timber will be harvested on steep country and in more difficult conditions. This will unavoidably result in higher logging costs unless major technological changes to harvesting systems occur.

As noted by Sessions et al (1986), in referring to similar trends in Western North America, "scaling down harvesting systems to match timber size will not ensure competitiveness with other timber producing regions. The trend, instead, will be toward increasing mechanisation of felling and bunching, substitution of ground-based systems for cable yarding where feasible, and selection of efficient silvicultural prescriptions which recognise the limitations imposed by harvesting technology and economics."

Sauder (1988) identified two trends that are likely in cable logging in the future :

- A move towards mechanical felling and bunching enabling the full potential of grapple yarders to be realised.

  Current mechanical felling units can negotiate 17 - 27° ground slopes and one unit claims to have gradeability of 56° (150%). Felling and bunching heads up to 70 cm capacity and feller-director heads up to 85 cm capacity are available. Mechanical felling offers the contractor the opportunity to fell more timber per day, with more control over wood presentation and with greater safety than manual felling. Bunching smaller diameter timber can increase hauler payload, and hence productivity.

- The introduction of mechanical processing on cable landings.

  Mechanised processing equipment offers the opportunity to reduce the interference between hauling and processing phases of cable logging, and the potential to reduce costs, through improving productivity. Mechanical delimbing will be a necessity if mechanical felling is introduced on a large scale. In its turn mechanical processing will require loaders capable of sorting logs from stacks and disposing of slash efficiently. Hydraulic knuckleboom loaders are seen as the ideal type of loader to fit into a mechanised cable logging operation due to their efficiency at sorting a large number of log types.

CONCLUSIONS

From the survey of the literature available on the mechanisation of steep country harvesting it is obvious that we are living in a period of exciting developments in the field of industrial mechanisation world-wide. Developments in computers, microprocessor control, hydraulic systems, and robotics are changing the face of manufacturing technology. Industrial mechanisation is advancing into the forest harvesting industry and advances have already been made in mechanised harvesting on easy terrain.

In most industrialised countries, a high level of mechanisation is generally applied in wood harvesting. This is dictated by high cost of labour, frequent scarcity of labourers and the demand to supply large quantities of logs to established forest industries (Heinrich, 1985). On easy to hilly terrain in even aged forests, tree harvesting operations are fully mechanised. Highly mobile feller bunchers, harvesters and processors have largely replaced chainsaws in logging in Scandinavia, Canada, the US and Australia. The same developments could occur on easy terrain in New Zealand.

In steep terrain however, felling and trimming is generally still done by chainsaw, and cable logging will still remain the preferred method of extraction. Nevertheless, alternatives to manual felling do exist, and the use of mechanical processors on cable landings is developing. Machines such as the Timbco and the ATH-28 for felling, stroke delimbers and more robust grapple processors such as the Steyr KP60 and possibly New Zealand's Waratah processor show potential.

In Europe, mobile grapple processors are positioned on mountain forest roads to delimb, cut to length and sort and stack. As previously discussed, the introduction of this technology into New Zealand will require both extensive operational trials and commitment by management. In developing countries these modern harvesting machines are still far too expensive and technically too advanced to be of use in forest operations. They will also be socially unacceptable as they require a minimal and highly skilled labour force (Heinrich, 1985).

The same situation could be argued in New Zealand given the high owning and operating cost of machinery and the generally low level of training for loggers in cable systems. A major effort in logging training is required if New Zealand is to avoid the problems associated with the shortage of skilled machine operators and machinery in the logging industries of other developing countries. The aim must be to raise the level of skills and expertise in planning and using a variety of logging systems and thereby improve the efficiency of cable logging operations.

To ignore the benefits of increased productivity, reduced physical effort, and overall improved worker safety, is to ignore the potential for reduced total logging costs in the future.

<u>ANNOTATED BIBLIOGRAPHY</u>

<u>1. Mechanised Felling on Steep Terrain</u>

Arola, R A; Miyata, E S; Sturos, J A; Steinhilb, H M (1981) : "Felling and bunching small timber on steep slopes", USDA For Serv Res Pap NC-203. North Central For and Range Exp Stn, St Paul, Minnesota, (1981).
Field trials of the Menzi-Muck model EH3000 climbing backhoe used as a feller buncher. Productivity was 60 stems per PMH or 15 tonnes/PMH, in a pole stand (0.25 m³ tree size), and 101 stems per PMH or 6.5 tonnes/PMH, in a sapling stand (0.06 m³ tree size). Slopes ranged from 19° to 40° (35 - 85%). Utilisation ranged between 84 - 87%.

Arola, R A (1983) : "Steep slope felling and bunching - the Menzi Muck", In "Timber harvesting in the Central Rockies : Publication No XCM-87, Colorado State University, Fort Collins, Colorado : 154 - 165, 1983.
Another review of the Menzi-Muck EH3000 feller buncher studies on steep terrain.

Carson, B; Mann, C N; Schiess, P : "An Evaluation of Cable Yarding Bunched Trees on Steep Slopes", In "Proceedings of the Council on Forest Engineering, 8th Annual Meeting, August 18 - 22, 1985, Tahoe City, California.
A study of a cable operation yarding bunches of whole trees created by a Kaiser Spyder feller buncher on slopes up to 35° (70%). Conclusions were that bunching trees on steep slopes appears to be a feasible method of increasing yarding production of small diameter stems. Bunch weights could be assembled that were appropriate for medium yarders.

Crawford, P (1983) : "Steep slope feller bunchers : the Hydro Buncher", In "Timber harvesting in the Central Rockies", Publication No XCM-87, Colorado State University, Fort Collins, Colorado : 153, 1983.
A review of the Timbco Hydro Buncher feller buncher on steep terrain.

Deal, E L (1983) : "Steep slope felling and bunching in small timber", In "The Small Tree Resource : A Materials Handling Challenge". Proc 7306, FPRS, Madison, Wisconsin : 111 - 128 (1983).
A study of the Menzi-Muck EH3000 climbing backhoe felling and bunching small timber in the south-east US. It was found that slope had no significant effect on productivity.

Folkema, M P (1984) : "Circular saw and cone saw felling heads : an update". FERIC Technical Report, No TR-56, 1984.

Tests were made on five 'non-shear' felling heads : (a) Koehring disc saw; (b) Harricana circular saw; (c) Denis SJ-24 twin saw; (d) Boreal DD-20 double-deck saw; and (e) Lokomo L450A cone saw. FERIC recommends that a side-tilt (wrist) feature be mandatory for all five saws when used on any carrier vehicle except a Timbco 2518, which has a four-way tilt on the turntable. The main charateristics of the saws and factors to consider when purchasing a felling head are summarised in a table.

Gingras, J-F (1988a) : "The Feller Buncher/Grapple Skidder System : Optimizing Bunch Size". FERIC Technical Report, No TR-81, 1988
The performance of feller bunchers is affected by many operational and physical factors. They are , in order of their perceived relative effect on machine productivity :
- Tree Volume
- Merchantable stand density
- Operator decisions
- Accumulator capacity
- Bunch size
- Terrain

Terrain has the least significant effect on feller buncher productivity except in extreme conditions, when its importance increases. The major recommendations for maximising feller buncher productivity was to maximise bunch size through :
- felling as many trees as possible from one set up by increasing swath width or using the accumulator function to the fullest;
- travelling back to the bunches when terrain was suitable;
- building up a load of trees in the head to carry forward to the next bunching point.

Gingras, J-F (1988b) : "The Effect of Site and Stand Factors on Feller-Buncher Performance", FERIC Technical Report TN-84, November 1988.
Report describes the results of a project aimed at correlating feller buncher performance with measurable stand and site parameters. A John Deere 693, with a Harricana shear felling head, and a Timbco 2518 feller buncher were studied. The John Deere worked in favourable stand and terrain conditions. Maximum slope was 10°, with 12° sideslope. Productivity averaged 170 trees/PMH (32.3 m^3/PMH in 0.19 m^3 tree size). The Timbco operated in a range of conditions including wet pockets, steep slopes, rocky outcrops and dense stands. Productivity averaged 210 trees/PMH (31.5 m^3/PMH in 0.15 m^3 tree size). Maximum slope was 20°, with 20° sideslope. Productivity decreased with increasing slope although the degree of influence was different for the two machines. Major reductions in productivity of the John Deere occurred when slope exceeded 8°. The Timbco did not experience major productivity reductions unless grades exceeded 20°.

Gonsior, M J (1986) : "Mechanised harvesting and processing in Mountainous Terrain of Western Montana : A case study", Reprinted from 9th Council on Forest Engineering Meeting, Mobile Alabama 1986.
This Report summarises some of the results of a study of mechanised harvesting in Western Montana, USA, using a Timbco steep terrain feller buncher, a Hahn Harvester and a Harricana delimber. With trees of 35 cm DBH the basic production rate of the Timbco was 46 trees per scheduled machine hour, or 370 trees per scheduled 8 hour day. Although the Timbco can harvest timber on slopes up to 31° (60%) and travel directly up and down the slope on even steeper ground, it cannot so readily handle sideslopes on such terrain. Technologies like the Timbco extend the advantages of mechanisation to terrain that was formerly operable only with manual methods that are less efficient and more hazardous to workers.

Gonsior, M J; Mandzak, J M (1986) : "Mechanized systems for harvesting small-stem Lodgepole pine in mountainous terrain", In

"Management of Small-Stem Stands of Lodgepole Pine Workshop", Fairmont Hot Springs, 1986: p 53 - 66.
A review of the Timbco feller buncher and Hahn Harvester operating on steep terrain.

Hemphill, D C (1983) : "Spyder steep-slope feller buncher". LIRA Technical Release Vol 5 No 2 1983.
Powered by a 40 kW Deutz diesel, and with a felling capacity of only 33 cm, the Kaiser Spyder is limited to a maximum tree size of 0.9 m^3. The practical operating limit, however, is 60% (31°). Productivity in thinning is expected to be about 50 trees per PMH.

Hemphill, D C (1988) : "Log processing on steep slopes, US Pacific Northwest Practices". LIRA Technical Release Vol 10 No 5 1988.
In the Pacific Northwest there is a trend toward feller bunching on steeper ground with many models operating on slopes to 35%, the Timbco to 60% and the Allied (Tree Harvester) over 70%. This is seen as the key to ultimate cost containment with declining piece sizes. It will, of course, mean processing on the landing.

Hensel, J S (1980) : "Timbco Hydro-buncher", APA Technical Release No 80-R-58, American Pulpwood Association, 1980.
Presents information and machinery specifications of the original model of the Timbco feller buncher designed and built by Pat Crawford of Shawano, Wisconsin.

Lanford, B L; Stokes, B J (1984) : "Performance of Timbco Hydro-buncher on Steep Terrain", In "Proceedings of the 1984 Mountain Logging Symposium", Morgantown, West Virginia, 1984.
The Timbco was studied in steep country thinning of Loblolly pine. Slopes ranged from flat (less than 8°) to steep (more than 31°). Blocks were thinned from 1700 sph down to 300 and 900 sph respectively. Production studies were conducted : up-slope, down-slope, across slope and on level terrain. Mean total productivity averaged 140 trees per hour (0.10 m^3 tree size). Slope did not affect the Timbco directly. The machine performed equally well on varying degrees of slope. The cutting pattern was the most significant variable tested. Productivity ranged from 167 trees/PMH (cutting up-slope and bunching to the front) to 127 trees/PMH (cutting down slope and placing the bunches behind the machine).

Mann, C N; Kuga Y; Miyata, E S (1985) : "Technology for future mechanisation on steep slopes", In "Improving Mountain Logging Planning, Techniques and Hardware". Proceedings, Joint Symposium of the IUFRO Mountain Logging Section and the 6th Pacific Northwest Skyline Logging Symposium; May 8 - 11 1985; Vancouver, BC.
A review of current logging methods for steep terrain logging. Changes in technology in the next four years will result from current research and development activity in areas of mechanical felling and bunching, innovations in vehicle design for steep slopes, and in development of substitute earth anchor systems.

McMorland, B (1984) : "Production and performance of mechanical felling equipment in Interior BC : Harricana circular saw". FERIC Technical Note, No TN-74, 1984.
A Harricana circular saw felling head mounted on a Drott 40 carrier vehicle was tested in British Columbia over a period of 149 calendar days. Production per shift averaged 281 m^3 or 639 trees. Productivity was 44.7 m^3 per productive machine hour. Mechanical availability was calculated at 68%. Since these data were collected, modifications have been made which should reduce repair and service time.

McMorland, B (1985) : "Production and performance of mechanical felling equipment on coastal BC : Timbco feller buncher with Rotosaw head". FERIC Technical Note No TN-85, 1985.
Results are presented of trials, over a period of 59 productive shifts, with a Timberjack Timbco Model 2518 Hydrobuncher with a Rotosaw felling head, at MacMillan Bloedel Limited's Northwest Bay Division on Vancouver Island. The buncher formed part of a fully-mechanised harvesting operation in a 110 year old stand of second-growth Douglas fir, cedar and hemlock. Machine availability was considered poor - 70.5%. At an average tree volume of 0.58 m³, productivity per PMH was 35.4 m³ from 61 stems. Working 2 full shifts per day, daily production averaged 405 m³. Although performance was generally good, the Timbco was considered to be undersized for Coastal BC application.

McMorland, B (1986) : "Production and performance of mechanical felling equipment in Interior BC : Timbco Feller buncher with Rotosaw head", FERIC Technical Report TR-67, 1986.
FERIC has been monitoring the progress of the steeper-slope machines, and particularly that of the Timbco. It has a higher degree of cab levelling than other feller-bunchers; also, there are currently more Timbcos in BC than other makes of steep-slope feller-bunchers. A Timbco 2520 feller buncher was studied in a block composed of spruce, with lesser amounts of balsam and pine. Approximately 5% of the block exceeded 30% slope. Over all 75 working shifts, the shift length averaged 9.3 hours, of which 67% was spent in the normal functions of cut, bunch, and move. At an average tree volume of 0.86 m³, productivity per Productive Machine Hour (PMH) averaged 60.1 m³ from 69.9 stems. Daily production for the day shift was 394 m³. Estimated in-shift availability was 78 - 79%. These results are similar to those from other FERIC studies on felling machinery in Interior BC winter conditions.

Miyata, E S; Mann, C N; Ortman, T L : "Field Evaluation of Menzi-Muck Feller-Buncher on Difficult Terrain in Southeast Alaska", In "Proceedings of Mountain Logging Symposium, Morgantown, West Virginia, 1984.
A study to test the semi-walking Menzi-Muck feller buncher in difficult terrain. Adverse conditions are characterised by steep slopes, wet and shallow soils, rocks and ground obstacles, windthrown timber and frequently the lack of suitable stump anchors. This paper presents preliminary results of four different applications of the Menzi-Muck :
(1) Commercial thinning
(2) Piling of logging slash
(3) Land preparation for replanting
(4) Installation of rockbolt anchors
The machine could travel over steep slopes up to 63% (32°), however wet or soft terrain tended to slow the machine down. No major problems were encountered in slash piling and land preparation, and the machine worked well in installing rock bolt anchors.

Murphy, G (1982) : "Alternative Felling Patterns, Techniques, Breakages and Value Loss". FRI Production Forestry Division Project Report No 38.
Unpublished Internal Report on a felling study in Whakarewarewa State Forest Park.

Murphy, G E; Gaskin, J E (1982) : "Directional Felling Second Crop P Radiata on Steep Country", LIRA Report Vol 7 No 1 (1982).
Report on a study of four manual felling patterns in a stand of radiata pine on steep country in Whakarewarewa State Forest Park.

Murphy, G E (1984) : "Felling Breakage and Stump Heights of a P Radiata Stand in Tairua State Forest". FRI Bulletin No 57, 1984.
Report on a study of stump heights, butt damage and breakage in a manual felling operation in Tairua State Forest.

NZFS (1985) : "Inventory of 1940 - 1960 P Radiata Stands, Kaingaroa Forest", Unpublished Internal Report.

Sauder, E A (1988) : "Future Equipment Needs in Coastal BC", FERIC Special Report SR-49, 1988.
The survey indicates that, overall, more timber will be on slopes greater than 50% (27°) and less on slopes less than 30% (17°). Piece size is predicted to decline in all zones in BC. Ground-based extraction systems and mechanical felling will have potential. Mechanical felling is predicted to increase. Cable logging will continue to be dominant harvesting system but a small increase in ground skidding is predicted. Cable yarders and loaders will be required to have fast cycle times or the ability to handle several pieces at a time. A trend towards the replacement of highlead towers with grapple yarders is predicted. The use of mechanised processing equipment is expected to increase over the period 1985 - 2005. Although most respondents had not fully considered how they would use the concept, there appears to be major potential for using mechanical processing equipment in BC. The equipment would have to be capable of handling tree length logs from roadside windrows. In easier terrain environmental concerns may restrict the use of ground-based equipment. Mechanical felling equipment, however, may have potential to directionally felling of timber beside or within streamside management zones.

Schiess, P; Martin, R (1982) : "Mechanized Harvesting on Steep Slopes", In Proceedings, 5th National Symposium Council on Forest Engineering, Corvallis, Oregon; August 1982.

Schiess, P; Schuh, D; Miyata, E S; Mann, C N (1983) : "Concept evaluation of a walking feller buncher - the Kaiser X5M Spyder", In Proceedings, "Timber Harvesting in the Central Rockies" Publication No XCM-87, Colorado State University, Fort Collins, Colorado : 166 - 212, 1983.
Studies of felling and bunching on steep country in Washington State using a Kaiser-Spyder feller buncher. Slopes ranged from flat to 90% (42°), with an average slope of 50% (27°).

Schiess, P; Schuh, D; Carson, B (1984) : "Steep Slope Harvesting with the Kaiser X5M Spyder feller-buncher," In Proceedings of a Seminar on "Pacific Northwest Bioenergy Systems : Policies and Application", US Dept of Energy and PNW and Alaska Bioenergy Program, Portland, Oregon, May 10 - 11, 1984.
Another report on the field test program of the Kaiser X5M Spyder "walking" feller buncher.

Schiess, P; Schuh, D (1985) : "Steep Slope Harvesting : The Kaiser Spyder Feller Buncher", In "Improving Mountain Logging Planning, Techniques and Hardware". Proceedings, Joint Symposium of the IUFRO Mountain Logging Section and the 6th Pacific Northwest Skyline Logging Symposium, May 8 - 11, 1985. Vancouver BC.
Overview of tests on the Kaiser X5M Spyder feller buncher. Slopes ranged from 35 - 55% (19° - 29°) with tree DBH ranging from 20 - 48 cm. The production rates were most sensitive to changes in move speed, accumulator use, and boom reach caused by slope. Further mechanical refinements of the prototype were recommended. Mechanical bunching operations on steep slopes appear to be a promising approach to effectively use large cable yarders in small timber.

Schuh, D D; Kellogg L D (1988) : "Timber-Harvesting Mechanisation in the Western United States : An Industry Survey", Western Journal of Applied Forestry, Vol 3, No 2, April 1988.
A survey of logging operations in the Western US located over 140 contractors using mechanised equipment. Seventy-five percent of feller buncher owners owned a single felling machine. Slope conditions play an important role in feller buncher selection. It was found that owners of swing boom feller bunchers work in much steeper terrain (slopes of 50%+) than owners of fixed-shear machines. With the introduction of new machinery such as clambunk skidders and leveling feller bunchers, the traditional limits to economical and environmentally sound ground based harvesting may be changing.

Selby, J S (1986) : "The Weyerhaeuser Feller Director", LIRA Technical Release Vol 8, No 11, 1986.
A report on the development of a large capacity feller director based on the Hultdins F60 feller director. Mounted on a Timbco 2518 feller buncher base, the Weyerhaeuser W-34 could cut 86 cm diameter trees on slopes up to 60% 31°). Productivity was measured at 71 trees/PMH in 1.3 m^3 tree size (92.3 m^3/PMH) and 58 trees/PMH in 2.2 m^3 tree size (127.6 m^3/PMH). Availability and utilisation was 85% and 74% respectively. Grapple yarding productivity in bunched wood was found to increase by 50 - 100%. This unit is now manufactured by Equipements Denis Inc. Quebec, as the Denis D85 feller director.

Sessions, J; Iff, R H; Cottell, P L (1986) : "Mountain Logging in North America - Trends for the next Decade", In Proceedings of the 18^{th} IUFRO World Congress, Division 3, Ljubljana Yugoslavia, September 7 - 21, 1986.
The forest industry in western North America is in a period of transition. Average size of harvested trees is decreasing; labour rates are high and concerns for environmental quality are strengthening. The trend, will be toward increasing mechanisation of felling and bunching, substitution of ground-based systems for cable yarding where feasible, and selection of efficient silvicultural prescriptions which recognise the limitations imposed by harvesting technology and economics. Equipment and strategies for processing full trees in mountainous terrain still remain to be developed.

Stokes, B J; Lanford, B L (1985) : "Evaluation of Timbco Hydro-Buncher in southern plantation thinning". Transactions of the ASAE 1985, 28(2) : 378 - 381.
Another evaluation of the Timbco Hydro-Buncher on easy terrain. Production functions are presented to enable simulation of performance.

Vaughan, L; Biddle, B (1987) : "Felling Techniques to Minimise Butt Damage", LIRA Project Report PR33, 1987.
Report of a project to identify manual felling techniques that were most effective in controlling felling damage. A study of existing felling techniques was undertaken, then a series of trials examined the effectiveness of good basic techniques and the consequences of altering key factors in these techniques. A number of recommendations to improve current practice were made.

Wellburn, G V (1987) : "Developments in Wood Harvesting Technology in Canada", Paper presented to the Canadian Forest Industry Technology Seminar, Forest Research Institute, Rotorua, February 17, 1987.
A description of current harvesting methods, machine systems and likely future developments in the Canadian wood harvesting industry.

2. Mechanised Processing in Roadside/Landing Applications

Andersson, B (1982) : "The Hahn Pulp/Logger II Limber-Slasher as a Component in Full-tree Harvesting Systems", Pulp and Paper Canada 83:3 (1982), p 39-42.
Report on two short field trials of the Hahn at Great Lakes Forest Products Limited. The Hahn Limber-slasher is a two-operator machine that delimbs, slashes and sorts pulpwood and sawlogs. Productivity in 0.24 m^3 tree size averaged 20.3 m^3/PMH or 14.3 m^3/SMH.

Auboeck, F (1982) : "Mechanized wood harvesting and the optimal opening up of forests in mountain areas of Austria". FAO/Austria Training Course on Mountain Forest Roads and Harvesting, Ossiach, Austria, 1 June 1981. FAO Forestry Papers No 33, p 225 - 230, 1982.

Becker, G (1978) : "The Use of Processors Under Central European Conditions", In Allgemeine Forstzeitschrift, 1978, No 8, p 186 - 189. Language : German.
Study of the Kockums 850/78 Processor.

Bennecke, K (1985) : "Whole-tree harvesting in young Norway spruce stands". Allgemeine Forstzeitschrift 1985, No 19 : 464, Language : German.
Work studies are reported on the cable line-thinning method in the Harz Mts, Lower Saxony. Skidding cable paths are established at intervals of 1 - 4 m and extraction lanes at intervals of 30 - 40 m. Two stands were studied : 1) a 46 year old stand on a site partly accessible by road, (average log size 0.29 m^3); 2) first thinning of a 38 year old stand on a steep slope, (average log size 0.09 m^3). The operation studied felling to primary conversion at roadside using a Stenab 40 processor. It was concluded that the method was suitable for use in second thinnings, except on very steep sites.

Bernhard, A; Wenter, W (1977) : "Work studies and establishment of time requirement values for mechanical branch trimming and cross-cutting with the Osa 705 processor in mountain forests", Allgemeine Forstzeitung 1977, 88 (5): 123 - 126. Language : German.
Studies of a modified Osa 705/260 processor. Modifications included a longer grab arm and faster feed rate.

Bernhard A (1978) : "Work studies on felling/cable skidding operations : use of the mobile processor (Kockums 850/78) in mountain forests". Forstarchiv 1978, 49 (11) : 237 - 240 Language : German.
Report on the Kockums 850/78 processor in steep terrain.

Besprozvanny, V I; Kovalev, A P (1985) : "Logging technology in mountainous conditions in the Soviet Far East", In "FAO/ILO Seminar on the technology and mechanisation of logging operations in mountainous regions and related environmental problems", FAO Report (1985) No TIM/EFC/WP 1/Sem 20. Proceedings of a meeting of the FAO/ILO Joint Committee on Forest Working Techniques and Training of Forest Workers, held on 2 - 7 September 1985, in Krasnodar, USSR.
Regulations have been developed by the Far East Scientific Research Institute for the mountain forests of the Far East. These allow for the determination of the degree of mechanisation in logging taking into account forest, soil and terrain conditions. Mechanisation in logging is most important for increasing logging productivity and for overcoming the shortage of manpower. Several logging trials are being carried out, including testing of mobile cable units.

Bieberstein, D (1985) : "Technologies and machines for complete or partial felling in technically mature stands depending on the slope gradient"In "FAO/ILO Seminar on the technology and mechanisation of logging opera-

tions in mountainous regions and related environmental problems", FAO Report (1985) No TIM/EFC/WP 1/Sem 20. Proceedings of a meeting of the FAO/ILO Joint Committee on Forest Working Techniques and Training of Forest Workers, held on 2 - 7 September 1985, in Krasnodar, USSR.
In wood harvesting in the German Democratic Republic, manual methods as well as mobile delimbers and chippers were used. Productivity figures were given for :
- Extraction by skidder : 10 - 15000 m³ /year;
- Cable cranes attached to agricultural tractors : 5000 - 12 000 m³ /year;
- Delimbing machines : 50 - 150 m³ /day.

Brabeck, W : (1979) : "Centralized versus mobile whole tree harvesting in Austria". Paper presented at the KWF-IUFRO Seminar, 'Centralized versus mobile processing', 12 - 15 June 1979, Donaueschingen, German Federal Republic.
Mobile processors serve as a link between logging operations in the forest and centralized processing. In future mobile processors working at the forest roadside may have to carry out delimbing and cross-cutting, because curving mountain roads cannot be used to transport whole trees. Small trees from thinnings can be transported as whole trees to centralized processing units.

Dietz, P; Rieger, G (1984) : "Opening-up of Forests and Timber Harvesting on Difficult Mountain Slopes", In Allgemeine Forstzeitschrift 1984, No 4, p 58 - 59, Language : German.
Report on whole tree extraction and roadside processing in steep terrain.

Duggan, M (1989) : "System Evaluation - Waratah Processor in Steep Country Thinnings". LIRA Project Report PR41, 1989.
Report on a steep country Radiata pine thinning operation. The system comprised manual felling, full tree extraction with a Komatsu D37 tractor, a John Deere 440D skidder and a Timbermaster hauler. Wood was processed with a Waratah grapple processor, and a knuckleboom loader mounted on an agricultural tractor was used for loading out. Processor productivity in 0.3 m³ tree size averaged about 85 trees per hour (25.5 m³ /PMH). The system had potential productivity of 183 tonnes per day before the processor became limiting.

Donovan, V (1988) : "Logging Operations on Restricted Landings (USA)", LIRA Report Vol 13, No 13 1988.
This Report is a presentation and discussion of several reports entitled "Logging Operations on Restricted Landings - Some Examples from the Pacific Northwest" prepared by Dallas Hemphill, a logging consultant from Oregon, USA.

Eeronheimo, O (1985) : Discussion on "Mountain logging from the Finnish point of view" presented to the FAO/ILO Seminar on the Technology and Mechanisation of Logging Operations in Mountainous Regions and Related Environmental Problems; Krasnodar (USSR), 2 - 7 September 1985. FAO Report (1985) No TIM/EFC/WP1/SEM20.
Finland's interest in mountain logging is mainly explained by the export of forest machines and the provision of technical co-operation to countries with mountainous conditions. Harvesters and feller-bunchers can be effectively used on slopes of 9 - 11°; processors mounted on a forwarder chassis on slopes of 11 - 14°; forwarders and excavator-based logging machines on slopes of 14 - 17°. On steeper slopes winches mounted on farm tractors can be used. During the discussion of the paper the Norwegian delegate Mr T Inderberg, explained that in Norway, delimbers and processors were used on slopes with gradients up to 22° provided the surface was level.

Folkema, M P; Levesque, R (1982) : "Evaluation of the Hahn Pulp/Logger II Limber-Slasher", FERIC Technical Report No TR-52, April 1982.
An evaluation of an early model of the Hahn working both as a roadside processor and on a landing. The machine delimbs full trees and cuts to measured length. Six studies are reported. Tree size ranged from 0.12 m^3 to 0.31 m^3. The Hahn commonly delimbed two trees per cycle and productivity ranged from 49 trees per PMH in 0.30 m^3 (14.9 m^3/PMH) to 137 trees per PMH in 0.18 m^3 (24.6 m^3/PMH). Multiple stem delimbing tended to reduce the adverse effect of small tree size on productivity. The production of sawlogs and pulpwood vs pulpwood only, for any given tree size, did not appear to affect productivity, provided there was adequate room for stacking (ie provided no clearing slash was necessary to stack sawlogs). The accumulation of slash on the road was a limitation to the Hahn. Delimbing quality was excellent with limbs up to 13 cm in diameter cleanly removed. 1982 costings indicated that the Hahn was more expensive to operate than a sliding boom delimber only.

Galbraith, J E (1987) : "Cable Logging Productivity in New Zealand : How Do We Compare?", Paper presented to the NZ Forest Owners' Association Annual Conference, Blenheim, October 1987.
The performance of New Zealand cable logging does not compare well with overseas operations. Our better operators only achieve around 70% of the daily production levels of efficient Pacific Northwest operators, in similar tree size. Adherence to tree length logging, inadequate loaders and limited use of available cable systems and carriages are seen as the main reason. These factors will need to be improved if the new crop forests with smaller tree sizes on steep, difficult terrain are to be satisfactorily and economically logged.

Gleason, A P (1984) : "Mechanised processing in conjunction with a cable hauler", LIRA Report Vol 9 No 7, 1984.
Report on the Hunt delimber working in a cable operation in Hanmer State Forest, New Zealand.

Gonsior, M J (1986) : "Mechanised Harvesting and Processing in Mountainous Terrain of Western Montana : A Cable Study", Reprinted from 9th Council on Forest Engineering Meeting, Mobile Alabama 1986.
This Report summarises some of the results of a study of mechanised harvesting in a variety of terrain, stand and climatic conditions in Western Montana, USA. The array of machines studied included a Hahn Harvester and a Harricana delimber. Overall, the Hahn system's productivity was reasonably well matched with the Timbco's, averaging about 310 trees per 8.5 hour scheduled workday. This equates to a mean processing time per tree of 50 seconds or 36 trees per scheduled hour (range 23 - 60 trees/SMH). It was found that the Hahn Harvester was compatible only with relatively large, flat landings. Unless the steep terrain immediately adjoined relatively flat terrain, the opportunities for using the Hahn were limited. Indeed, some of the intended harvest areas were abandoned because it was deemed unfeasible to employ the Hahn system on narrow roads in steep terrain. While the brief trial with the Harricana stroke delimber indicated reasonably good prospects for mechanised delimbing and cutting to length and stacking on narrow mountain roads, a full operational trial was not conducted. The extension of mechanised, multiproduct recovery systems into relatively steep terrain can readily occur if such terrain immediately adjoins and rises above gentle terrain on which opportunities for large landings are abundant. However,

such mountainous terrain, with characteristically narrow roads incised in steep slopes, presents obstacles in mechanised timber harvesting that remain to be overcome.

Hauska, E; Bernhard, A; Lugmayr, J (1976) : "Work studies in mechanical branch trimming with the Osa 705 processor in mountain forest". Allgemeine Forstzeitung 1976, 87 (2) : 53 - 57. Language : German.
Work study of the Osa 705 processor trimming and cross-cutting on a roadside not wider than 3.5 m. Recommendations were made for increasing power in order to handle the larger dimension wood of the Austrian mountain forests.

Heidersdorf, E; Gingras, J-F; Golsse, J M (1986) : "Performance of Wheeled Roadside Delimbers". FERIC Technical Note TN-94, December 1986.
A report covering three studies of the Timberjack TJ90 wheeled delimber and one study each of the Hood HSP-42 wheeled delimber and the truck-mounted ProPac CB-138T delimber. The report covers a description of each machine and its productivity, and a discussion of machine mobility.

Heinrich, R (1985) : "Mountain Logging in Developing Countries " In, "Improving Mountain Logging Planning, Techniques and Hardware : A Joint Symposium of the IUFRO Mountain Logging Section and the Sixth Pacific Northwest Skyline Logging Symposium, May 8 - 11, 1985, Vancouver, BC.
Paper describes the opening up of mountain forest resources in developing countries and the importance of appropriate logging technology. Several extraction systems are described within the framework of labour intensive, intermediate and highly mechanised logging operations. Recommendations for enhancing the development of appropriate logging systems are made.

Hemphill, D C (1988) : "Log Processing on Steep Slopes, US Pacific Northwest Practices", LIRA Technical Release, Vol 10, No 5, 1988.
In the Pacific Northwest, tree length logging with mechanical processing at the landing has been widely accepted on skidder ground. On cable ground, however, only a few companies have been successful in mechanically processing on tower landings. These have used either a specially-designed version of the Hahn Harvester, or a boom delimber such as the Roger or Denis, or a feed-roll processor such as the Steyr. No off-landing mechanical processing has been done on cable ground in the Pacific Northwest.

Hunt, R (1983) : "Log Processor and Stacker", LIRA Technical Release Vol 5, No 5, 1983.
Report on a locally designed and built processor working in a roadside cable operation in New Zealand. The processor has a grapple shear on an excavator boom and a hydraulically operated delimber fixed to the excavator base. Working alongside the hauler delimber production was about 50 m^3/day (0.4 m^3 tree size).

Leitner, A (1979) : "Mechanised Smallwood Harvesting in the Mountain Forests of the Austrian Federal Forests", In "Proceedings of the IUFRO Symposium on Mountain Logging", College of Forest Resources, University of Washington, No 38 : 131 - 135, September 1979.
A description of a mechanised cable operation in Austria using a Koller K300 skyline hauler and a Stenab 35 miniprocessor. The system uses manual felling and full tree yarding to roadside. On slopes up to 22°, the hauled trees are piled at right angles to the road and delimbed and cut to length by the processor. Logs are stacked in two sorts on both sides of the road (at right angles). On

slopes greater than 22°, full trees have to be hauled out from the skyline corridor using a skidder and piled along the road. The trees are processed butt first and stacked parallel to the road. Multiple log types can be cut and sorting is done during loading. Processor productivity is approximately 54 - 63 m³ of smallwood timber per nine hour day. An operation using another type of processor, the Strama 45 is also described. Trees are delimbed, cut to length and sorted on roadside, into two sorts - sawlogs and industrial wood. Performance is 40 - 70 trees per hour, or 18 - 45 m³ per nine hour day (0.05 - 0.07 m³ tree size). The capacity of the Strama 45 processor however, is about 100 m³ per day, so that one processor can service three cable operations.

Leitner, A (1985) : "Harvesting Methods in Mountainous Terrains using a Device Combining Yarder and Processor", In "Improving Mountain Logging Planning, Techniques and Hardware". Proceedings, Joint Symposium of the IUFRO Mountain Logging Section and the 6th Pacific Northwest Skyline Logging Symposium; May 8 - 11, 1985, Vancouver, BC.

Further development of harvesting methods with the Koller smallwood skyline yarder and the Stenab 35 processor led to the construction of a combined yarder/processor called the Mauko. The yarder and processor crane are mounted on a truck and the processor can be replaced by a grapple loader according to the required operation. The processor has a capacity range of 5.5 - 40.0 cm, a circular crosscutting saw, and electronic length measurement. The system is a two man operation : 1 faller and 1 yarder/processor operator. The yarder operator works the processor during the felling and hooking on parts of the work cycle. The crane clears the slash from the roadside and processed logs are stacked on roadside. This system ensures a continuous work cycle for the two workers, and costs are lower than conventional manual processing.

Muhl, R G (1985) : "Contour felling for cable crane and forwarder extraction on steep slopes", In "Seminar FAO/ILO Seminar on the technology and mechanisation of logging operations in mountainous regions and related environmental problems", FAO Report (1985) No TIM/EFC/WP 1/Sem 20. Proceedings of a meeting of the FAO/ILO Joint Committee on Forest Working Techniques and Training of Forest Workers, held on 2 - 7 September 1985, in Krasnodar, USSR.

In the UK, contour felling gives safe working conditions on steep slopes combined with the ergonomic and resource concentration advantages of bench felling. The method was used in clearfell operations on slopes greater than 20°. In Sitka spruce, felling productivity increased by 30% and resulted in a considerable increase in output during extraction.

Olteanu J; Stan, J (1985) : "Technologies and machines used in logging operations in mountainous conditions in Romania", In "Seminar FAO/ILO Seminar on the technology and mechanisation of logging operations in mountainous regions and related environmental problems", FAO Report (1985) No TIM/EFC/WP 1/Sem 20. Proceedings of a meeting of the FAO/ILO Joint Committee on Forest Working Techniques and Training of Forest Workers, held on 2 - 7 September 1985, in Krasnodar, USSR.

The logging machines in mountain forest operations in Romania were reviewed. Cable systems, wheeled and crawler tractors and processing machinery are used in logging mountain forests. One thousand cable cranes accounting for 20% of the harvesting operations are in use.

Othmar, H (1982) : "Mechanisation of Delimbing and Bucking - Rationalisation Possibilities regarding Wood Harvest in the Mountains", Report of the Director-General of the Austrian State Forest Service, 28 June 1982.
Report covers the development of the Strenab 60 grapple processor in Austria. The processor is operated on roadside in steep country cable operations. The slash is deposited over the slope into the forest stand. Sorting is also possible. The length of the slope and distance from the hauler influences the performance of the processor as much as the number of different log assortments.

Pease, D A (1988) : "Delimbers join yarders in mountainous terrain", Forest Industries Vol 115(11), November 1988 : p 16 - 17.
Description of a contract cable logging operation in Oregon using Denis slide boom delimbers with Madill swing yarders. Working in 40 - 50 year old Douglas fir/Hemlock, productivity averaged 685 pieces per day, a gain of 1 - 2 loads per day over manual delimbing. Other benefits were : reduced labour requirement; reduced turnover; and increased accuracy in log manufacture. The delimbers cut logs to within 2 cm of target length over a preferred log length of 13.4 m. The delimbers had a maximum capacity of 71 cm and worked well in 66 cm diameter timber.

Peterson, J T (1986) : " Evaluation of Processing in a Central Yard", FERIC Technical Note TN-92, August 1986.
This study measured the productivity and cost of a Hahn II Harvester and Prentice 810 log loader processing and sorting full tree timber in a central yard. The Hahn II Harvester produced 104.5 m^3/PMH or 52.8 m^3/SMH in 1.0 m^3 tree size. Machine availability and utilisation averaged 88.9% and 50.5% respectively. The majority of delays were related to the start up of a new system and yard. Analysis indicated that a 70% utilisation level was achievable. This would result in a production rate of 73.1 m^3/SMH. In September 1985, the Hahn II Harvester was used in a roadside processing application. Experience showed that steep terrain hampered machine efficiency because the high banks and steep drop-offs made it difficult for the Hahn to extract windrowed trees and stack processed logs. At the productivity level measured it was estimated that the Hahn should be able to process trees from two grapple yarders, averaging 450 - 500 m^3/shift of which 200 - 400 might be full trees and the rest logs bucked in the bush. The main advantage of a yard operation compared to roadside processing is the Hahn's productive capacity when wood is placed before it. Possible advantages with this kind of system could be increases in felling productivity by leaving trees under 60 cm diameter as full trees, and also in yarding productivity.

Peterson, J T (1987a) : "Survey of Mechanised Processing Equipment : Evaluation of the Caterpillar DL221 Processor", FERIC Technical Note TN-103, July 1987.
A study to measure the cost and productivity of the Caterpillar DL221 processor working in coastal old growth Balsam fir and Hemlock (1.48 m^3 per tree). A Madill 084 grapple yarder hauled the timber to roadside windrows. The processor then extracted each stem from the windrow, processed and stacked the logs for loadout by Cat 225 log loader. Productivity averaged 26 trees per PMH (38.8 m^3/PMH). Machine availability and utilisation averaged 70.2% and 52.6% respectively. The study indicated that a 73% utilisation rate was achievable to give daily production of 226 m^3/8-hour day.

Wood presentation was critical for efficient mechanical processing. Trees must be presented butt first and piled parallel to each other. The absence of high banks caused by road construction also improves processing efficiency (+90%).

Peterson, J T (1987b) : "Survey of Mechanised Processing Equipment : Evaluation of the Lim-mit Processor", FERIC Technical Note TN-105, July 1987.
A study measuring the cost and productivity of a processor working in old growth timber (pine-spruce-fir) in the BC Interior. The processor worked both on roadside and at the landing. The machine produced 88 trees per PMH (79.7 m^3/PMH) in 0.90 m^3 tree size. Machine availability and utilisation was only 73% and 59% respectively but indications were than a 71% utilisation rate was achievable. Daily production was 373 m^3 per 8-hour shift.

Peterson, J T (1988) : "Cost and Productivity Comparison of Mechanised Tree Processors", In Proceedings of 69th Annual Meeting, CPPA Woodlands Section, 1988.
A summary of 23 studies of mechanical processors working in a range of tree size, terrain and logging systems in BC. Coastal BC operations are now following the trend of Interior BC operations into mechanised tree processing. The processing applications studied were : landing processing, a combination of landing and roadside processing, roadside processing and central yard processing. The effect of logging system on cost is examined. On a basis of productivity in trees/PMH, the Denis stroke delimber performed best in roadside or landing/roadside applications. The Hahn Harvester which normally requires auxililary equipment to be most efficient worked best in landing and sortyard applications.

Powell, L H (1981) : "Interior Limbing, Bucking and processing Study Evaluation of Hahn Tree-Length Delimber", FERIC Technical Note TN-51, December 1981.
Report describing three operations using Hahn tree-length delimbers working in Interior BC. The first operation was in a central processing yard. Full tree piles were delimbing and cut to various log lengths using the Hahn. Full trees were fed into the delimber by the knuckleboom loader and processed logs ejected onto the ground at the other end of the machine. In this operations a Cat 966 wheeled loader sorted and stacked logs and cleared slash. The Hahn produced cleanly delimbed logs and accurately measured and cut to length. Mechanical availability averaged 87% and utilisation averaged 84%. Average production was 342 m^3/day or 43.3 m^3/PMH (0.38 m^3 tree size). A second machine was studied operating on a landing with wood supplied by skidders. Tree size was 0.28 m^3 and productivity averaged 128 trees/PMH. (35.7 m^3/PMH). Machine availability and utilisation averaged 78% and 67% respectively. The third Hahn was working in small sized old growth Balsam fir and Hemlock in a central yard on Vancouver Island. In tree size of approximately 0.49 m^3 the Hahn productivity averaged 85 trees/PMH (41.4 m^3/PMH).

Raymond K (1988a) : "Mechanised Harvesting Developments in Australia", LIRA Project Report PR37, 1988.

Raymond K (1988b) : "Multiple Log Sorting with a Hydraulic Knuckleboom Loader", LIRA Report Vol 13, No 5, 1988.

Raymond O (1989) : " "
Paper presented to the IUFRO Conference on "New Approaches to Spacing and Thinning in Plantation Forestry" Rotorua, April 10 - 14, 1989.

Selby, J S; Horsfield, B C (1986) : "Weyerhaeuser Limber-Processor", LIRA Technical Release Vol 8 No 12, 1986.
Report on the development of the Weyerhaeuser S60 processor from the Stenab S60, originally designed by the Austrian Bundesforste. Maximum delimbing diameter is 60 cm and grappling capacity was increased to 76 cm. The processor was mounted on a Linkbelt 5400 loader. Trials were undertaken in a variety of applications, including processing roadside stockpiles from both grapple skidder and grapple yarder operations, processing under highlead towers and processing in log yards. This unit is currently manufactured by Steyr-Daimler-Puch in Austria and marketed as the Steyr KP60.

Schuh, D D; Kellogg L D (1988a) : "Timber-Harvesting Mechanisation in the Western United States : An Industry Survey", Western Journal of Applied Forestry, Vol 3, No 2, April 1988.
A survey of logging operations in the Western US located over 140 contractors using mechanised equipment. Fifty percent of the operations using feller bunchers also used a delimbing machine. Stationary deck (bed) delimbers outnumbered stroke-boom delimbers by 4 to 1. Modern grapple processor technology has also been introduced into the western region, and flail delimbing/ debarking is also generating much interest.

Schuh, D; Kellogg, L (1988b) : "Mechanized Delimbing at a Cable Landing", In "Proceedings of the International Mountain Logging and Pacific Northwest Skyline Symposium", Oregon State University/ IUFRO Portland, Oregon, December 12 - 16, 1988.
A stroke boom delimber achieved a production rate of 82 logs per PMH (77.6 m³/PMH) delimbing and processing second growth Douglas fir and cedar in an Oregon Coast Range operation. The block was manually felled with trees larger than 76 cm LED manually bucked. Hauler productivity averaged 50.9 m³/PMH in 1.28 m³ tree size. Each tree was delimbed and cut into 1.35 logs (0.95 m³/log). Delimber utilisation was relatively low at 42.6 percent. Factors contributing to low utilisation were low stand volume being logged, a production quota limit, insufficient yarding production to balance delimber capability, and interferences on the small landing due to the hot logging operation. Opportunities to enhance logging system efficiency are discussed.

Stirling, J (1986) : "Field Trial Report : Tilting Cat 227 Logger Levels Steep Slopes", British Columbia Lumberman 1986, 70(6) : B11 - B12.
Report on the Caterpillar 227 Logger feller buncher working on steep slopes in British Columbia.

Schechtner, K (1986) : "Using processors in Austrian mountain forests". Internationaler Holzmarkt, 1986 vol 77 (20), p 1 - 5. Language : German

Stockel, J (1984) : "Technological studies on a cable crane/processor combination", Architecture, Hydrology and Forestry Reprint Series 5, No 14. University of Dresden, Tharandt, German Democratic Republic. Language : German
A report on the use of a mobile cable crane and trimmer/cross cutter (mounted on a 138 kW lorry), designed by the Austrian Federal Forest Service, in thinning operations in a 65 year old stand on steep slopes in East Germany. Performance using the system averaged 4 m³/hour with work time savings of 40 - 60% compared with the logging system conventionally used.

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forests", Seminar on Mechanisation and Techniques of Thinning Operations, Report No UN--TIM/EFC/WP.1/SEM.7/R.5. Joint ECE/FAO Agriculture and Timber Div; International Labour Organisation, Geneva (Switzerland).

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Vyplel, K (1979) : "Mechanised Harvesting in Steep Terrain", In "Proceedings of the IUFRO Symposium on Mountain Logging", College of Forest Resources', University of Washington. September 1979.
Paper reviewing the development of mechanisation in the Mayr-Melnhof Forest Enterprise in Austria. In 1974, studies began into full tree yarding in order to investigate the possibilities of mechanical delimbing using a Kockums 278 processor. From this experience the company developed their own processing unit, the MM-800. The processor is basically a two-grip processor mounted on a four wheeled carrier (320 HP). The delimber consists of four spiked feedrollers driving the trees through two sets of three delimbing knives. Processed logs are stacked on roadside and later sorted and loaded by self loading truck. Productivity was dependent on tree size and the number and size of branches. Output varied between 130 and 250 m^3/day with average performance of 180 m^3/day. Results indicate that in 1978 mechanised logging was 35% cheaper than motor-manual harvesting. Developments are continuing in improving both machines and work methods in order to minimise cost.

Vyplel, K J (1980) : "Development of logging methods in steep terrain", In "Forest-to-mill : Challenges of the Future". Proceedings of Weyerhaeuser Science Symposium held at Tacoma, Washington, September 15 - 17 1980.
The development of logging methods in Austria is marked by a 100% increase in cable yarding from 1975 to 1979 while other extraction methods fell by 8%. The cable crane proved to be very efficient not only in tree-length yarding but also when fully mechanised operations developed using processors for mechanical delimbing and cutting to length. In downhill yarding, studies showed full tree extraction was more productive than tree length. This was because the weight of trees was of no great influence and full trees were easier to control. In uphill yarding, however, performance dropped considerably for full tree extraction. In company operations, 40% of the annual cut is produced using fully mechanised cable crane systems.

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A description was given of an operation using a cable crane, grapple skidder and a simple delimbing machine. A 3 - 5 man crew produced 40 m^3 of logs per day. The cable crane had a 1 - 5

tonne capacity, producing 8000 m^3/year in a full-tree system with cable corridors of 250 - 350 m^3 length. The main advantages of the system were increased work productivity (+60%) and reduction in cost (-20%) and the removal of slash from afforestation sites.