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Machine design and working methods in thinnings

Proceedings of IUFRO P4.02.01 Conference
September 17–22 1989 Hyytiälä, Finland

Edited by Matti Sirén

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PREFACE

The need for mechanization of thinnings increases rapidly all over the world. Although the level and methods of mechanization vary greatly, the questions for research to solve are basicly the same everywhere; how to combine productivity and good economic result with the silvicultural and ecological needs of the forest. Simultaneously, it is becoming more and more important to study the relation of man and machine. Particularly in mechanized thinning, physical and mental demands on machine operators are high. This is a great challenge for machine manufacturers and also for machine operator schools.

The IUFRO Working Party P 4.02.01, Thinning and Mechanization, is aimed to collect together people involved with the development of mechanized thinnings. Since the recent development in thinning mechanization has been fast and successful in the Nordic countries especially, the Working Party, in cooperation with the Finnish Forest Research Institute, organized in Central Finland in September 1989 a seminar and a study tour dealing with the problem area mentioned above. In addition to scientists, many of the participants were practical foresters. This enriched the meeting and gave new ideas for researchers. Only by active co-operation between research, machine development, training and practical forestry, can the many problems in mechanized thinnings be solved.

I wish to express especial appreciation for the personnel of Jämsänkoski Forestry Training Institute and Hyytiälä Forestry Field Station of the University of Helsinki. Also, I want to thank the machine manufacturers, who made the excursion possible. To Professor Pentti Hakkila, Deputy Coordinator of IUFRO Division 3, and Hans Knutell, P 4.02 Chairman, who guided me in arranging the meeting, I want to express my gratitude. Last, but not least, I want to thank the personnel of the Department of Forest Technology, who helped with organizing the meeting and editing these proceedings.

Matti Sirén
P 4.02.01 Chairman

CONFERENCE "MACHINE DESIGN AND WORKING METHODS IN THINNINGS"

SUMMARY

The IUFRO Working Party P 4.02.01 meeting "Machine design and working methods in thinnings" was held in Hyytiälä, Finland on 17 to 22 September 1989. Twenty-nine participants from 16 countries attended the meeting and discussed several problems including:

- The state of stands after mechanized thinning
- Machine design for reduced damage
- Planning of mechanized thinning
- Training of labour for mechanized thinning

The programme included:

- 17 papers
- Visit to the Jämsänkoski Forestry Training Institute
- Demonstrations of mechanized thinning methods and machines
- Presentation of The National Board of Forestry and different forest industries

Aspects of mechanized thinning were discussed in a friendly atmosphere. Several participants were practical foresters from different parts of the world. This enriched the discussions and gave new ideas for research.

In the conclusions the following topics were discussed:

1. When developing mechanized thinning machines and methods, the silvicultural aspects must be evaluated to get knowledge of the total economy of thinnings.

2. The development of machines has been active. Specific areas for further research are machine design and methods to minimize soil and tree damage.

3. Mechanized thinnings set great demands on machines and machine operators. The ergonomics of machine work must be studied. One possibility for reducing stress is to change operators during the day between multi-function machines and forwarders.

4. Schooling of machine operators is most important, but also expensive, and therefore the drivers should be carefully chosen for aptitude before schooling. Also the status of logging work should be raised to interest young people.

5. The mechanization level in Scandinavia is high. Problems are different in less developed countries. It would be most interesting to approach these problems in an European country, where the degree of mechanization is lower. The possibility of having the next meeting in Hungary in 1992 was discussed.

6. The proceedings of the meeting will be published in the series of the Finnish Forest Research Institute.

IUFRO WORKING PARTY P 4.02.01
THINNING AND MECHANIZATION

CONFERENCE "MACHINE DESIGN AND WORKING METHODS IN THINNINGS"

September 18-22.1989
Hyytiälä, Finland

PROGRAMME

17.9.	5.00	Meeting at Helsinki airport
	15.30	Travel by bus from Helsinki to Hyytiälä
	18.45	Registration at Hyytiälä
	20.00	Welcome party, Ministry of Agriculture and Forestry
18.9.	7.00	Breakfast
	8.45	INTRODUCTION Hans Knutell, Swedish University of Agricultural Sciences THE STATE OF STANDS AFTER MECHANIZED THINNING Moderator: Hans Knutell, Swedish University of Agricultural Sciences
	9.00	The impact of machinized thinnings on the remaining stand - Aivars Epalts, NPO, Silava
	9.45	Coffee break
	10.00	Cost of mechanized thinning to the stand - how to evaluate - Matti Sirén, The Finnish Forest Research Institute
	10.45	Effects of damage on the newly thinned stand due to mechanized forest operations - Iwan Wästerlund, Swedish University of Agricultural Sciences
	11.30	Lunch

		MACHINE DESIGN FOR REDUCED DAMAGE Moderator: Stanislav Sever, The University of Zagreb
	13.00	Tractive forces and torque distribution on a forwarder equipped with an all hydrostatic transmission - Ulf Eriksson, Swedish University of Agricultural Sciences
	13.45	The effect of mechanized harvesting on timber quality - Tommy Helgesson, TRÄTEK
	14.30	Coffee break
	14.45	Yugoslav experience in designing thinning machines - Stanislav Sever, University of Zagreb
	15.30	The technical and technological requirements on forest tractors for thinning in young stands as well experience of their use in the German Democratic Republic - Wolfram Schulz, Forest Research Institute Eberswalde
	17.00	Dinner
19.9.	7.00	Breakfast
		PLANNING OF MECHANIZED THINNING Moderator: Glen Murphy, Forest Research Institute, New Zealand
	8.30	The state of mechanized precommercial thinning in Central and Eastern Canada - Michael Folkema, FERIC
	9.15	Manipulators with telescopic boom for thinning and their influence on formable stand - Romualdas Ramanauskas, The Lithuanian Forest Research Institute
	10.00	Coffee break
	10.15	The modification of planting layout to improve production thinnings - Glen Murphy, Forest Research Institute, New Zealand
	11.00	Die technologischen Verfahren der Jungbestandspflege und Dünnholzgewinnung unter den forstlichen Bedingungen der DDR - Peter Haschke, Forest Research Institut Eberswalde

	11.45	Lunch
	13.15	Working methods in thinnings. Logging systems and working techniques - Gilber Hoellinger, ARMEF
	14.00	Coffee break
	14.30	Possibilities of multi-tree processing in thinnings - Risto Lilleberg, Metsäteho
	15.00	Logging technologies and utilization of biomass from thinnings - Jan Ilavsky, Forest Research Institute, Czechoslovakia
	15.30	Time for voluntary papers
	17.00	Dinner
20.9.	7.00	Breakfast
		CONFERENCE ON TERRAIN
	8.00	Different working methods with small multipurpose machines - Matti Sirén, The Finnish Forest Research Institute
	8.15	Presentation of The National Board of Forestry - Timo Hiltunen, District forester
	9.00	Travel by bus to Mänttä
	9.45	Mechanized thinning on soft soils. Presentation by Nokka Forest - Director Martti Issakainen and Metsäliitto
	11.15	Travel by bus to Hyytiälä
	12.00	Lunch
	13.00	Travel by bus to Västilä
	14.00	Presentation of FMG Forest machine programme - Pertti Rauva, Lokomo Forest.
	15.30	Travel by bus to Tampere. Accommodation at Hotel Tampere
	16.30	Free time
	20.15	Dinner at Hotel Tampere

21.9.	7.00	Breakfast
		CONFERENCE ON TERRAIN
	8.30	Travel by bus to Jämsänkoski
	10.00	Coffee break
	10.15	Visit to Jämsänkoski Forestry Training Institute. Presentation of training programme.
		The development of forest machine training in Finland - Armas Hakanpää, Director of Jämsänkoski Forestry Training Institute
	13.00	Lunch
	14.00	Demonstration of different mechanized thinning methods in forest - Armas Hakanpää, Eino Ikkala ja Reino Seppänen, Jämsänkoski Forestry Training Institute, Pekka Sarkola and Jukka Viskari, Norcar
		Coffee at Palvia
	17.30	Travel by bus to Hyytiälä
	19.00	Dinner Finnish folk music by Hyytiälän pelimannit
22.9.	7.00	Breakfast
	8.30	SUMMING UP AND CONCLUSIONS CLOSING THE MEETING
	12.00	Lunch
	13.00	Travel by bus to Helsinki

THE IMPACT OF MECHANIZED THINNINGS ON THE REMAINING STAND

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SUMMARY

The conventional motor-manual methods used in thinnings appear to have exhausted their possibilities for increasing efficiency and elimination of manual labour. A substantial efficiency increase and optimum work environment can be achieved only by introducing basically novel systems of machinized logging. A 6 to 8-fold efficiency increase is achieved by using feller-buncher or grapple harvester. The adverse impact of these machines on the remaining stand is insignificant since most of the damage occurs during hauling. Presented here are experimental data concerning tree stem, root system and ground cover damages on the striproads with different thinning systems used. Assessement and comparison of the results is given.

INTRODUCTION

The total forested land area of Latvia amounts to 3235 thousand ha, which accounts for 41% of the total territory. The annual cut adds up to 3.5 million m^3. In logging operations, two principal systems have up to now been used: tree-length and shortwood. The tree-length system accounts for 58% of the total amount of clear cuttings and 10% of thinnings.

Such factors as small and often scattered logging sites requiring small-scale operations, the bulk of the total cut coming from thinnings, lack of transport facilities especially by rail, primitive and deteriorated lower landings, low labour productivity in logging (resulting in manpower shortage, accordingly), etc. have forced the Latvian Forestry Association "Latvijas Mezs", which is responsible for this sector of economy in Latvia, to seek out ways to restructure logging operations and timber transportation. A change-over to the shortwood system based on forwarder type machines has been one of the ways to tackle the task. Motor-manual felling has until recently predominated in logging operations including also delimbing and bucking.

The systems used appear to have exhausted their possibilities for increasing efficiency and elimination of manual labour. Research has proved these systems to be objectionable from the point of view of ergonomics.

A substantial efficiency increase and optimum work environment can be achieved only by introducing basically novel systems of machinized logging. With this end in view, especially in thinnings, we have started to field test a number of feller-bunchers, processors and grapple harvesters, as well as delimbers and forwarders.

However, when changing over to machinized systems in thinnings, the final aim has been an increase in overall stand productivity, while retaining top quality of the remaining stand. A follow-up of a number of stands treated by using heavy, self-propelled vehicles has revealed a prohibitively high percentage, up to 25%, of damaged stems in the remaining stand.

STUDY OF THINNING SYSTEMS

Research on the impact of mechanized thinnings on the state and productivity of the remaining stand is a highly involved task, especially considering the ever continuous introduction of new machinery for thinnings. Its solution must be extended over a prolonged period of time, requirs concerted efforts of specialists in diverse fields, and, in consequence, is still under way with no final and concrete conclusions inferred.

Considered here are preliminary data for a study under typical operating conditions on mechanized thinnings using following tree-length, full tree and shortwood methods (Figs. 1 and 2).

1. Motor-manual felling and delimbing; hauling the tree length stems to the upper landing

   - by wheeled tractor (weight 4.5 t);
   - by crawler tractor (weight 9 t)

2. Motor-manual felling; hauling full trees to the upper landing by wheeled tractor (weight 4.5 t). In both cases the distance (axial) between the striproads was 40 m, striproad width - 3 m. Directional felling was at an angle of 30^o to 40^o with the road.

3. Felling, extraction and bunching on the striproad by feller-buncher (boom reach 10.5 m); bunch skidding of full trees

   - by wheeled tractor, weight 4.5 t (average bunch volume 1.0 m^3);

   - by crawler tractor, weight 9 t (average bunch volume 3.1 m^3; distance (axial between the striproads 20 m, striproad - 4 m.

4. Motor-manual felling; delimbing, bucking, piling along the striproad edge and preliminary sorting of the material with logging slash accumulated on the striproad by means of two-grip (conventional) processor Pika-36 based on wheeled tractor LKT-81; forwarding the shortwood assortment to the upper landing by a forwarder based on wheeled tractor LKT-81; distance (axial) between the striproads 30 m.

5. Motor-manual felling; delimbing, bucking, piling along the striproad edge and sorting the material with slash accumulated on the striproad by means of one-grip (grapple) processor Valmet 940 with Valmet 882 K as base vehicle; forwarding the short wood assortment to the upper landing by a forwarder based on wheeled tractor LKT-81; distance (axial) between the striproads 30 m.

6. Felling, delimbing, bucking, piling along the striproad edge and sorting with slash accumulated on the striproad by means of a one-grip (grapple) harvester Keto-51 based on LKT-81 tractor; forwarding the shortwood to the upper landing by a forwarder based on LKT-81 tractor; distance (axial) between the striproads 20 m.

For case 6 an alternative with 30 m distance between the striproads and motor-manual felling in the zone outside harvester's reach was also considered. Here harvester operated as processor for about 30% of the total amount of work.

For the shortwood method, with distance between the striproads 30 m, both motor-manual and mechanical felling was performed in a two-step mode. At first, the stems on the striproad and both sides within the machine's boom zone were cut and processed. The second step involved

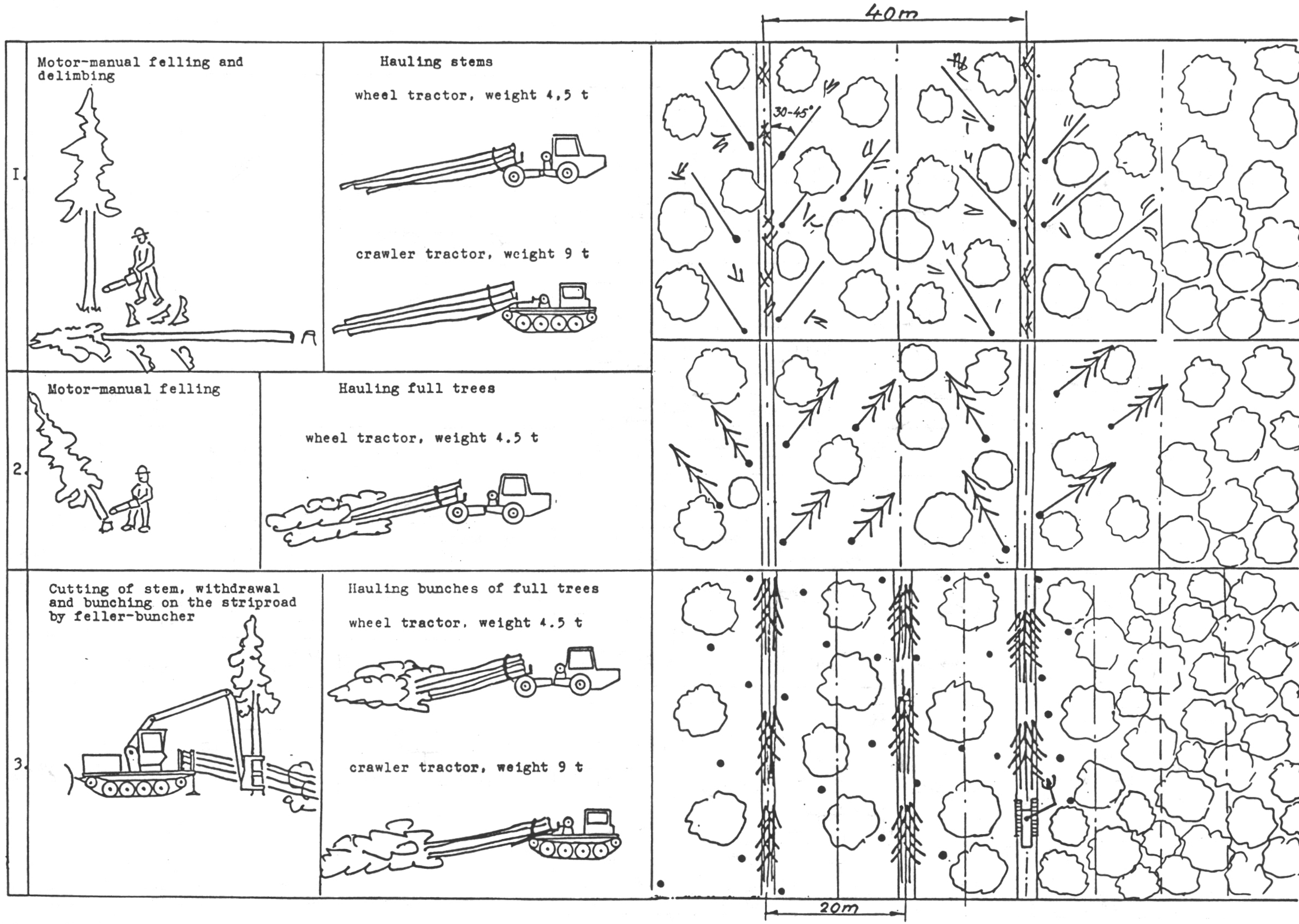

Figure 1. Thinning systems studied, tree-length method.

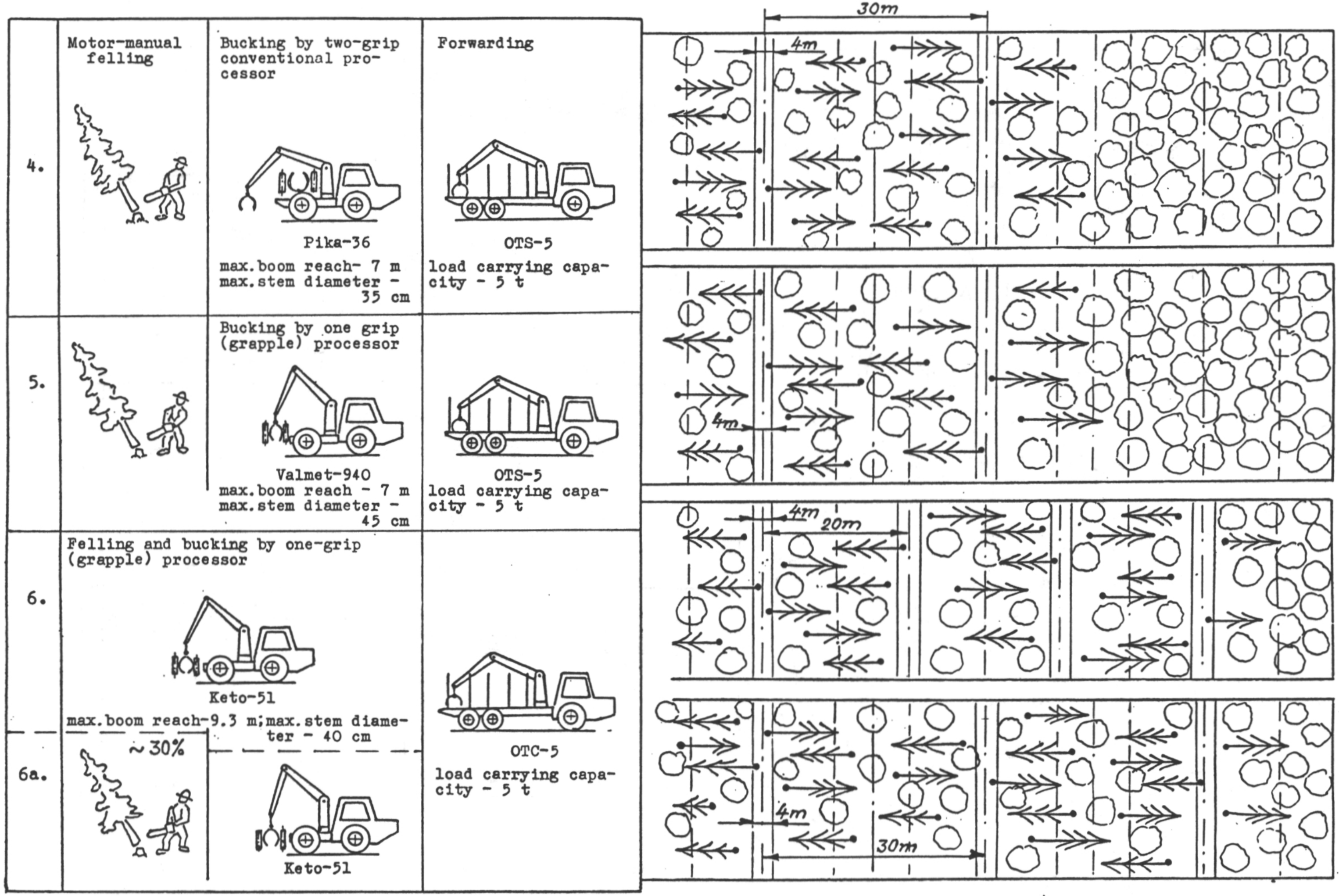

Figure 2. Thinning systems studied, shortwood method.

directional, preferably at right angles to the striproad, motor-manual felling of stems outside boom zone with the tops falling to within boom reach.

Processing was done by machines in two stages, the machine was operated as processor. Conventional processor is used only to displace the stem to subsequently reverse it grappled by butt end. Grapple head performed only bucking and piling (sorting) the material along the striproad. Bucking along with delimbing is done by conventional processor.

Field testing, covering a period between 1981 and 1989 was done on pine and mixed stands having an average volume of stem 0.08-0.13 m^3.

Efficiency estimates were recorded as were exponents immediately responsible for quality of thinnings, i.e., the state of the remaining stand: volume of timber to be hauled, number of machine passes, number of visible signs of stem, crown, root, ground cover (depth of rutting created by vehicles), damages, soil compaction.

Subsequent to the thinnings, a silvicultural assessement was done, generally in terms of basal area, number of stems, their quality, etc. A follow-up of stand performance over a prolonged period of time is also envisaged.

RESULTS

Since the research project is still under way, the given results should be treated as tentative (Table 1).

Since hauling accounts for a large number of stand damages in thinnings, especially those of roots and soil, research was purposefully focused on hauling. Diverse means for hauling were studied, and the results

Table 1. Stand damage at different thinning methods (average number of damaged trees in each operation, %).

Basic operations	Number of damages per 1 ha of treated stand for each thinning method		
	Full-tree and tree-length method no.		
	1	2	3
Felling:			
- motor-manual	3-4 (0.4%)	3-4 (0.4%)	-
- mechanized	-	-	44 (2.6%)
Hauling of stems:			
- by wheeled tractor	58 (5.5%)	-	-
- by crawler tractor	181 (11.5%)	-	-
Hauling of full trees:			
- by wheeled tractor	-	161 (14.3%)	-
Hauling of bunches made by feller-buncher:			
- by wheeled tractor	-	-	18 (0.9%)
- by crawler tractor	-	-	34 (2.5%)
Total (avg.) number of damaged trees (%)			
- tractor	62 (5.9%)	165 (14.7%)	62 (3.5%)
- crawler	185 (11.9%)	-	81 (5.1%)
	Shortwood method no.		
	1	2	3
Felling:			
- motor-manual	15 (0.9%)	15 (0.9%)	6 (0.7%)
- mechanized	-	-	2 (0.2%)
Pre-skidding to start treatment, bucking, sorting	92 (5.4%)	52 (3.0%)	44 (2.5%)
Forwarding to the upper landing by forwarder	60 (3.5%)	60 (3.5%)	60 (3.5%)
Total (avg.) number of damaged trees (%) *)	167 (9.8%)	127 (7.5%)	108 (6.5%)

*) Total amount of damages on a stem is 1.7-2.5 times higher since quite a lot of stems are damaged repeatedly.

juxtaposed. Along with stem damages, ground cover (rutting, soil compaction, soil displacement) was also examined. Although this problem has been amply researched in many countries with the results published, we would present some generalizations concerning the conditions in Latvia. Their authenticity, unfortunately, is diminished by a limited variation of conditions.

The number of machine passes, weight of the load and climatic conditions are found, apart from chassis design, to be the principal factors determining the amount of stand damages in hauling. Although, it may appear tempting to increase bunch volume hauled per machine pass, to increase machine productivity, research has proved bunch hauling to be responsible for almost 90% of stand damages in thinnings. An increase in bunch volume from 2 to 3 m^3 will sharply raise the liability for stand damage.

Damage to the main roots growing in the strip road zone belonging to the trees on its edge accounted for 97.6% out of the total uncovered for inspection. Half of them were broken, in both the wheeled and crawler tractor areas. Up to 45% of the total area in horizontal projection taken up by roots was found to show signs of damage. The average depth at which damages to the root system occurred, was 67% deeper when hauling with a crawler tractor compared to a wheeled tractor for an equal volume of timber hauled. The average area of damages found on a single stem was also 46.9% higher when crawler tractors were used.

The upper root layer, a horizon from 15 to 30 cm deep (depending upon the forest site type and soil conditions) was experimentally established to possess the least initial density of soil.

The compaction of the upper soil layer within the rut created on the stripboad was found to be doubled after two, three machine passes (dead walking included). The character of further compaction depends upon soil conditions. In podzolic sand loam soils, compaction increases progressively with the machine passes. In sandy soils, for which higher initial density and resistance to compaction is typical, it is little more than doubled. The two above types of soil are known to be highly resistant to loads.

Ground cover damage, apart from soil compaction, was also observed on the striproads. Initial ground cover was found to account for 6.9 to 15.8% of the surface area in the striproad zone. Biologists have studied the impact of machine passes on the forest ground cover.

CONCLUSIONS

1. A change-over to machinized systems in thinnings, providing a significant increase in efficiency, reducing manual labour and improving work environment, has been proved by research, experimentation and practical experience to be expedient.

2. Thinning systems based on the use of feller-bunchers or grapple harvesters appear to be most effective for the operating conditions currently existing. Each of the alternatives has its advantages and drawbacks and is to be applied depending upon the actual conditions. The concept of conventional processors may be said to be out-of-date to a certain extent, mainly due to a narrow spectrum of application.

3. Machinized felling in thinning systems, result in virtually no increase in stand damage. Root system and soil damages caused by feller-buncher or harvester passes (usually one or two) along the striproad are very small. However in all the systems considered, hauling (pre-hauling) with shortwood method is done

by tractors and is responsible for an increase in residual stem damage, and in root and ground cover damage. This can have very adverse results, the damage is often concealed, and its impact is hard to predict.

4. A system based on feller-bunchers has a number of advantages. Compared to harvesters, they are more efficient in treating difficult mixed stands. Stems are with-drawn from the stand in a vertical position and bunched on the striproad, resulting in higher efficiency and less damage during hauling.

5. Although the root and ground cover damages done by self-propelled vehicles have been fairly well researched, no novel machine design feature completely excluding soil compaction, rutting, root damage has as yet been incorporated in a single machine. This task, highly involved as it is, nevertheless, calls for solution. Some researchers are of the opinion that a fundamentally novel concept of transporting machine is needed.

6. In view of the above-mentioned (point 5) an interest in small-scale mechanization has grown of late, i.e., in light-weight machinery in which combined systems or small-scale logging may prove highly efficient.

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COST OF MECHANIZED THINNING TO THE STAND - HOW TO EVALUATE

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SUMMARY

Logging costs of different thinning methods are well known. However, thinning also causes indirect costs. Increment losses are caused by stem, root and soil damage, strip roads, nonoptimal tree selection and nutrient losses. Stem and root damage cause quality losses. Sometimes secondary losses caused by wind, snow and insect damage may be significant.

Harvesting trace with different methods has been inventoried in many countries. Influence of stem and root damage, losses caused by strip roads and other factors have been studied. In designing thinning machines, good harvesting trace has an important role. However, not much study work has been done on calculating the amount of all possible indirect costs with different methods. Only by knowing both direct and indirect logging costs, can we find the optimal solution for different circumstances.

In this paper, some information about the possibilities of calculating these costs is given. The level of costs is different for forest owner, wood processing industry and national economy. When the costs are realized after 20-30 years, methods for discounting the losses over time effect on the level of costs. This paper does not present the costs in concrete terms but rather discusses the theoretical possibilities for calculating losses and the influence of different factors upon those losses.

Key words: Thinning damage, indirect logging costs

INTRODUCTION

Damage to the stand during harvesting and its consequences have been a focus of attention since the beginning of mechanization. In the Nordic countries harvesting trace has been researched by Fröding (1982), Kärkkäinen (1970), Eriksson (1981), Hannelius and Lillandt (1970), Lilleberg (1984 and 1986), and Sirén (1981, 1982 and 1986). The differences in inventory methods slightly lessens the comparability of the studies. The comparability of inventory methods and possibilities to unify research methods have been recently studied under the auspices of the Nordic branch of forest technology research cooperation (NSR-cooperation).

The consequential effects of damage, increment loss and decay inflicted on the stand have been analyzed in various quarters. The effect of strip roads on growth has also been a focus of analysis. The generalization of various whole-tree and tree-section methods especially in Sweden has centered attention on the effect of harvesting on the forest stand's nutrient balance. The secondary effects of harvesting, such as wind and insect damage, have been studied in various parts of the globe. Wind damage has little effect in thinnings in Finland, but in Ireland, for example, thinning cannot be done at all in some places because of the high risk of wind damage.

Much research which fits into this topic has been done, but an overall picture of the costs inflicted on the forest by thinning harvesting is quite inadequate. Studies have clarified partial areas, which have not, however, been combined in order to analyze economic significance. The amount of damage and distance between strip roads have a definite effect on the choice of machine and method of harvesting. Forwarders, for example, have undergone drastic development in making them more environmentally sound. The net weight of machinery has been decreased without jeopardizing load capacity and efficiency, and machinery has become more environmentally sound with the introduction of wide balloon tires. A good harvesting trace has become a marketing trump card for various light harvesting machines, such as light rubber-tracked crawlers. Although harvesting costs are generally high with small machines, they are marketed as machines with a good harvesting trace and low costs inflicted on the forest stand. Nevertheless, clear calculations for the volume of costs these machines inflict on the forest have not existed.

This presentation will concentrate on determining the costs inflicted on the forest stand by harvesting and the calculation of their amount. Expenses will not be calculated in marks, rather an attempt will be made to give an idea of the bases for cost calculation.

FACTORS CAUSING INCREMENT LOSS AND THEIR DETERMINATION

Increment loss is caused by the harvesting machines' damage to the stand and soil, strip roads, as well as in some methods the removal of nutrients.

Increment loss caused by damage to the tree stand

Andersson (1983) has researched the increment loss caused by stand damage for Scots pine and Isomäki and Kallio (1974) correspondingly for Norway spruce. Damage causes slightly greater increment losses for spruce than pine. The volume of increment loss depends primarily on the size and depth of injury. Because the effect of damage causing increment loss is mostly based on the disturbance of nutrient and water flow, how much of the tree's mantle is covered by the injury is of great significance also. Figure 1 presents the effect of damage to the tree stand on the tree's diameter growth for both pine and spruce (Andersson 1983, Isomäki and Kallio 1974).

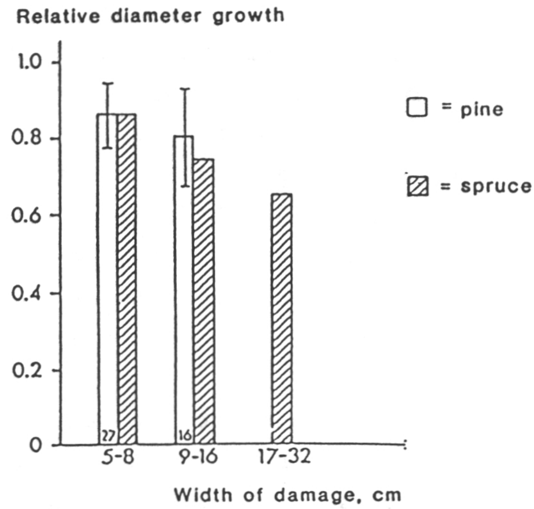

Figure 1. Influence of stem damage on diameter growth (Andersson 1983, Isomäki & Kallio 1974).

Increment loss caused by damage to the soil and root system

Quite often, especially in summertime harvesting, rutting, occurs, which affects the soil and root system. The calculation of the effect of ruts on tree stand growth is based on Froelich's (1976) idea, which states that the consequences of damage depend on how much of the root system of bordering trees is exposed to rutting.

In order to estimate how many trees are exposed to rutting, information is needed on the volume of remaining standing crop, its distribution on the stand marked for cutting and the number of strip roads. On the basis of inventory we know the number and width of strip roads as well as the volume of the remaining standing crop on the stand marked for thinning. On the basis of inventory (Lilleberg 1984) the remaining standing trees are not, however, evenly distributed throughout the stand, instead more trees than usual are left along the strip road to take advantage of the open space. On the other hand more information is needed on the structure of the root system.

Wästerlund (1986) has presented a formula for the calculation of the extense of a tree's root system. When a tree's age is known, the extense of its root system is found in the following formula:

$$R = 0.21\ A^{0.73}$$

when R = root system's average radius

A = tree's age

When the volume and distribution of the tree stand in the strip road zone, the root system's average radius, the width of the strip road and the width of the rut left by the harvesting machine are known, it is possible to calculate to what extent and how many trees' root systems are exposed to possible rutting damage. Wästerlund (1983) has presented a way (Figure 2) of calculating increment loss when it is known how much of a tree's root system has been exposed to rutting. The increment loss presented in the figure occurs when ruts are deep, over 10 cm in depth. Nevertheless, the average rut depth even in summertime harvesting is substantially smaller and the increment loss is presumed to be correspondingly smaller. The total increment loss caused by rutting is achieved by adding the increment losses of all trees exposed to rutting.

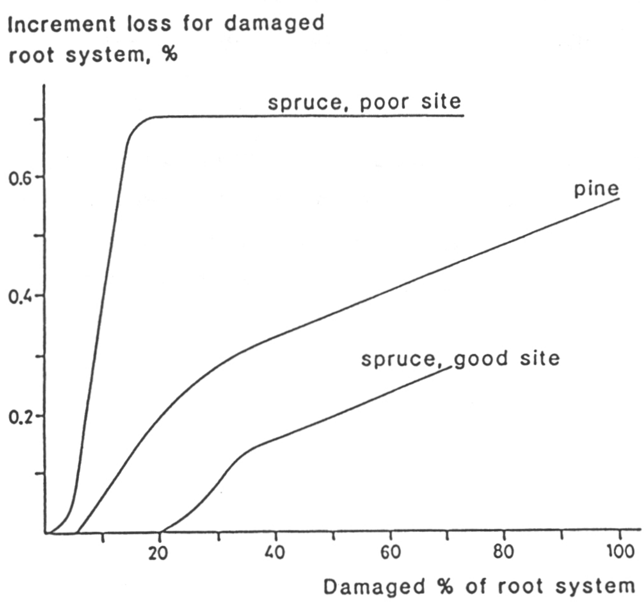

Figure 2. Increment loss caused by rutting (Wästerlund 1983).

Increment loss caused by strip roads

In mechanized harvesting strip roads are opened to facilitate harvesting machines. In Finland the standard strip road is 4 m wide and placed at 30 m intervals, in which case the strip roads and their connecting roads take up about 16% of the area of the stand. Strip roads cause loss in two ways. Strip roads cause deviation from optimum tree selection. Strip road area is partly out of wood production, although the bordering trees, assuming they are not too badly damaged, can take partial advantage of the growing space created by the strip road. The strong growth reaction of bordering trees, so-called border effect, is stronger in spruce stands than in pine stands (Isomäki 1986). Border effect cannot, however, in any conditions completely replace the yield losses caused by the strip road.

Niemistö (1987) has studied increment loss caused by strip roads in practical experiments and by simulation. The study results are for spruce stands, but are also applicable to pine on an average growing site. According to Niemistö (1987) the layout of strip roads is presently quite well planned, taking into consideration the growing tree stand. According to research studies 4.4% of trees to be raised are forfeited. This is the result of inadequate tree species selection due to strip roads.

Although the trees bordering the strip road take advantage of the freed growing space, they cannot completely replace the loss caused by the strip. According to Niemistö the increment loss caused by the strip roads can be calculated with the following formula:

$$VL = 100*(OW - \sqrt{10\ 000/N}\ /SI)$$

when VL = Volume loss
OW = outer width of the strip road
N = number of stems
SI = strip interval

The outer width of the strip road is calculated by the area defined by the trees bordering the strip road divided by the length of the strip road. Increment loss is suited to the formula only when the thinning intensity corresponds to standards. It is also presumed that border trees are not injured.

Increment loss caused by the removal of nutrients

The effect of the removal of nutrients became an item for discussion in the 1970's when in Sweden especially whole-tree and tree-section methods were used in thinning harvesting. In these whole-tree and tree-section methods all or at least a substantial part of the crown, branch and needle biomass which usually remains in the woods in the shortwood assortment method is removed from the forest. The question of nutrients is also relevant in multi-purpose machine harvesting, when logging residue is often concentrated in piles.

The nutrient question is emphasized in thinnings, since in Finnish conditions the nutrient requirement of a tree stand is at its highest around age 30-50 years. At this point even a small nutrient deficiency has an effect on growth. The significance of logging residue as a nutrient source is emphasized by the fact that logging waste contains all nutrients necessary to trees at a nearly optimal ration (Kukkola and Mälkönen 1987).

In Norway, in as early as 1928, a research experiment was begun to study the effects the removal of nutrients had on increment (Brantseg 1962). In a pine stand in the thinning stage part of the logging residue was taken from the cutting area to another experimental site, where twice the amount of logging waste built up. The difference in increment showed even 32 years after thinning, and the increment of the area which received an abundance of logging residue was an average 20% higher than that on the area which had had its slash removed.

In Sweden Andersson (1983) has studied the effect of nutrient removal on increment especially in pine stands. According to study results the removal of logging residue has caused an approximate 10% increment loss.

In Norway Tveite (1983) has studied the effect of nutrient removal on increment in both pine and spruce. The increment loss over a 6 year period after thinning was 7% for pine and 11% for spruce. The large increment loss for spruce is partly because the thinning intensity and correspondingly the nutrient quantity thus forfeited in the spruce stand was large.

Olsson (1984) has used figures from Table 1 in his calculations on increment loss caused by thinning. Olsson's figures are based on Andersson's (1983) and Lundmark's (1983) research studies.

Table 1. Increment loss caused by the complete removal of logging residue (Olsson 1984).

	Increment loss % growth				
Time from thinning	0-10	10-20	20-30	30-40	years
Pine, poor site	-10	-8	-5	-2	
Pine, average site	-10	-5	-2	0	
Spruce, poor site	-10	-5	-2	0	
Spruce, good site	-10	-2	0	0	

In the study results by Olsson and those stated previously, the assumption is that all the biomass of thinned trees is removed from the stand during thinning operations. This is, however, not done in any method used in Finland, rather some of the tops and branches remain in the forest. When using study results in calculations, it is necessary to know how much of the logging residue is removed in each method and the volume of increment loss should be calculated for this amount.

The determination of the effective time of increment losses

The duration of increment loss caused by strip roads can be approached by researching the growth change of the border tree stand and, for example, the restoration of the root system can be used as a basis for the estimation of the duration of tree stand and soil damage. Nevertheless, information on the duration of disturbances is insufficient, and most research data is so young that a picture of long-term development is not available.

Niemistö (1987) verifies that the formula for the calculation of increment losses by strip roads gives losses for a 10-year period, after which increment losses would no longer occur. It seems strange, however, that an abnormality in growth should remain at a certain level for a specific length of time, after which it would suddenly have no effect. More probably, the effect of the disturbance culminates after a certain time, and as time passes its effect lessens until it is no longer of any consequence.

Olsson (1984) has based his calculations on the premiss that the development of increment losses conform to the development of a forest stand's response to thinning. In this case the disturbance would culminate sooner on good sites than on poor sites. Olsson (1984) bases his estimation of the development of increment losses on thinning response models, on the basis of which he presents the development of increment losses as a function of time in accordance with Figure 3.

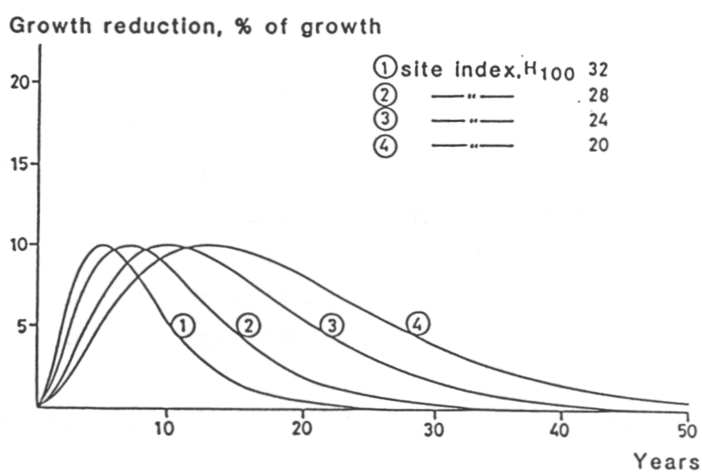

Figure 3. Development of increment losses (Olsson 1984).

FACTORS CAUSING QUALITY LOSSES AND THEIR DETERMINATION

Quality losses are caused by injuries to standing trees during harvesting. Tree species respond to injuries in different ways. Spruce and birch are quite susceptible to decay following injury. Hakkila and Laiho (1967) studied the effect of a ax blaze on the development of decay in spruce. According to the study, spruce develops decay from an ax blaze almost without exception. An ax blaze corresponds closely to a medium-sized wound occurring in harvesting. Pine, however, does not develop decay from injuries, rather wounds usually occlude well.

Reports on decay in Nordic countries have concentrated on spruce, because of its great economical significance. The development of decay depends on the position, size, and depth of an injury as well as partly the time when an injury occurs.

Decay can develop as a result of root, root collar and stem damage. According to Nilsson and Hyppel (1968), however, only 5% of badly damaged roots over 1 m away from the stem caused decay. Therefore, we can restrict ourselves to inspecting root damage within a 1 meter distance from the stem.

Isomäki and Kallio (1974) studied the effect of type of injury on the development of decay. The size of the injury accounted for 22% of decay development, width for 16.2% and depth for 10.5%. Damage occurred in early summer caused decay to develop more quickly.

On the basis of literature Olsson (1984) has drawn up a figure (Figure 4) which presents the probability of decay development according to injuries on different parts of the tree. The information given in the figure can be used to calculate the consequential effects of injuries.

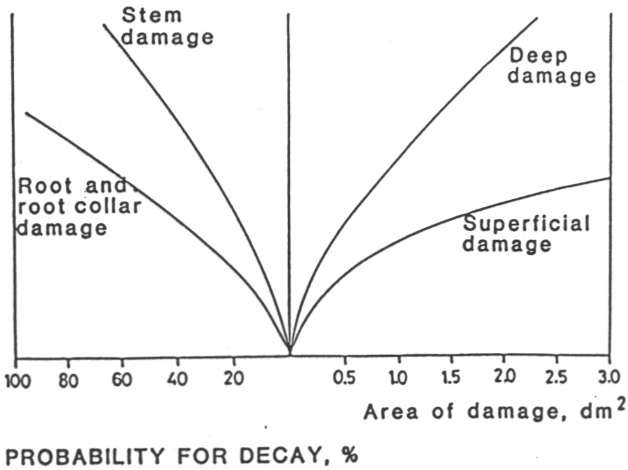

Figure 4. Probability of decay development (Olsson 1984).

The speed of decay advancement has been studied in Finnish conditions by Isomäki and Kallio (1974). According to research study results, decay advanced at an average rate of 19.9 cm/a from root injuries, 28.4 cm/a from root collar damage, and 18.3 cm/a from stem damage. Figure 5 (Isomäki and Kallio 1974) presents average decay advancement in various damage groups.

The advancement of decay slows down with time. Isomäki and Kallio (1974) verified that the advancement of decay changed over time according to figure 6. When the losses caused by decay want to be computationally explained, the development and advancement of decay in tree stands can be forecast on the basis of the research data presented above. Damage inventories, which are used as the basis for calculation, have clarified the amount and characteristics of injuries in various harvesting methods.

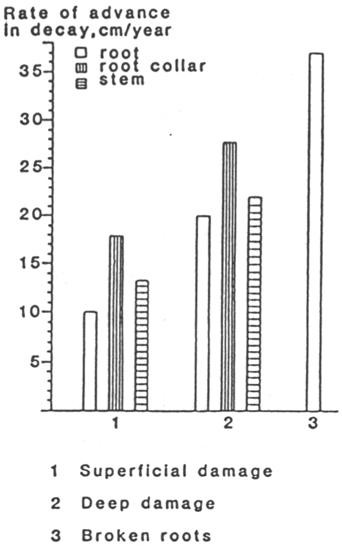

Figure 5. Rate of advance in decay (Isomäki & Kallio 1974).

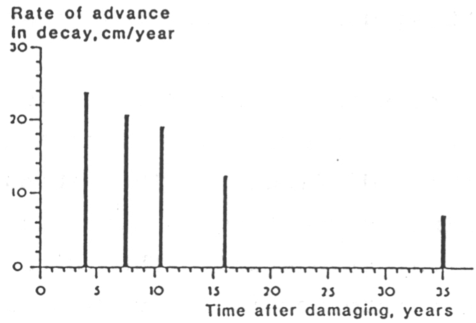

Figure 6. Rate of advance in decay during the time (Isomäki & Kallio 1974).

INDIRECT DAMAGE CAUSED BY HARVESTING

Harvesting may also cause indirect damage. This damage is, however, connected with special circumstances and is difficult to estimate by means of calculation. These indirect consequences are wind, snow and insect damage, which may be quite vast per stand marked for cutting.

The susceptibility to wind and snow damage increases in conjunction with increasing thinning intensity. In Finland damage is more or less localized, but in some countries it is especially important to take wind and snow damage into consideration.

Wind as well as snow damage are associated with mechanized harvesting. If harvesting machines produce ruts and damage trees' root systems, trees bordering the strip road are more susceptible to damage. The significance of wind damage in

Finland is emphasized in drained areas, whose thinning requirement will increase in the coming decades. In peatlands root systems are quite close to the surface and the danger of rutting during harvesting great.

The risk of insect damage is quite restricted to the area marked for cutting and its assessment for various harvesting methods difficult. The standing crop which has been injured during harvesting is more susceptible to insect damage than a healthy tree stand. The risk of insect damage must also be taken into consideration when storing timber in the forest.

BASES FOR THE CALCULATION OF EXPENSES

In converting the consequential effects of harvesting into money, the final outcome depends on the angle from which the question is approached. In the calculation of quality losses caused by damage to the standing crop, the decrease in the value of timber can be examined from the forest owner's point of view, focusing on the tree's value at the road side, or from the angle of the wood product manufacturer and national economy by using as a basis for examination the wood processing value of sawn timber got from a stem and the possible export price received in global markets.

The process of cost calculation

Information on harvesting trace is the basis for the calculation of expenses. In the comparison of harvesting methods information is based on inventory data. This includes the volume, type and position of damage, as well as the number of strip roads, rutting and volume of remaining standing crop and its distribution on the stand.

When the level of damage is examined in various conditions, it is confirmed that spruce stands are especially susceptible to damage in summertime harvesting (Sirén 1981, 1982). Because the effects of damage in spruce stands are greater than in pine, due to spruce's susceptibility to decay, there is cause to examine consequential effects according to tree species and also focus on the timing of harvesting, dividing the examination in summer and wintertime harvesting.

Costs can be calculated for the whole rotation age starting with the first thinning or by examining the time period between the last thinning and final cutting. The most logical, however, is to approach the problem with alternative harvesting methods and the whole rotation in mind.

In making calculations, information is also needed on the development and growth of forest stand types to be examined, in order to estimate the forest yield during rotation and on the other hand to calculate the effect of increment and quality losses. In Finland Vuokila and Väliaho (1980) have drawn up treatment models on planted coniferous stands at the intermediate cutting stage, which make it possible to follow the development of type forest stands and estimate crop volume.

While examining rotation it is necessary to make assumptions on how many trees damaged in the first thinning will be removed in the second thinning, and also how much damage occurring in the second thinning will be focused on the same trees that were damaged in the first thinning. The operator of a multi-purpose machine often chooses the removed trees and it is difficult to see stem damage or root damage. We can therefore assume that trees damaged during the first intermediate felling are removed in the second intermediate thinning at an only slightly higher thinning yield than usual.

Various factors affecting calculations

While making calculations different assumptions are made, neither are results completely correct, but they can be seen to give the level of expenses inflicted on the forest by harvesting. The result is affected by which price is used in calculating the volume of quality losses. The price received by the forest owner, for example, could be used, or the price of sawn wood on the international market. The discount percentage which may be used also has a significant effect on the final result. After all, the majority of losses are realized in the final cutting, when the delay from the first intermediate thinning may well be 50-60 years. When the losses effected then are calculated for the present day, the value changes substantially.

IN CONCLUSION

Principles for calculating the indirect costs of thinning timber have been presented above. Althoug the bases for calculation include many assumptions and factors of uncertainty, they are a point of departure for the estimation of the level of indirect expenses. When direct costs for various harvesting methods are known, the total economics of harvesting can be calculated by also including these costs inflicted on the forest.

Even though at first glance it seems that the forest owner pays for the poor harvesting trace, the wood product manufacturing industry also suffers in the long run in the form of raw material losses. The good condition of the forest after harvesting benefits both forest owner and timber buyer. Since the costs of a bad harvesting trace are realized after a long period of time, they would not seem very high if thought of in terms of the present day. Nevertheless, a bad harvesting trace with a certain method causes difficulties in timber procurement, because forest owners do not want this kind of method used in their forests. Information of the right level of indirect costs combined with harvesting costs makes it possible to choose the correct method in different situations.

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EFFECTS OF DAMAGE ON THE NEWLY THINNED STAND DUE TO MECHANIZED FOREST OPERATIONS

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SUMMARY

Logging and transport operations in thinning stands take place among growing trees and occur on ground that is also utilized as a growth substrate. In mechanized forestry conflicts arise on whether it is worthwhile to be extra careful and reduce the damage. This review article indicates that it is worthwhile to avoid major injuries to stems and large roots and very worthwhile both to increase knowledge of root and soil damage and their effects in a thinned stand, and to increase efforts to adapt forestry machines better to ground conditions.

Large injuries to stems and large roots have a good chance of being infected by rotting fungi if the trees are susceptible. Deep wounds must be avoided. The injuries will cause reductions in both growth and quality. Healthy trees have intact bark!

Mechanical damage to the root system may lead to increased spread of root rot and increase the risk of wind-throwing. There is very little information on that subject as well as on the effect of soil compaction on the nutrient status.

The interaction of root and soil damage may reduce the growth of the trees closest to a strip road considerably.

The effect may last at least five years if the ruts are deep. Although it is not completely clear, it seems as if soil compaction could be the dominant component.

A newly made corridor in the stand will influence the trees closest to the opening to grow faster due to more light and less root competition on one side. However, if the corridor is too wide (>3 m?) the extra growth of the edge trees cannot compensate the loss of trees in the corridor.

In a situation of deep rut formation and root and soil damage the strip road is really unproductive, thus no extra edge tree growth and the above mentioned growth reduction and as well the "naked" part of the road if the road is too wide have to be counted on the list of damage.

Introduction

All transports in the forest stand occur on the ground that is used at the same time as a growth substrate. In the case of mechanized cleaning and thinning operations the machines are also operating within a growing stand. Do we have to designate the strip roads or the trails in the stand or may it be possible to talk about multiple use?

This paper will deal with damage and the effect of this damage in a thinned stand. It is maybe the most difficult stage of the stand for definition and quantification of the damage but probably the most urgent stage for measures. To begin with I shall give some glimpses of the kind of forestry operations I often see.

The spacing of the temporary roads could be 15-30 m. In Scandinavia most of the felled timber after thinning operations is yarded with a crane, either with the forwarder's crane or with the crane-mounted one-grip harvester. Winching of trees could be used in small scale forestry (private owners) or in steep terrain. However, winching is not so popular because of the high level of damage to the remaining trees. The assortment system is predominant and hauling is mainly done with a forwarder. Skidding is rarely used since we want to avoid dirtying the trees.

At a distance the newly thinned stand looks nice after the thinning operation. Although some discussions about selectivity and thinning grade may arise it is expected that the stand has a good quality and quantity growth. However, a closer look reveals that some of the stems have wounds and there are wheel rut formations in the soil from the forestry machines. Could it be wrong to classify the stand as a healthy well-growing stand after a successful tending operation?

Intact bark - healthy trees

Injuries to the tree that damage the inner bark or deeper layers start a wound reaction (Biggs et. al 1984). Deeper injuries also cause a dry zone formation and the initiation of a compartmentalization process, that is for example vessel blocking and barrier formation in the sapwood (Coutts 1977, Shigo 1985). This means that a part of the sapwood becomes non-conductive but the efficiency of the defense mechanisms against invading pathogens depends on the tree species.

Although bark wounds may be attacked by e.g. canker fungi, it generally requires a removal of the bark to really increase the risk for rot infections. There are many studies showing an increase of rot infections with increased wound size. The infection risk also depends on the season, the locality and the tree species. Birch, Norway spruce and sitka spruce belong to those species that are easily infected. According to Isomaki and Kallio (1974) and Meng (1978), a 100 cm^2 bark peel off on Norway spruce may give a 40% risk for rot infection which then spreads upwards in the stem at a rate of about 20 cm per year.

Deeper injuries that also include wounds or crushing of the wood fibres in the wood cylinder increase the risk of a rot infection considerably. The greatest risk of rot infection is in the root collar region. A 200 cm^2 wound with damaged wood cylinder in the root collar region has an almost 100% chance of getting infected.

Larch, oak and pine trees are seldom infected by wood-rotting fungi. However, the wound will give a loss in quality and the wound reaction blocks part of the transport paths and thereby also the growth. A study on Scots pine showed that the growth reduction is proportional to the wounded portion of the stem girth (Andersson 1987). A wounded portion of 1/8-1/4 of the stem girth reduces growth by 13% for at least 10 years. The growth loss is greater if the wound is located in the root collar region. Similar results have also been reported for Norway spruce (Isomäki and Kallio 1974).

The economic effects of stem wounds appear to be about 10-15% loss in the value of the tree (Meng 1978, Fröding 1986). Although the calculations are uncertain, they show that there are economical reasons to be careful and to avoid these damages. One way is to train the operators to be careful. Another, more expensive way, is to treat the tree wounds with chemicals (Bonneman 1979). According to Dimitri (1983) the costs of proper chemicals and the treatment would be a profitable investment (0.8-0.9 DM per tree).

diameter).

According to Nilsson and Hyppel (1968) wounds occuring on roots larger than 20 mm in diameter and less than 0.7 m from the trunk base may result in a rot infection that enters the stem. The probabilities for rot infections, rate of dispersal etc are not so well established but they appear to be similar to that for stem wounds. If long lateral roots are broken, the growth reduction of the tree could be 50% and the growth rate of the rot infection could be twice the stem infection (Isomäki and Kallio 1974). The effect of root wounds on growth may be overestimated since those trees are most likely also subjected to soil compaction.

The fine and medium sized roots may be crushed or torn off beneath a driven wheel (cf. Wronski 1984). The total number of tree roots may be at least 60-120 roots m^{-2} and the total length may be 200-500 mm^{-2} (Wästerlund 1989). Less than 7% of them are larger than 10 mm in diameter. Damage to these roots is not likely to be a direct cause of stem rots.

However, recent pilot studies of root rots in a stand show alarming results. In one study in three different stands on good sites in southern Sweden the frequency of root rots increased markedly with decreased distance to the strip road (Figure 1, Bernhardsson and Martinsson 1986). The high frequency of stumps in the strip road is one reason, but root damage to trees standing close to the strip road must probably be another reason for that high rate of infection.

Growth reduction

A literature survey showed that trees standing close to a temporary road or a strip road may have reduced growth (Wästerlund 1983).

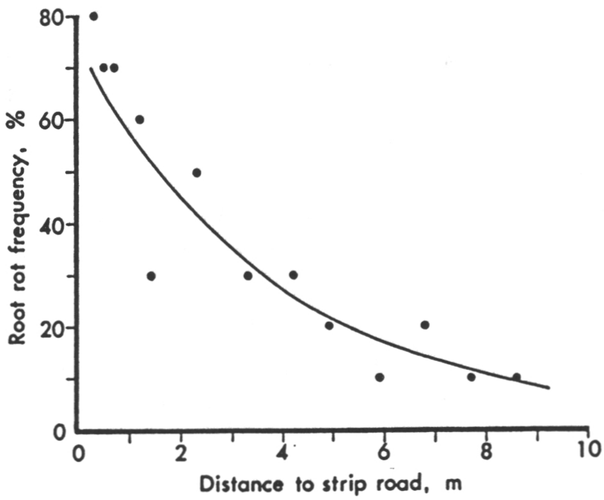

Figure 1. Average distance to strip road and root rot frequency. 10 trees per group. 3 newly thinned stands (3rd - 4th time) of 60 year old Norway spruce trees, Biskopstorp (Bernhardsson & Martinsson, 1986).

The growth reduction should depend on how much of the tree root system that is influenced and therefore a root growth model for the average horizontal spread of the root system has been developed (Wästerlund 1983, 1987). The closer the tree the rut formation is and the deeper it is the more the tree should be influenced by the damage (Figure 2). The total growth effect depends also on the kind of tree species and the site index. On an average Scandinavian site or poorer, the Norway spruce trees standing near a strip road with deep rut formation may loose up to 30% of the growth on average during a five year period after the damage has occurred.

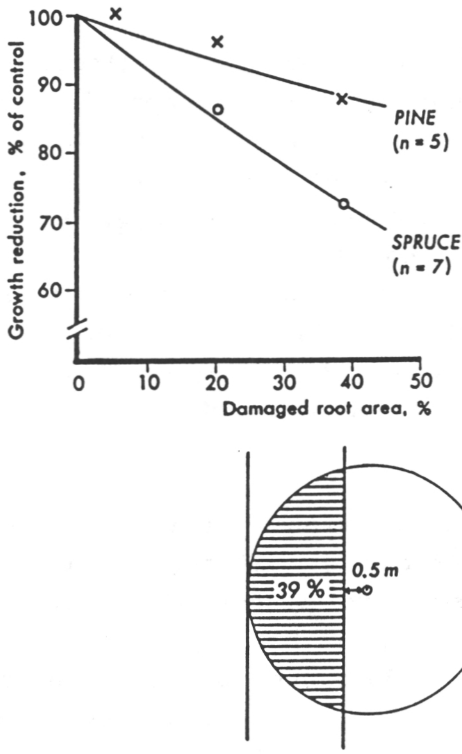

Figure 2. Growth reductions due to root and ground damage according to a literature survey. The growth losses are assumed to depend mainly on how much of the tree root system is damaged by the strip road (Wästerlund, 1983).

A 10 cm deep rut formation may cut off or damage many of the feeding tree roots. Even a 6 cm rut may do harm. If the soil is not moist enough for the rut formation to be due to plastic flow, there will also be a compaction of the soil. Most likely the regeneration of new roots will occur quite soon after a severe injury to the old root. However, the recolonization of the old territory may be impeded by the compacted soil. The impediment depends inter alia on soil texture and tree species, e.g. Norway spruce is more impeded than Scots pine (Wästerlund 1985).

According to experiments with uptake of labelled phosphate and surveys until active tree roots are back in their former territory (Wästerlund 1987 and 1989). Prediction models for the recovery time and such factors as climate and soil type do not appear to exist.

The growth effects probably depend on the interaction between soil compaction and root damages. Although there are no satisfactory experiments showing the effects of each type of damage, it appears that soil compaction may be a more severe and longer lasting type of damage than root wounds (cf. e.g. Cochran and Brock 1985). In a study of the growth after mechanical cleaning, a 25% growth reduction was observed for the young trees standing nearest to the wheel rut during the two first years after cleaning (Wästerlund 1988). In the wheel ruts only a few root injuries could be detected but the machine having an average ground pressure of up to 90 kPa caused compaction of the soil.

Poor aeration and mechanical resistance seem to be the main effects of soil compaction (cf. Wästerlund 1985). Soil compaction does not seem to affect the nutrient content of the soil very much but the microbial immobilization might be slowed down due to poor aeration (Miller and Sirois 1986, Dick et al. 1988). On dry sites moderate compaction could be favourable in that it increases the water holding capacity of the soil.

A rut formation with breakage of the humus layer and the mixing of the soil and the humus together might be favourable for the microbial turn-over (Miller and Sirois 1986). However, soil compaction drastically decreases the rain water infiltration rate. If the rut formation occurs on slopes, there is a major risk of a nutrient leakage together with the soil erosion.

Windthrowing

In newly thinned stands the risk of windthrowing is high because of the openings in the stand subjecting unadapted trees to the wind (Persson 1975). Root damage along the strip roads will decrease the stability of the trees. Increased rot infections due to root wounds will also decrease the stability of the trees. However, the role of root damage in the total risk for windthrowing appears

2.3 m wide area (leaving 1.7 m "unproductive"). The edge trees were on average growing about 40% more in volume than trees further in. Similar basal area increment of edge trees was measured by Eriksson (1987). Thinned plots had lower volume production (7-16%) than unthinned control, but the differences between 3.5 and 5 m strip road width appear to be small. The results from the studies of Niemistö (1989) and Pukkala (1989) indicate that a 2-3 m wide opening would give almost no growth reduction but 4-5 m (a. 17% treeless area) would give about 6% growth loss. The referred data concern 30-70 year-old stands and in general it seems as if Norway spruce respond better to the opening than Scots pine do.

More data are needed to make good predictions on edge tree growth and the effect of openings on the total stand volume production. However, the referred data all show an extra growth of undamaged trees close to an opening that can be regarded as a yield on a part of the opening (Figure 3A and 4A).

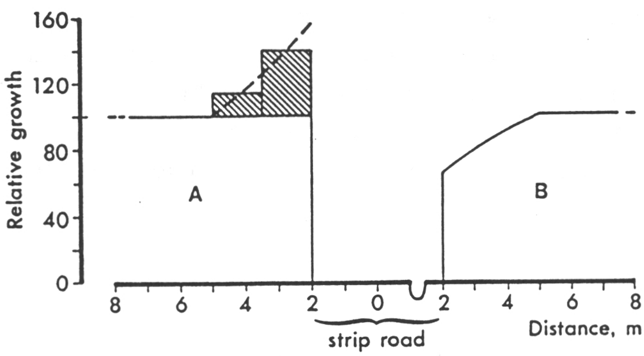

Figure 3. Schematic drawing of the growth in a newly thinned 40 year old stand. A. The positive edge tree growth at the opening chiefly according to Isomäki (1986) and Eriksson (1987). The root growth model is suited to the data (dashed line). B. Growth reduction due to root and soil damage (rut formation) in the strip road according to figure 2.

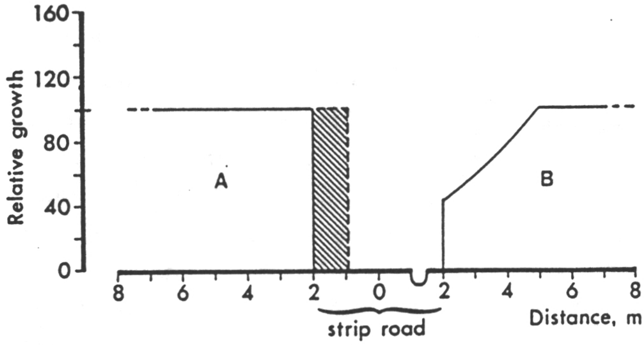

Figure 4. Interpretation of figure 3. (A) The extra growth of the undamaged edge trees can be regarded as the yield of a part of the corridor, or (B) as a further decrease of the growth of damaged edge trees to "truer" values.

This yield should also depend on the size of the tree root systems, e.g. the older the trees are the deeper in the stand the growth effects might be expected according to my root growth model (Wästerlund 1987).

As a consequence of these new findings, my growth reduction model for damaged trees (cf. Figure 2) may be an underestimation of the growth reduction. Most of the data in that model are based on a comparison of the edge tree growth with growth of trees in the middle between strip roads. In reality the growth of damaged edge trees should be compared with undamaged edge trees (cf. Figures 3B and 4B). Then the "real" growth reduction of severely damaged edge trees could be in the magnitude of 50%!

Conclusions

Facing the newly thinned stand and the scars resulting from the thinning operation, comments could be as follows.

Stem wounds and root wounds may cause rot infections, reduced wood quality and reduced growth. Roughly, a normal rate of damage could reduce growth by 10% and the tree value by 10-15%. Experience from Scandinavia shows that good methods and well-trained operators may keep the damage level below 5%. That level gives roughly < 5% lost of the value at harvest.

Deep rut formation in the strip roads may cut off many roots. This damage might severely increase the spread of root rot infections and increase the risk of wind throwing. Soil erosion and nutrient losses may occur in the ruts in steep terrain. Further research must be done on these subjects before it is possible to quantify the costs for this damage.

The interaction of root and soil damage will cause a growth reduction of the edge trees during at least 5 years. Suppose the strip road width is 4 m, the distance between these roads is 25 m and they have deep ruts. The growth reduction could then amount to about 5% and roughly the same in value.

If the strip road had only been an undamaged opening in the stand, then it would have cost maybe 5-7% of the production. Now with deep rut formation we have to add the lost extra growth of the edge trees which could amount to 9%. According to these figures the bad strip road may roughly cost 20% of the production, whereas the imagined, smooth, 2.3 m wide machine would not even cost the production loss in the road!

These figures are mainly my rough interpretations of available information and should not be taken too literally. However, two things are quite clear. One is the need for better knowledge of the effects of damage in the thinned stand. The second is the need - and there are also good economical motives - to adapt forestry machinery better to the ground conditions in the forest.

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TRACTIVE FORCES AND TORQUE DISTRIBUTION ON A FORWARDER EQUIPPED WITH AN ALL HYDROSTATIC TRANSMISSION

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SUMMARY

This report describes the characteristics of the hydrostatic transmission on the NORCAR 490* forwarder, with respect to torque distribution and tractive forces. The torque distribution is used as an instrument to illustrate the risk of damage to the soil and forest floor. Some comparisons are made with a transmission based on mechanical distribution of power to the wheels.

A NORCAR 490 has been equipped with transducers for measuring pressure, return pressure, steering angle, bogie angles and speed of the wheels. The vehicle studied has 8 wheelmotors (8 WD) with its rear wheels trailing in the tracks of the front wheels. Different test series have been carried out, where ground conditions, weight distribution, steering angle and driving conditions have been varied.

The results indicate that this type of transmission reduces the risk of damage to the forest floor, in comparison with a stiff mechanical transmission. A stiff mechanical transmission refers to a transmission (8 WD)

* The trademarks NORCAR 490 and KOCKUMS 83-35 are used in this report only for information to the reader. The purpose is not to compare different forwarders from different manufactures. The objective is to compare the characteristics of different principles for the design of transmission.

which has some kind of differentials on the rear and the front axles but has no differential on the axle between the rear and the front, i.e. the most common type of transmission used in the forwarders of today.

The reason why this type of hydrostatic transmission reduces the risk of damage to the ground, is due to the design of the transmission. It has two hydraulic circuits with two pumps. The circuits are lying in a cross on the machine, i.e. one bogie in the front and the rear bogie on the opposite side of the machine are supplied with oil from the same pump. All motors on one circuit are coupled in parallel. The two wheelmotors in a bogie are mechanically connected with a chain. This means that there are differential effects between the rear and the front and between the sides of the machine (not between two wheels in a bogie due to the chain). These "differentials" smooth out the inner tensions which can arise from, for example, an uneven weight distribution, which in turn causes different radious on the wheels. Dynamical changes in the torque distribution, caused by for example a change in steering angle (not constant turning radious), are on the other hand not levelled out by these differentials.

A machine equipped with a stiff mechanical transmission, under impact of an uneven weight distribution between the rear and the front, causes a certain slip on the wheels to even out the difference in travelled distance for the circumferences on the wheels. The same behaviour yields, when turning, for a machine equipped a stiff mechanical transmission which has not the rear wheels trailing in the tracks of the front wheel. The results from this study have not shown the type of inner tensions, which the behaviour just described causes, when a vehicle equipped with an all hydrostatic transmission is driven straight forward or in a constant turn. The conclusion is hence that the later type of transmission ought to have less tendency for this type of slip. Other differences in tendencies to slip between the two types of transmissions have not been shown in this study.

The conclusion from this study is that the investigated hydrostatic transmission has better properties under steady state conditions or under constant course of events (defined as static properties in this report) than the stiff mechanical transmission, while the dynamic properties level. In reality the dynamic properties are superposed to the static properties and hence are the machine and the ground are under impact of both type of properties when driving in the forest.

INTRODUCTION

This paper describes the characteristics of the hydrostatic transmission on the NORCAR 490 forwarder, with respect to torque distribution and tractive forces. The torque distribution is used as an instrument to illustrate the risk of damage to the soil and forest floor. Some comparisons are made with a transmission based on mechanical distribution of power to the wheels.

Different test series have been carried out, where ground conditions, weight distribution, steering angle and other driving conditions have been varied.

The results indicate that this type of transmission reduces the risk of damage to the forest floor, in comparison with a stiff mechanical transmission. In this study a stiff mechanical transmission refers to a 8 WD transmission which has some kind of differentials on the rear and the front axles but has no differential on the axle between the rear and the front, i.e. the most common type of transmission used in forwarders of today.

TEST VEHICLE AND MEASURING EQUIPMENT

The research vehicle's weight is 7,8 tonnes and the loading capacity is 7,5 tonnes. It has 8 wheelmotors coupled in two hydraulic circuits with one pump for each circuit. The displacement angles of the pumps are proportional to the speed of the diesel engine and the pressure in the circuits. The circuits are lying in a cross on the machine, i.e. one bogie in the front and the rear bogie on the opposite side of the machine are supplied with oil front the same pump. All motors on one circuit are coupled in parallel. The two wheelmotors in a bogie are mechanically connected with a chain. This means that there are a differential effect between the rear and the front and between the sides of the machine but not between two wheels in a bogie due the chain. The differential lock function is accomplished by one flow divider valve on each circuit.

On the vehicle studied the rear wheels trails in the tracks of the front wheels.

The test vehicle has been equipped with transducers for measurement of oil pressure, return oil pressure, oil temperature, steering angle, bogie angles, speed of the wheels and diesel engine speed. A strain gauge has also been used to measure drawbar pull.

TEST RESULTS

Driving straight forward

The test vehicle has an even torque distribution insensitive to an uneven weight distribution. Driving without load (57% load on the front bogies) on asphalt with 8-WD causes a torque distribution according to figure 1. With full load (66% load on the rear bogies) the torque distribution will be according to figure 2.

Tests with a vehicle with a "stiff" mechanical transmission, without load (59% load on the front bogies) on asphalt with 8-WD (figure 3) show that the front wheels has a negative torque, which means that they are breaking, while the rear is pushing. This due to the fact that all wheels are forced to have the same speed but the weight distribution compresses the front wheels to a smaller rolling radius than the rear ones and therefore they are travelling a shorter distance.

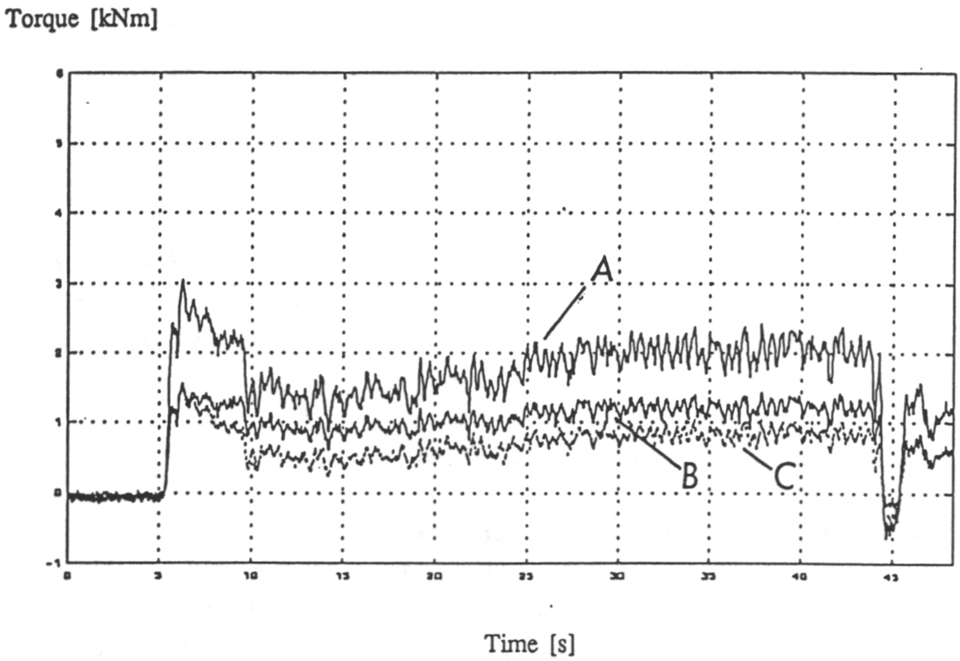


Fig 1. Torque while driving straight forward without load on asphalt with 8-WD. A: Required torque for the whole vehicle. B: Total torque on the front bogies. C: Total torque on the rear bogies.

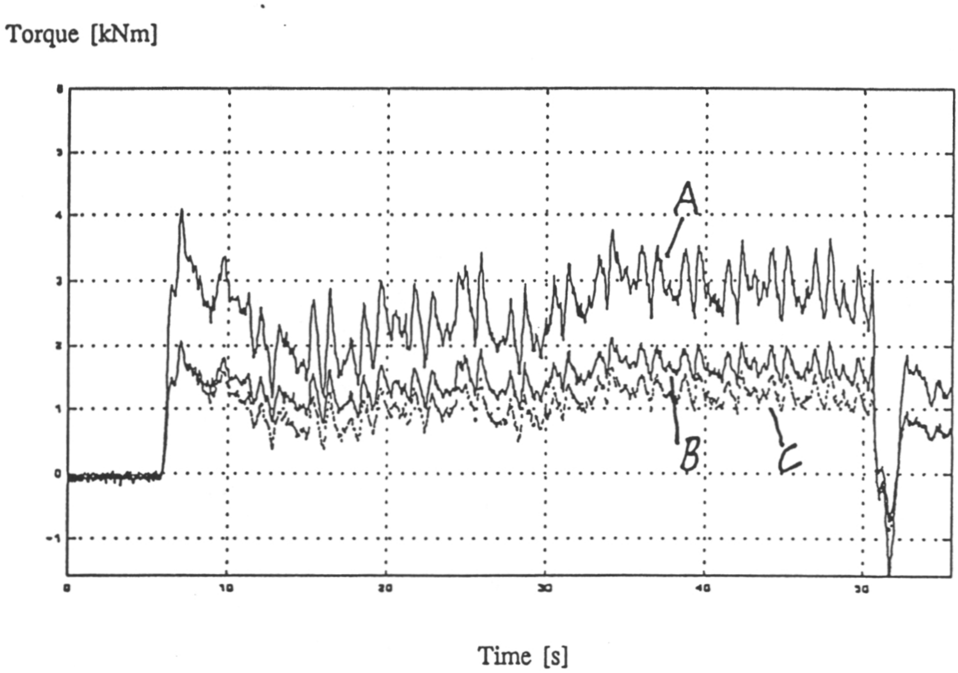


Fig 2. Torque while driving straight forward with full load (6.6 ton) on asphalt with 8-WD. A: Required torque for the whole vehicle. B: Total torque on the front bogies. C: Total torque on the rear bogies.

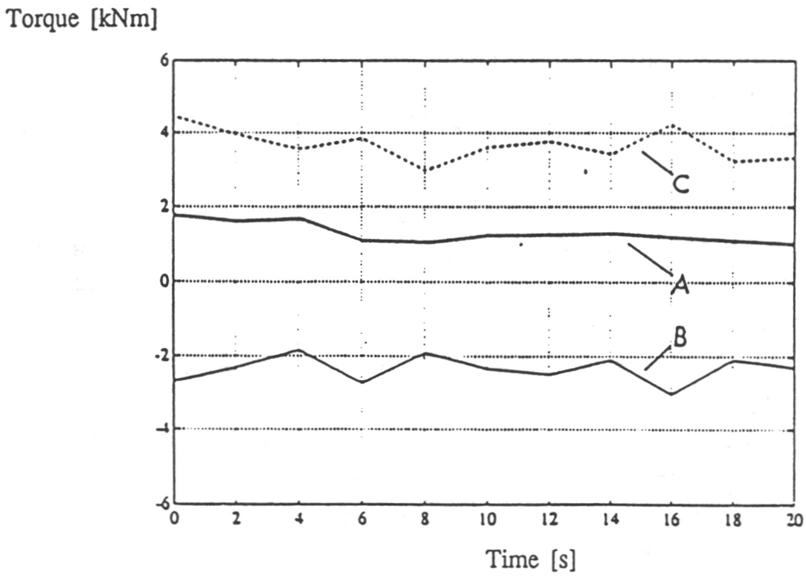


Fig 3. Torque while driving a nose-heavy vehicle with a "stiff" mechanical transmission straight on without load on asphalt with 8-WD. A: Required torque for the whole vehicle. B: Total torque on the front bogies. C: Total torque on the rear bogies.

Driving in a curve

An ideal transmission should be smooth without inner tensions. This is not the case with the tested transmission.

While driving in a constant curve i.e. no change of the steering angle, without load on asphalt and with 8-WD, there are no inner tensions in the transmission. However, there will be an increase of the torque with 1 kNm on each bogie. This is due to the forces needed to pull the bogies around.

Dynamical changes of the steering angle causes a change in the torque distribution which is not levelled out by the transmission. In figure 4 we can see the steering angle while driving in a S-curve on asphalt without load and with 8-WD. After having started straight on the vehicle turns first to the left, then to the right and finally back to driving straight forward again. In the left turn (20-30 sec in figure 5) the reduction of wheel speed on the left front bogie is greater then the increase of wheel speed on the right rear bogie. This means that the hydraulic circuit's oil demand decreases which causes an increase of the oil pressure (figure 6). In figure 8 we can see that this increases the torque on the left front and the right rear bogies. During the change in steering angle the opposite happens to the other circuit, right front- and left rear bogies. The overall increased wheelspeed is so great that it causes the wheelmotors to act as pumps (figure 7). This means that we have a negative torque during this part of the experiment (figure 8). The behaviour above is due to that the flow delivered by the pumps mainly depends on the engine speed which means that they work as if it had been a differential lock between the circuits.

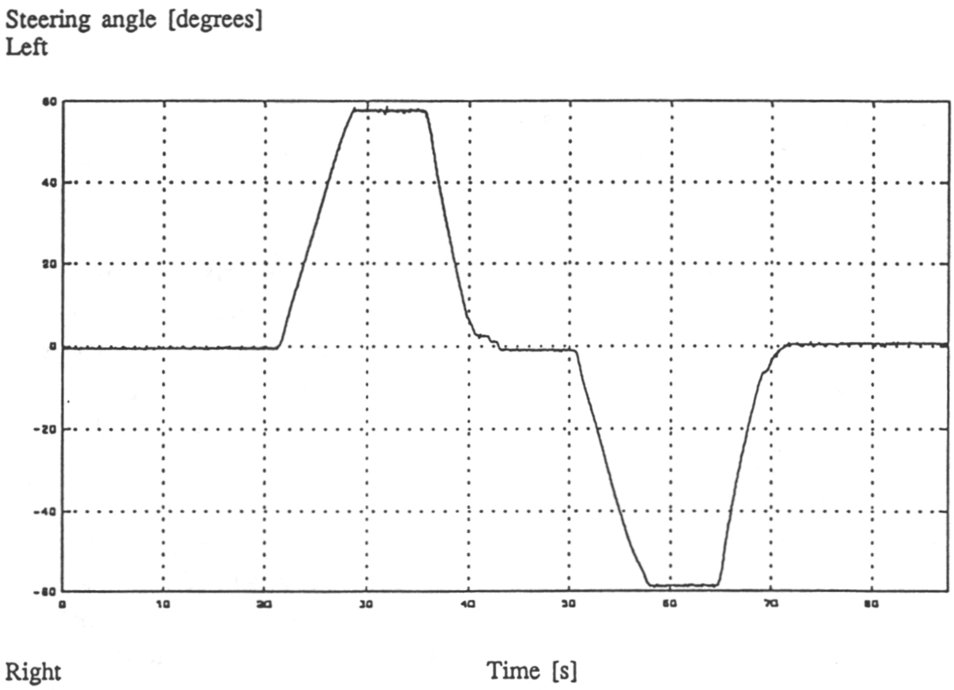


Fig 4. Steering angle while driving in a S-curve on asphalt without load and with 8-WD.

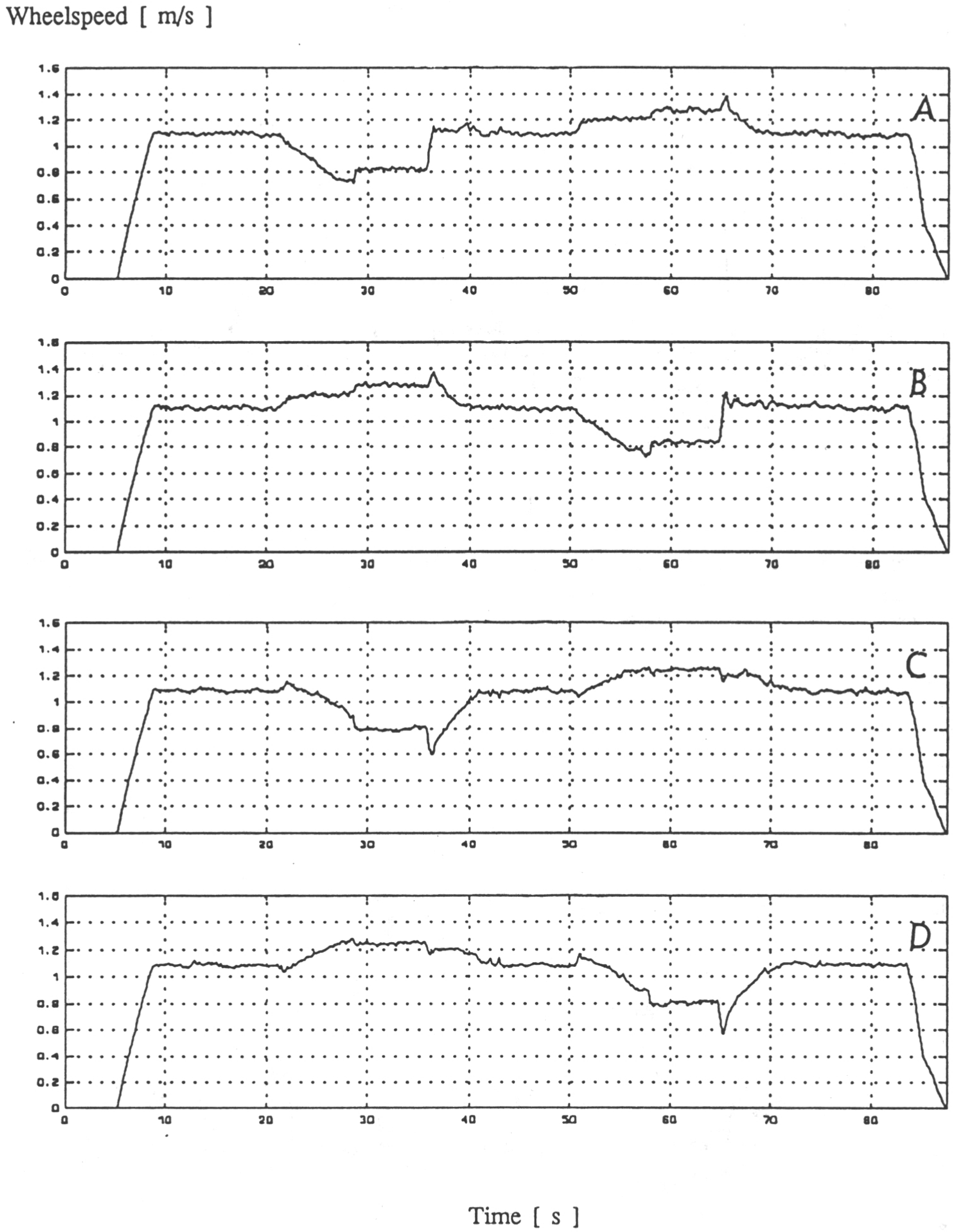
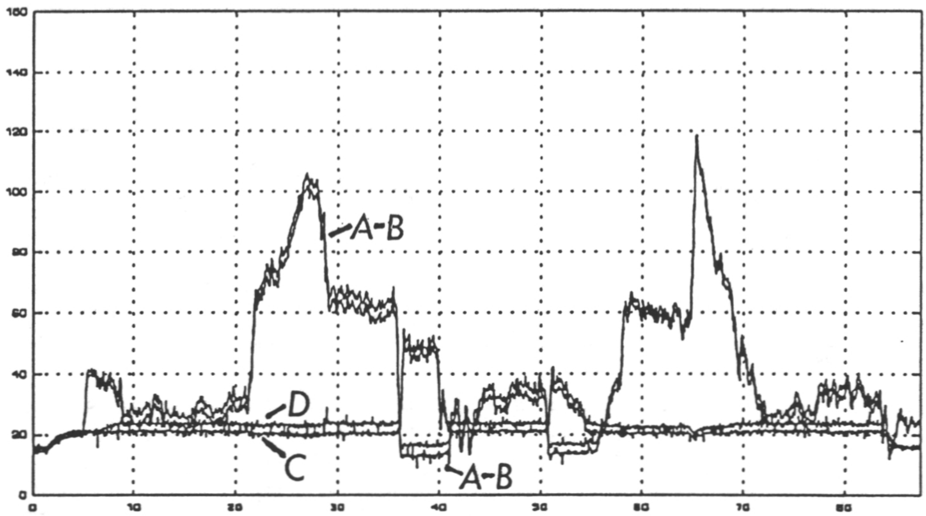


Fig 5. Wheel speed while driving in a S-curve without load on asphalt with 8-WD. A: Left front bogie. B: Right front bogie. C: Left rear bogie. D: Right rear bogie.

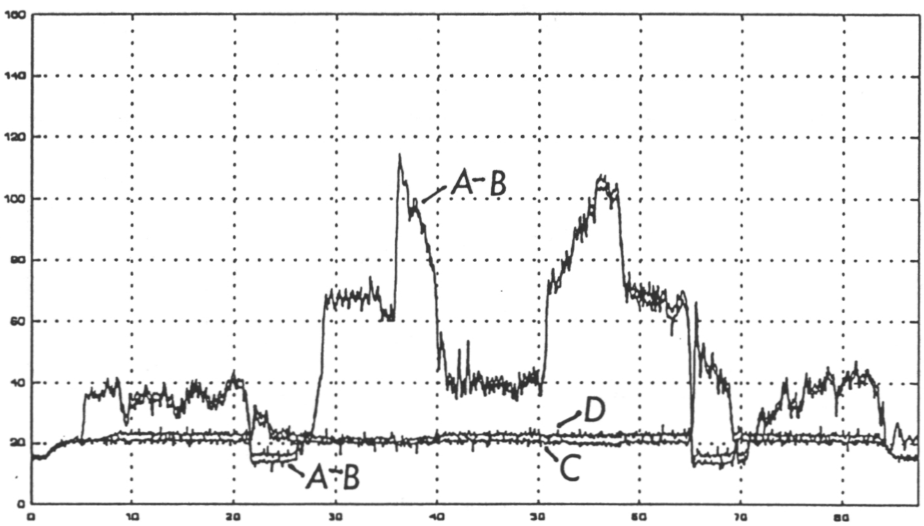
Pressure [bar]



Time [s]

Fig 6. Pressure in the circut for right rearbogie and left frontbogie while driving in a S-curve without load on asphalt with 8-WD. A-B: Pressure in the bogies. C: The return pressure for the front bogie. D: The return pressure for the rear bogie.

Pressure [bar]



Time [s]

Fig 7. Pressure in the circut for left rear bogie and right front bogie while driving in a S-curve without load on asphalt with 8-WD. A-B: Pressure in the bogies. C: The return pressure for the front bogie. D: The return pressure for the rear bogie.

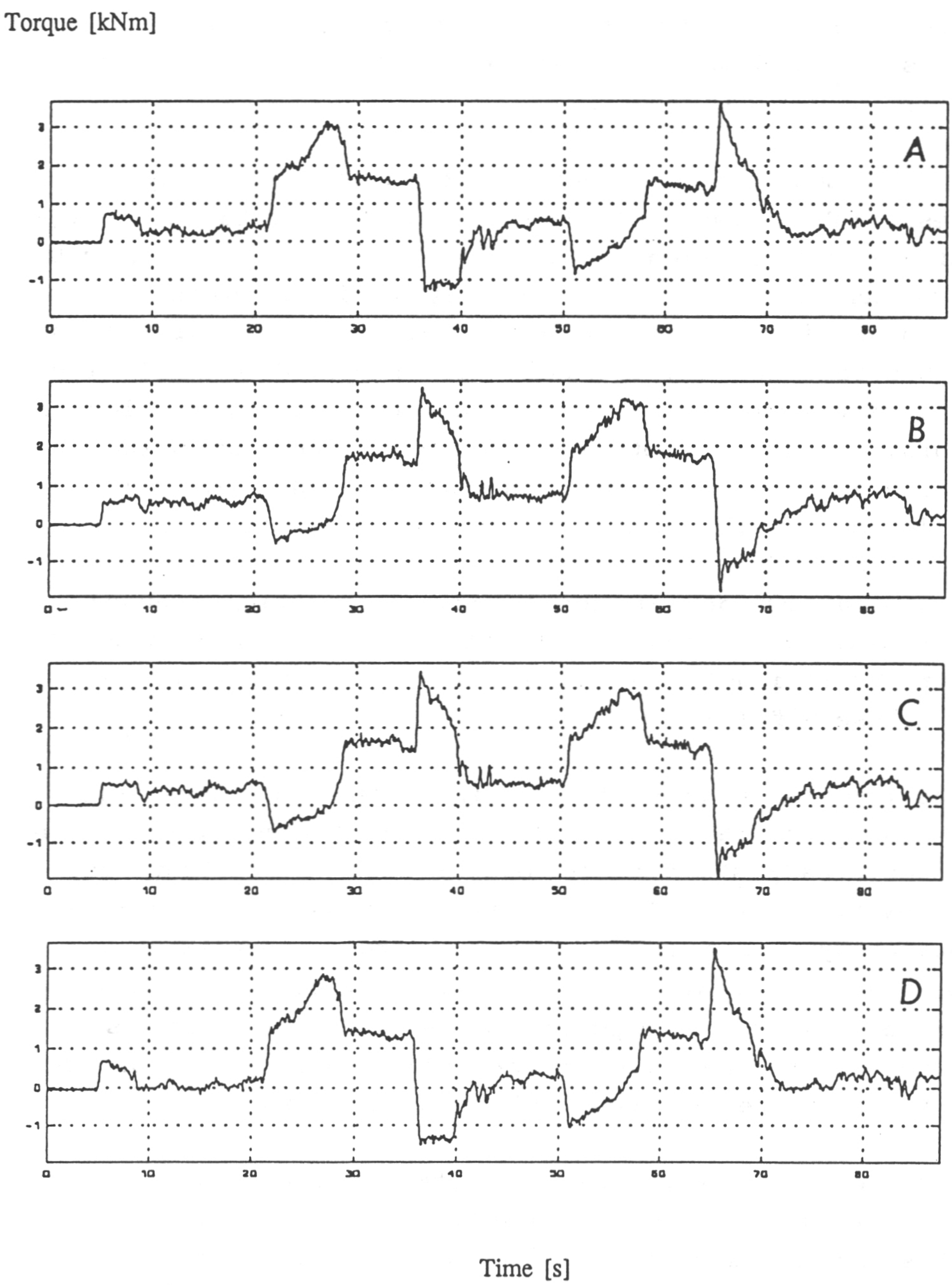


Fig 8. Torque while driving in a S-kurve without load on asphalt with 8-WD. A: Left front bogie B: Right front bogie. C: Left rear bogie. D: Right rear bogie.

DISCUSSION

The results indicate that a hydrostatic transmission may cause less damage to the forest floor, compared to a stiff mechanical transmission.

The reason why the hydrostatic transmission may cause less risk of damage to the ground, is due to the design of the transmission. It has two hydraulic circuits with two pumps. The circuits are lying in a cross on the machine, i.e. one front bogie and the rear bogie on the opposite side of the machine are supplied with oil from the same pump. All motors on one circuit are coupled in parallel. This smooth out the inner tensions which can arise from, for example, an uneven weight distribution, which causes different rolling radious on the wheels.

Dynamical changes in the torque distribution, caused by for example a change in the steering angle (not constant turning radious), are on the other hand not levelled out by these differentials.

The conclusion from this study is that the investigated hydrostatic transmission have better torque distribution under steady state conditions or under a constant course of events than a stiff mechanical transmission. However, during dynamic conditions the compared transmission types behave in a similar "bad" way. In reality the dynamic properties are superposed to the static properties and hence are the machine and the ground under impact of both types of properties when driving in the forest.

One way to improve the hydrostatic transmission is to build a one-circuit system with automatic flow dividers, this can be done on a mechanical transmission as well. But with a differential on the axle between the front and the rear and with automatic differential locks on all axles. An even better solution would be a slip control system. This system should in an early stage prevent the wheels front slipping. This reduction of slippage should also reduce the risk of damage to the soil and forest floor.

THE EFFECT OF MECHANIZED HARVESTING ON TIMBER QUALITY

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In mechanized harvesting the timber being dealt with is liable to suffer from various types of damage which affect the quality and thus also the value of the timber. Examples of such damage include damaged caused by slipping from feeding device, damaged bark and splits incurred during the felling and crosscutting operations.

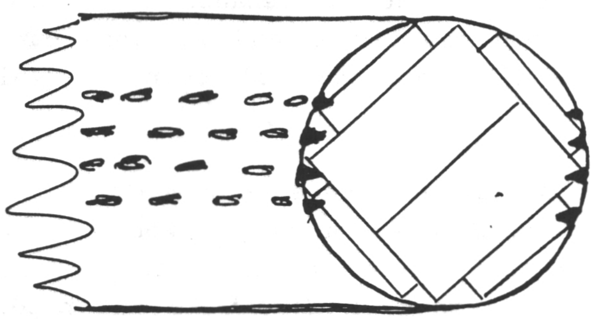
The causes of timber damage can be traced to shortcomings in machine design and to improper maintenance and operation. The damage is found in both saw timber and pulpwood but is of the greatest economic significance when it occurs in high-quality timber.

The economic result of timber damage is revealed in the form of yield losses and downgrading of quality. Who has to carry the cost of these losses will depend on how this is decided in the course of business dealings from forest to end product and is something that varies from one country to another. In Sweden, matters of this kind are regulated in the wood measurement instructions promulgated by the Timber Measurement Council. In these instructions, a description is given of, for example, what saw timber of a certain quality should look like and how deviations should be assessed.

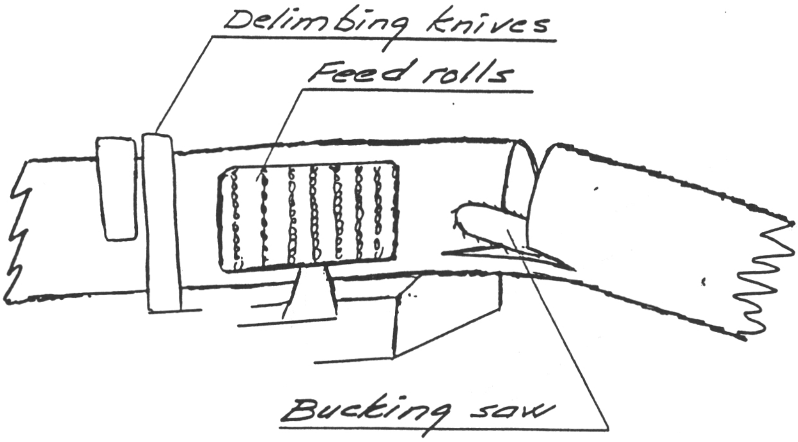
Key words: timber damage, harvesting, yield losses

Typical timber damage

Feed damage from the log feeding device in the form of damage inside the wood caused by spikes on the feed rolls is attributable in its entirety to the design of the machine. Damage caused by spikes on the feed rolls leads to attacks of blue-stain fungus if the timber is stored without protection during the summer months and early autumn. Upon sawing, the mechanical damage caused by spikes on the feed rolls gives rise to yield losses. Moreover, if the timber is attacked by blue-stain fungus it will also have to be downgraded. In Sweden there are deduction rules for timber damaged by spikes on the feed rolls. The reduction in value varies from two to twelve per cent, depending on the depth of the holes caused by the spikes and the proportion of damaged logs in the batch. Damage of this kind is avoided by using rubber feed rolls.



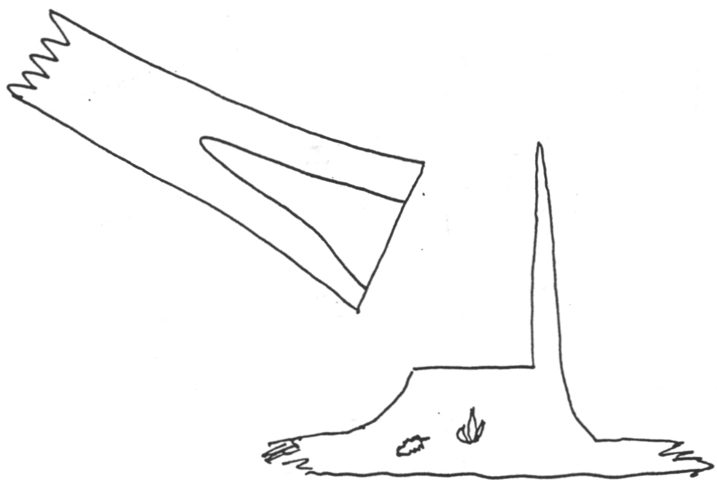
Crosscutting splits are a form of damage that can be attributed to the design of the machine but may also be a consequence of improper care and maintenance of the chainsaw. The cutting splits extend in the log ends from the cross-cut. The splits are detected only in exceptional cases but lead to split losses upon final trimming in the sawmill. The losses are of the order of magnitude of one per cent of the value. Cutting splits are avoided by correct dimensioning, are and maintenance of the crosscut saw.



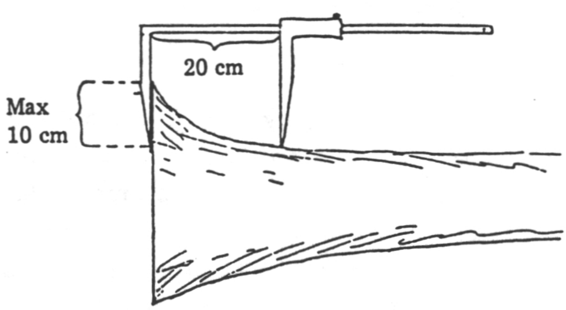
Damage caused by slipping from the feeding device is also a kind of damage that can be attributed to the design of the machine but also to how the machine is set. The correct choice of machine for the stand and harvesting season also influences the result. Slip damage of a more serious nature leads to refusal of saw timber. As a rule, losses due to damage caused by slipping are small and can be avoided by the correct choice of machine for the stand and by setting the machine correctly.

Bark damage is a type of damage usually caused by faulty grinding of the limbing knifes but may also depend upon how the limber is handled and the time of the year. Damaged bark also results in a reduction in value in Sweden. If the bark damage exceeds twenty per cent of the mantle surface for all logs in a batch the value is reduced by two per cent. Normally, bark damage occasions very modest value deductions. During the sapping period, however, there is a particularly great risk for timber processed with one-grip harvesters.

Butt-splitting damage constitute a type of damage which is either operator-dependent or due to the choice of the wrong machine for the stand. Butt-splitting damage are comparable to cutting splits and cause the same problems. The losses are of the order of magnitude of up to two per cent. Avoidance of butt-splitting damage is usually a matter of giving appropriate training to the machine operator. However, snow problems and excessively thick trunks in relation to the capacity of the machine also influence results.



Excessively large buttresses cannot really be regarded as timber damage. Logs with excessively large buttresses nevertheless give rise to problems during handling and sawing and are therefore allocated a one-module (30 cm) length deduction upon being measured (according to the Swedish measurement rules). This is equivalent to roughly seven per cent reduction in value. As a rule, the buttress is manually adjusted with a motorsaw in the forest, and consequently value losses are normally small.



Poor limbing is a type of timber damage attributable to the design of the machine and to some extent to how it is taken care of. Here, too, there are regulations governing how limbing is to be carried out. Deviations lead to refusal upon measuring. The loss due to poor limbing is usually small for saw timber, whereas a reduction in value is more common for pulpwood.

Damage from grab arms and cutting damage from delimbing knives in the wood is usually attributable to the handling of the machine. Deep injuries lead to yield losses in the sawmill. Damage of this kind, however, is rather unusual and losses are normally small. The damage is avoided by adequate operator training.

How much does timber damage cost?

In a study conducted in Sweden we have attempted to determine the magnitude of the damage described in the foregoing. The study was carried out on three commonly used machines during autumn, winter and sapping conditions. All of the machines used in the study were fairly new, had feed equipment with rubber feed rolls, were thoroughly maintained and run by experienced operators. Despite this, the results indicated that timber - damage gave rise to losses amounting to 0.3 to 1.8 per cent of the value of the timber produced. For these particular machines, this was equivalent to SEK 50,000 - 225,000 per machine and year. With older and technically inferior machines, the losses could easily be three times as great. It is essential to minimize timber damage!

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YUGOSLAV EXPERIENCE IN DESIGNING THINNING MACHINES

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SUMMARY

Development of logging machines in a semideveloped country like Yugoslavia is closely connected with its general economic conditions; low inland prices of wood, a relatively low degree of wood products finalization, considerable dependency on imported equipment, rising national debts, high level of the national currency inflation - all these facts determine the design of home-produced forest machines and equipment, particularly the small-scale techniques suitable for thinning operations. The vehicles for extraction of small-size wood are here the most important. The paper deals with three projects of Yu-produced equipment based on agricultural and high-series components of machines, or on basic carrier vehicles such as farm tractor with three-point linkage, category 1, for attachment of mounted implements for lifting and carrying of wood.

Key words: thinning operations, small-size machines, off-road transportation

INTRODUCTION

Strategies in the field of thinning operations, both technology and work methods, are closely connected with the general economic conditions of forestry and timber industry in Yugoslavia, and with real economic and social situation. The part of small-size wood from thinning operations ranges between 10 % and 60 % of the annual cut, in different forestry enterprises, Tomičić (1986), Štefančić (1989).

Small-scale technology and techniques have been characterized same as in thinning operations by the following (Moberg et al., 1988):

- **Low level of capital investment** resulting in low unit capital costs is required (we usually compare some small-scale techniques with horse skidding from cutting area to strip road);
- **Unsophisticated technology** which is easy to learn and apply;
- **A high degree of manual intensive work** is required but less than motor-manual system (cutting and bunching from cutter);
- **Ease of maintenance** etc.

With the **exsisting techniques** we have encountered problems with spare parts, especially with the imported machines and unusual devices, with low strength and need for strengthening, low safety factor etc. The greatest problem is the use of unsuitable vehicles on off-road transportation of timber.

Forestry mechanization in Yugoslavia in 60-ties (Sever & Slabak, 1988); chain saws in 1958, skidders 1968, forwarders 1971, farm tractor adapted with forestry winches in middle sixties, hydraulic cranes on trucks and tractors equipage in 1968 etc.

Although all these machines are **intended for final cut** predominantly of the residual sort of mid dia. over 40 cm, every vehicle is commonly used in summer time at thinning operations. Every machine for transportation of wood, especially for hauling operations was developed and home-produced, e.g. skidders LKT-80 and -81, skidder S-101 (100 kW engine), forwarder IMT 5132 (load capacity of 12 t, engine 101,5 kW), hydraulic cranes with lifting moment of 30, 50, 70, 90 and 110 kNm, trailers from 3 to 12 t net-load etc. Dimensions, maneuverability, soil compaction, ground pressure and other unsuitables technical features caused damage of soil and remaining trees, unfavourable energetic consumption, nonefficiency, and other problems.

To reach a decision on building new small-scale techniques for thinning operations, we have set some common well-known goals:

- Elimination of unsuitable equipment and vehicles used in final cut at hauling thinned wood;
- Designing the machines that will damage forest soil;
- Building energy-saving machines;
- Less pollution of the enviroment;
- Machines with good stability, maneuverability, trafficability, flotation etc.
- Building of robust and high-quality machines strictly intended for forest work;
- Other high performance, e.g. a very maneuverable system, high ground clearence etc.

All that must be done for the existing technology and work method, for our real machine operator and maintenance service, considerable dependency on the imported equipment, bad working conditions and social constitution of workers, and absence of their motivation.

All these aims of designing machines and solutions of technical problems require the world-wide knowledge of equipment suitable for thinning operations as well as how to solve many technical problems.

W O R K I N G   M E T H O D

The time between the idea and the actual creation of the prototype has two different steps; the preliminary work and investigation at the pre-building time, and the period of testing the machines. The first step was theoretical and involves collection of information. A number of factors hindered the development of our own equipment: **poor production of home machine components**, special lightweight components, as a large-series assemblies (especially hydraulic and electronic components). The components of home-produced equipment could be based on the already developed one, primarily on agricultural, building and mining machines and universal transporting devices.

With the conceptual projects, a number of construction problems must be solved, e.g. strengthening the bridges and chassis, choosing the suitable pneumatics and ring, securing a particular degree of stability, realizing the most favourable arrangement of graded gearbox speeds, etc. All these tasks emerged from the demands of satisfying the exploitation and technology factors.

In order to substitute the imported equipment as one of its goals, the projects must establish the following aims in the field of technical problems:

- to make the objectively best choice of machine components,
- to improve utilization of new machines in logging operations,
- to improve the criteria and guides for designing, building, testing and evaluation of machines.

Sometimes a starting point of this theoretical analysis is the historical background of a certain group of equipment in terms of their known structural, logging and other properties. Always theoretical research and evaluation was aimed at finding regularities in the development of mechanics in forestry. There are even opposite results shown in lower performance resulting from the obvious circumstances and that eternal question to be answered by designers when it goes for logging: **"Which of the two answers is correct?"**; for example, at using a skidder we sometimes decide through performance and energy consumption indirectly including the slipping parametar, but, more embracing research would require knowing the pull components, the parameters as utilization factor of load, skidding factor, one-end suspended factor, tractor pull factor, usability of horizontal component of the skidded load etc.

All tasks of Department of Mechanical Engineering from the Faculty of Forestry had one thing in common - **the results of given technical issues had to be a bridge connecting forestry and mechanical engineering production.**

Testing of equipment and vehicles has been lab/exploiting. The former was used for ergonomic testing and determination of engine power, centre of gravity (both tractor alone and with implements), pull, load frequency, top load etc.

Finally, results of the research in the field of skidding with new devices are conditions and economy of their use in the actual processes. Testing has primarily been directed to checking and adjustment of international procedures of investigating the ergonomic and technical parameters. The various tasks are:

- speed range (forward - backward),
- differential locking device,
- need for different speed of front and rear axle (outstripping of axles),
- problems of frame articulated vehicle stability,
- energetic suitability,
- impact of the all-regime regulator of revolution etc.

INVESTIGATION AND OTHER RESULTS

Evaluation of agregates, above all winches, hydraulic cranes, clam bunk, pumps, valves, steering system etc., must be done so that optimal technological requirements are tested.

At skidding or forwarding vehicles there are the wheel/ground system issues, e.g. the usability of wheels, the achieved pull factor, load redistribution, wheel slipping limit, soil compaction etc.

Clam bunk with hydraulic knuckle boom crane

The purpose of developing the clam bunk with hydraulic crane was to produce an attachment to most common farm tractors equipped with the three-point hitch of categorie 1. This wheeled tractor itself should be forestry equipped and have a sufficient hydraulic flow and lifting power to lift and carry wood suspended and by the grapple`s jaw. It brings whole trees, stems, logs etc. to the strip road where forwarders or trucks take over.

The project enables the attachment of implement (clam bunk with loading boom) to the rear of agricultural wheeled tractors by means of a three-link hitch in association with a power lift, giving basic technical properties: power lift capacity of clam bunk 600 kg, max. moment of crane 3 kNm, skidding load 0,6 m^3, transport height 820 mm, average skidding distance 30 m, expected daily effect 30 m^3/d, weight of implement ca. 340 kg.

Since 1973 hauling of wood thinning operations was started with s.c. "Pioneer-equipage", Sever (1987), but only at lowland on level ground. Sometimes there have been two steps at wood transportation by skidding;

1. Bunching of wood from a stand perpendicular on the strip road (manually, with horses or with some mechanical devices)
2. Forwarding of bunched wood at landing with forwarder or tractor with semitrailer.

Only in old stands it was possible to bunch and forward in one operation. Prerequisite for the method with two steps is a developed net of strip-roads and good hauling equipment. That was the reason for designing new implements.

At choosing the commonest farm tractors with three-point linkage, it was decided on the wheeled farm tractor IMT 539 (MOTOR AND TRACTOR INDUSTRY, Belgrade). Some problems with safety and stability occured with the tractor IMT 531, specially prepared for wood skidding with double-drum winches or grapple. Some general features of the tractor: engine 28,7 kW at

2000 min^{-1}; speed range 6 forward, 2 reverse; hydraulic system: lifting power 817 daN, oil pressure 175 bar, oil capacity 12 L/min; length 2975 mm, width 1625 mm, ground clearence 321 mm, wheel base 1830 mm, wheel tread rear 1200 to 1900 mm; weight 1440 kg (without cab).

The attachment of forestry equipment to the rear of agricultural wheeled tractor by means of a three-link hitch in association with a power lift is well known at logging (winches, cranes, silvicultural implements and equipments etc.). Each link is articulated to the tractor and the implement (clam bunk with crane) at opposite ends, in order to connect the implement to the tractor.

At the moment of loading stability is provided with two supports 162,5 cm apart. Front axles must be provided with about 240 kg weight for safe steering. Dimensions of two lower links for attachment of mounted implements are reduced from the standard 800 mm to 640 mm, which decreased the transfered load from the front to the rear axle. A weight 250 kg on the front axle increased the stability of the tractor. The height of the crane over the cab is a problem at tractor`s moving in stands, but turning and clearance diameters (radius) remain satisfactory.

Exept some ergonomic characteristics, the following was established: center of gravity, tightening force of jaws, real lift force of three-point linkage, technical characteristics of crane, soil characteristics on the pulling trial ground etc.

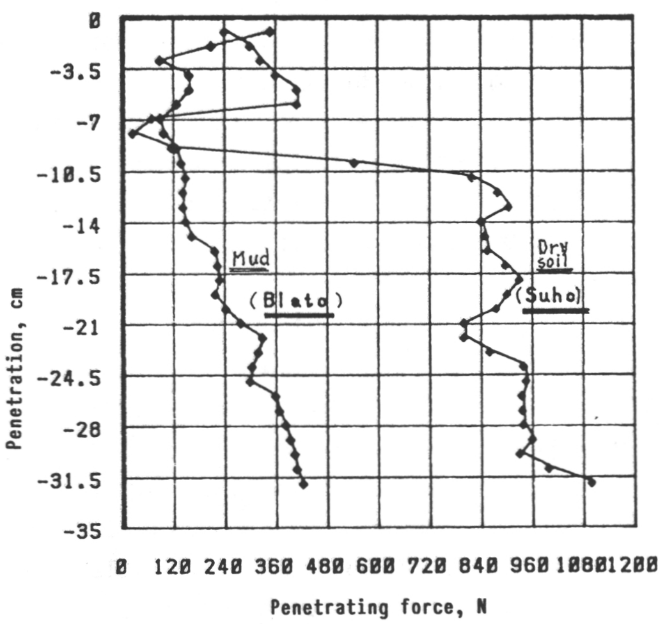


Figure 1. Relationship between penetrating force of conepenetrometer and penetration

Pulling trial has been carried out at wood skidding on dry or wet and soft ground. Fig. 1 shows the relationship between penetration and penetrating force for both dry soil and mud. Cone characteristics are for the ground outside the wheel rut. For the depth of about 7 cm the influence of root and other skeleton is obvious. Left curve for mud is during the experiment finished on 45 cm, the dry soil curve in spite of the increasing force, on 32 cm depth (effect of s.c. sole of the foot).

Tables 1 and 2 shows results of pulling trial, the first for dry soil and the second for wet soil.

Table 1. Parameters of pulling trial with farm tractor equipped with clam bunk and hydraulic crane attachment on three-point linkage on dry soil

F_H	M	P_p	F_t	δ	ϰ	η_w	G_a	μ_s	Q_f	Q_r	P_t	f	V	η
kN	kNm	kW	kN	%	-	-	kN	-	kN	kN	kW	-	m³	-
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0,06	0,35	0,08	0,61	6,16	0,03	0,10	19,74	0,07	0,93	0,98	0,84	0,02	0,1955	0,13
0,95	1,25	1,09	2,17	1,51	0,09	0,43	24,62	0,23	4,02	4,07	2,54	0,04	0,7569	0,50
0,76	1,11	1,10	1,93	1,50	0,08	0,39	22,91	0,27	2,94	2,84	2,83	0,04	0,5604	0,45
0,36	0,70	0,54	1,21	5,09	0,06	0,28	21,42	0,18	2,01	1,96	1,92	0,03	0,3652	0,33
0,41	0,58	0,68	1,01	7,62	0,04	0,38	24,68	0,12	4,07	3,49	1,82	0,02	0,7356	0,45
0,37	0,86	0,58	1,50	5,59	0,07	0,23	22,20	0,22	2,50	1,67	2,49	0,04	0,3784	0,30
0,48	0,78	0,75	1,36	3,06	0,06	0,35	23,77	0,19	3,48	2,60	2,17	0,03	0,6725	0,42

Table 2. Parameters of pulling trial with farm tractor equipped with clam bunk and hydraulic crane attachment on three-point linkage on soft and wet soil

F_H	M	P_p	F_t	δ	ϰ	η_w	G_a	μ_s	Q_f	Q_r	P_t	f	V	η
kN	kNm	kW	kN	%	-	-	kN	-	kN	kN	kW	-	m³	-
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0,24	0,84	0,39	1,48	13,16	0,7	0,14	19,74	0,25	0,93	0,98	2,71	0,05	0,1955	0,17
1,52	1,91	1,92	3,35	11,20	0,14	0,40	24,67	0,37	4,02	4,07	4,77	0,06	0,7569	0,47
1,40	1,97	1,82	3,46	12,87	0,15	0,35	23,11	0,49	2,94	2,84	5,14	0,07	0,5604	0,41
0,83	1,69	1,13	2,97	11,73	0,14	0,25	21,46	0,42	2,01	1,96	4,56	0,07	0,3652	0,29
0,84	1,50	1,27	2,64	14,55	0,11	0,27	24,69	0,24	4,07	3,49	4,68	0,06	0,7356	0,35
0,90	1,64	1,34	2,87	23,07	0,13	0,24	22,20	0,54	2,50	1,67	5,56	0,07	0,3784	0,29
1,00	1,65	1,37	2,89	16,64	0,12	0,29	23,76	0,38	3,48	2,60	4,77	0,06	0,6725	0,35

In tables 1 and 2 there are symbols for forces, energy and other parameters. They are:

1 - F_H = Horizontal component of tractive force, kN

2 - M = $M_l + M_r$ Sum of left and right torque on wheel, kNm

3 - P_p = $F_H \cdot v$; v=s/t; From the measured traveling distance and time is calculated the speed, which, multiplied with the horizontal force, results in the pulling power P_p, kW

4 - F_t = M/r_{st}; Tangential (peripheral) force of tractor wheel, W

5 - δ = Slip (calculated from real travel distance and theoretical distance; measuring with fifth wheel and inductive transducers on tyre), %

6 - $\varkappa$ = $F_t/G_{adh} = (F_H + F_f)/G_{adh}$ S.c. gross tractive factor

7 - η_w = $\eta_f \cdot \eta_\delta = (1-\delta) F_H/F$ Traction efficiency, s.c. wheel efficiency

8 - G_{adh} = $G_r + Q_f + G_f'$ Adhesive loading of tractor (sum of rear axle weight of tractor, part of vertical load of timber transfer on tractor and transfered load from the front to the rear axle), kN

9 - μ_s = F_H/Q_r Resistance coefficient of wood skidding at one-end suspended

10 - Q_f = Part of vertical load transfer on tractor, kN

11 - Q_r = Part of vertical load transfer on ground, kN

12 - P_t = $M \cdot \omega$ Power of wheels, kW

13 - f = $(F_t - F_H)/G$ Rolling resistance; G is overall tractor weight

14 - V = Volume of skidded wood, m³

15 - η = $(P_p + P_{ft})/P_t$ Skidding efficiency (ratio of the sum of pulling power and rolling resistance of suspended timber and tangential power).

As comment of tables 1 and 2, it can be said that slip on dry soil is between 1,5 to 6,2 %, and on wet soil from 11 to 23 %; traction efficiency on dry soil is between 0,1 to 0,43, and on wet soil 0,14 to 0,4; resistance coefficient of wood skidding with one-end suspended on dry soil between 0,18 and 0,27, and on wet soil from 0,25 to 0,54.

Some physical quantities determine dependencies between the skidded volume and the weight of wood. Fig. 2 shows equalization of two vertical parts of skidded load; supported from the tractor and supported on the ground. The range of the measured loads clearly shows that over half of the load is supported by the tractor.

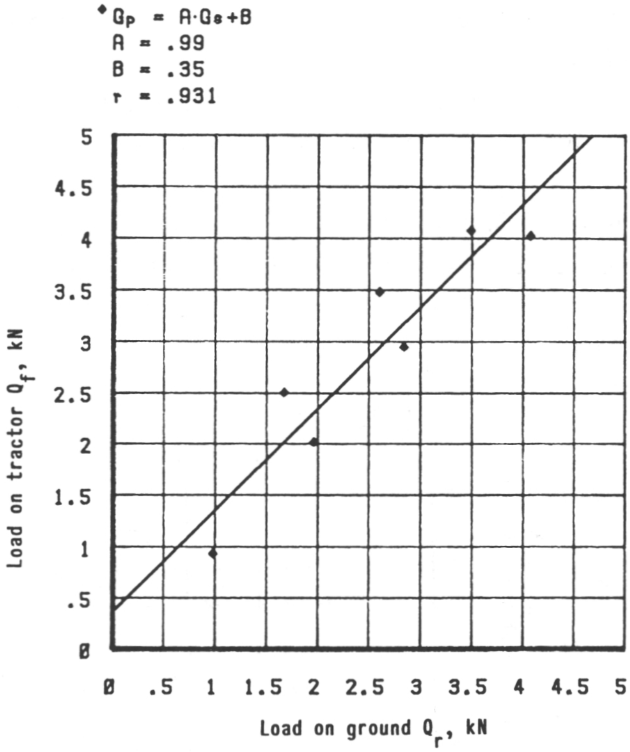


Figure 2. Relationship between supported load from the tractor and supported on the ground

Investigation of the relationship between the ground wood load and the volume of wood is shown in fig. 3.

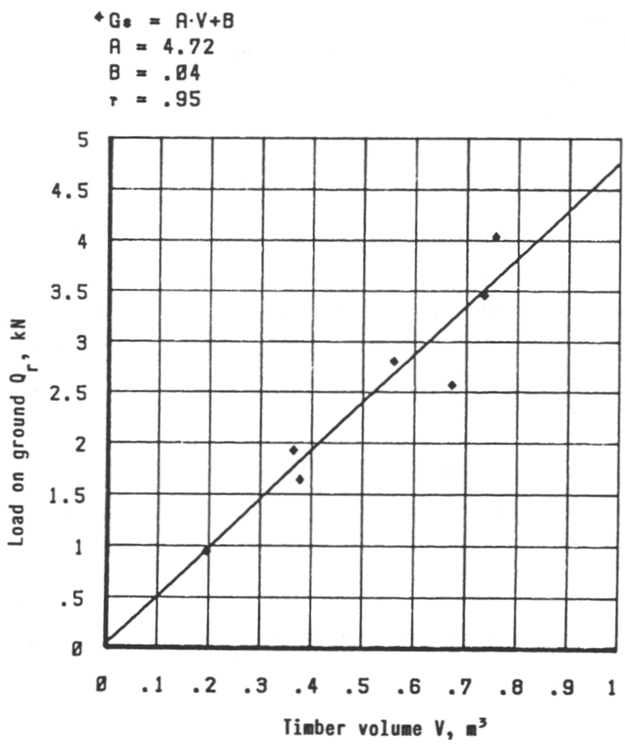


Figure 3. Relationship between the ground wood load and total volume of wood

The equalization indicates straight line together with the fact that the correlation coefficient is significantly high (correlation coefficient is 0,95). That is the reason for all further relations between important technical parameters and volumes of skidded timber.

On the dependencies shown in fig. 4 to 8, left side is correlation for wet soil and right side for dry soil. All trends are shown by line equalizations. The results are preliminary.

Fig. 4 shows the regression equalization of the functional dependence of the horizontal component of tractive force F_H and the volume of skidded wood. The correlation is strong. The analysis of the relationship shows a steeper line for the tractive force on dry soil.

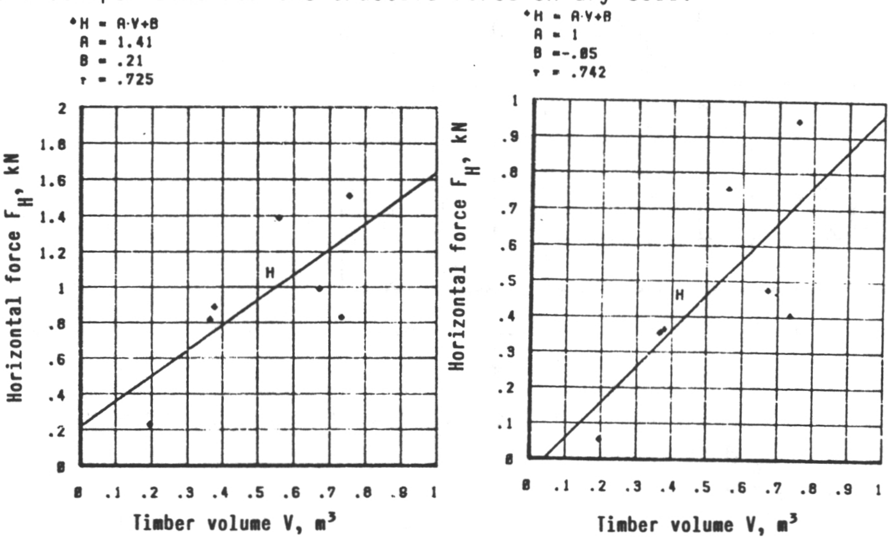


Figure 4. Relationship between the horizontal component of tractive force and the volume of skidded wood (left - wet soil, rihgt - dry soil)

Fig. 5 shows the results of the regressive analysis of the dependence between the wheel torque and the skidded volume, both for wet and dry soil. As for other equalization, separate groups belong to the classes defined by statistical tests. In the same manner all values of the test were equalized with the curve type $M = A \cdot V + B$. For all values, the needed torque is higher for the pulled wood on wet soil. It is interesting that the correlation coefficient for dry soil is lower.

Fig. 6 is the analysis of the relationship of the gross tractive factor (the so-called specific force) and the volume of the skidded wood. The biggest value of the tractive factor for all trials was 0,15. The examination results obtained show that skidders have a large mass (specific mass of tractors is high) and adhesive weight is increased with suspended load, Sever (1984), Hassan et al. (1986).

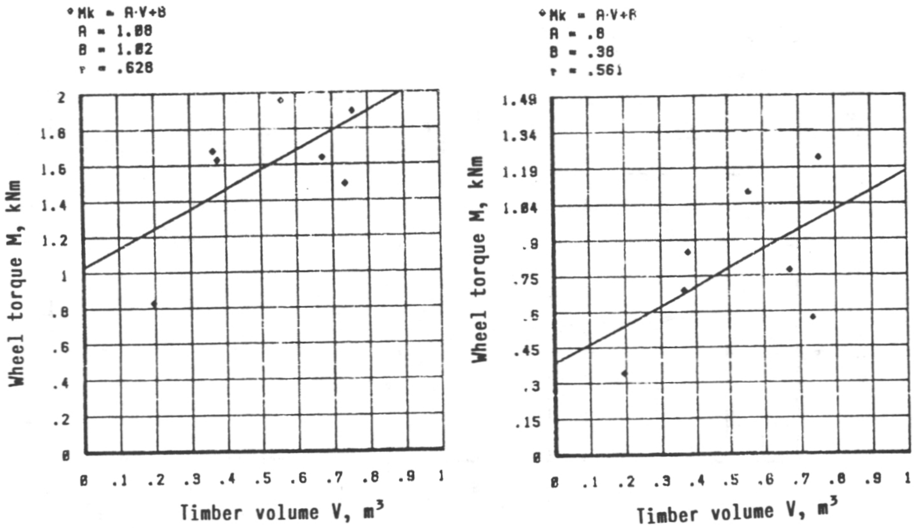


Figure 5. Relationship between wheel torque and the volume of skidded wood (left - wet soil, right - dry soil)

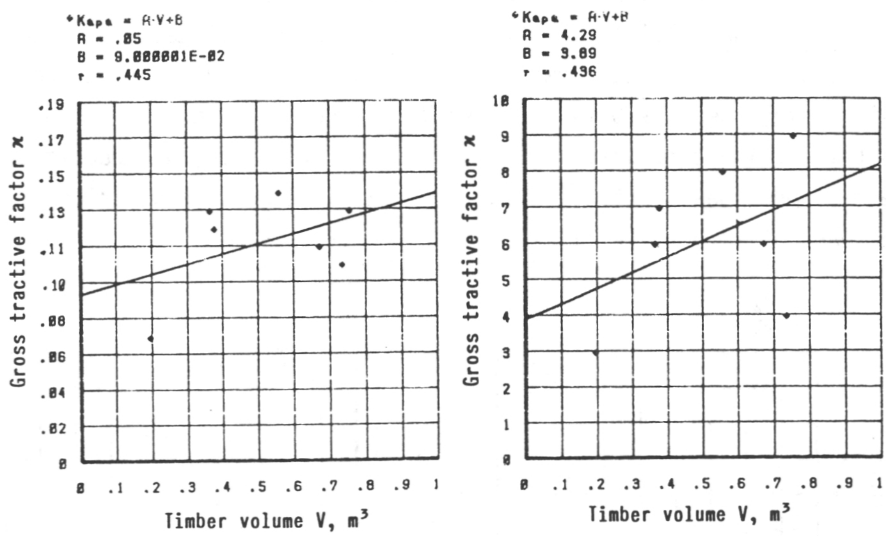


Figure 6. Relationship between the gross tractive factor and the volume of skidded wood (left - wet soil, right - dry soil)

The study of the resistance coefficient of wood skidding with one-end suspended for wet and dry soil for the first time shows different trends; for wet soil it is undependable, may be with a trend of decrease, and for dry soil it is established that the coefficient of correlation is 0,436. For the increase of the resistance coefficient as related to the increase of the hauled timber volume see fig. 7.

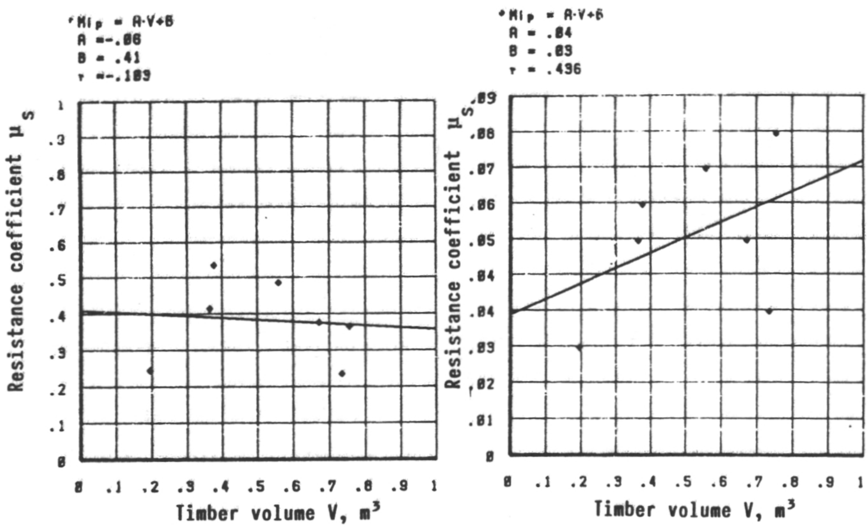


Figure 7. Relationship between the resistance coefficient of wood skidding with one-end suspended and the volume of skidded wood (left: wet soil, right: dry soil)

Skidding efficiency is an unknown parameter in literature. The idea was to express the rolling resistance of tractor and skidded wood together in the ratio with the wheel power. Fig. 8 shows the results of the regressive analysis of dependencies between these knew parameters and the volume of the hauled timber. The correlation is very strong. Straight line equalization on wet terrain produces coefficients of correlation 0,867 and 0,937 on dry soil. The increase of skidding efficiency on dry soil is steeper.

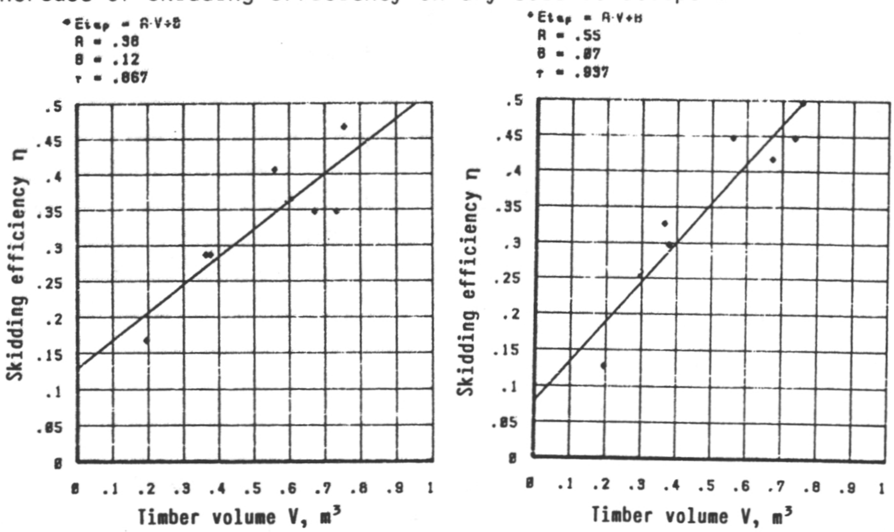


Figure 8. Relationship between skidding efficiency and volume of skidded wood (left - wet soil, right - dry soil)

In the field of pulling trial, the average soil moisture contents on dry soil ranges from 13,6 to 16 %, on wet terrain from 18 to 22,1 %, and in mud from 17,7 to 31,9 %, always decreasing from the surface to deeper levels of the ground.

M i n i - s k i d d e r

In order to find a small vehicle for extraction of thinning wood, a project was started for building a little track tractor, the so-called mini-skidder, or "iron-horse", or "mechanical horse", or "cutting ant", or "log caddie", or "goliat", etc. It was a tractor like the mini-skidder described by Karlsson and Risberg (1987), Nordfjell (1986), Risberg (1988), and many other authors.

As said in the introduction, there exists a need for suitable techniques adapted to specific conditions of thinning. It must be a device (vehicle) for handling trees of small dimensions in stands, primarily on flat grounds similar to Scandinavian countries in the last decades, used by contractors and woodlot owners. At this moment, extraction of thinning wood in Yugoslavia due to big and heavy base machines, which need great investments, relatively high annual costs, have a bad impact upon the stand from the biologic point of view, cannot be accepted.

All this has led to the development of special small dimension forest techniques for slightly soft, level grounds, stands with low stumps, and open stand conditions. Two years ago, a project was presented of the desired mini-skidder with optimal features.

The major use was planned in the man-machine system where bunching is desirable in the work operation system along the strip road. The real reason for that was the actual increase of the proportion of wood supply from thinning operations in Yugoslavia in the last ten years. With the existing technologies the working conditions at skidding of small dimension trees or logs or industrial wood, to the strip road are difficult and hard, always with high frequency of damage of the remaining trees and ground. This means that machines must be designed for specific use as small-scale systems in which skidding of trees or tree sections is included using either clam bunk skidders or mini forwarders, always hoping for very low damage.

To evaluate the economic convenience of small-scale techniques in thinnings was our next task. In order to provide a complete picture of the costs associated with any system used in thinning operations, the following factors should be considered:

- the effect of the stand`s size
- transportation distance between thinning sites (the moving costs)
- the effects of biological and mechanical damage on the future development of the remaining stand
- the proportion of home-produced and imported machine components.

When defining and describing the mechanical horse (mini skidder), it can be regarded as a track machine, small enough to be transported in a pick-up truck. It is a low-powered walk-along unit, designed in Sweden for different use, but for our purposes it is the best at skidding wood out of thinned stands. It is now also possible to equip them for **skidding of wood, or carrying of one stacked cubic meter**, or for pre-bunching along skid trails - always on sensitive terrain (problem of ground rutting at work with larger equipment). This machine is interesting for fuelwood harvesting too. It is interesting to remark that the operator walks in principle along or in front of the machine controlling the speed with a dead man throttle, located on the handle.

Desired performances of the mini skidder are given in a few points:

- Ability to surmount obstacles in a young forest stand - desired height: 40 cm (real 25 cm).
- Tilting angle - unloaded to 100 %, loaded to 80 %.
- Turning radius (rotation around the machine`s center point) - loaded and unloaded about 1,5 m.
- Tractive force - 8 kN.
- Speed range - 0,2 to 2,5 m/s.
- Ground pressure - loaded, less than 10 kPa.
- Sizes of the loads, on the average - 0,64 m^3f biomass.
- Load box for tools, e.g. chainsaw etc.
- Light winch for winching; large stems can also be loaded with the help of the winch.
- Machine reliability at work enviroment.

Fig. 9 shows the prototype 2 of the mini skidder. The main parts of the skidder are: motor section, flexible load bunk, control handle, tracks, transmission, winch etc.

Engine - 4-stroke, air cooled, diesel system, hand starting, 1 cylinder, 7,3 kW at 3000 min^{-1} (DIN 70020: B DIN 6270 6,6 kW; A DIN 6,0 kW; SAE J816 9,4 kW)
Torque 28 Nm, fuel consumption 255 g/kWh, weight 57 kg

Clutch - dry coupling

Gears - 4 forward, range 0,78...7,00 km/h
2 reverse, range 1,63...3,25 km/h

Steering - with planetary gears placed in track wheel, driven by band brake at gears moving the handle left or right. Turning radius is small with simultaneous braking and coupling.

Turning radius - less than 1 m (outside)

Brakes - mechanical with band

Inclination - uphill with load 80 %

Tracks - rubber 10 mm thick with steel treads, contact ground area 0,3724 m^2

Dimensions - length with handle 2,7 m
only skidder 2,15 m
width 980 mm
height with cab frame 1850 mm

Additional building - A: for forwarding 1 m^3 fuelwood 1200·(820...900) mm
B: Skidding industrial wood 3...5 length, wood area 0,64 m^2

Winch - 1 drum with planetary gears, pull 12 kN,
speed 0,71...1,58 m/s

Weight - overall 660 kg

Other assignment - transportation of fuel, tools, accessories etc. at off-road transportation on short distance.

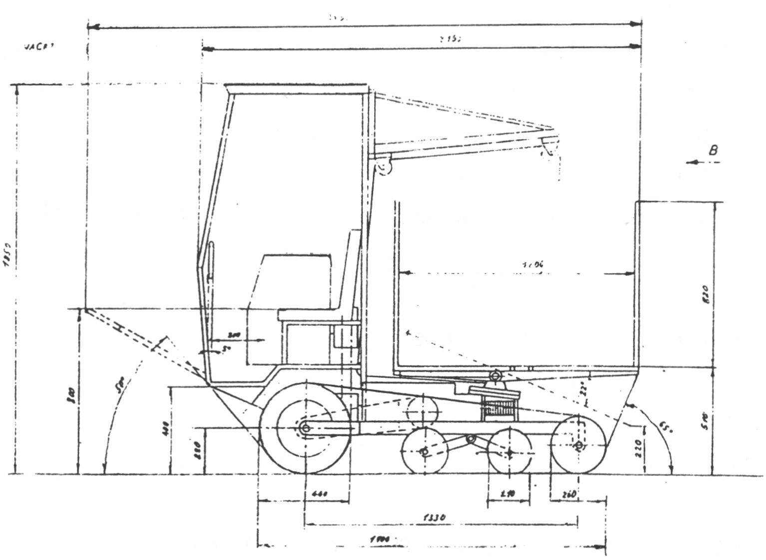


Figure 9. Schematic review of the prototype number 2 of mini skidder

As a **conclusion** some positive and negative aspects of designing the mini skidder can be repeated: as a general feature, it is useful in thinning, pre-bunching, fuelwood harvesting, all for small diameter (less than 20 cm); suitable for flat ground or gentle slope; causes little damage to residual trees; low ground pressure; low center of gravity; light steering with movement of handle which transmits drive to the appropriate track causing the vehicle to turn; low level of investment etc.

The system is expected to provide the basis for a biologically sound thinning operation as it is both small and manoeuverable, environmentally soft, a comparatively cheap machine unit.

During the trials the machine experienced some mechanical problems, especially with the winch, with the track, brakes and the operator`s comfort. The concept has proved to be interesting in both advanced and unadvanced enterprises.

Medium-sized skidder

Megille (1957) as many other authors carried out correlation between power and weight of tractors and dimensions of skidded wood. At skidding operations some devices and equipment help in bunching of small size timber (Tanasković, 1989), e.g. two drum winch, chokers, hydraulic operated grapple, clam bunk with crane etc.

Thinning operations of forest stands make about two thirds of all operations in even-aged forests, in terms of work duration, workers employed, and means of work (Tomanić, 1989). Of all annually cut wood in even-agen forests, sometimes 65 % is thinning wood.

Thinning system used in shortwood logging operations is usually combined from:

- Conventional motor-manual felling and processing (cutter),
- Bunching with mini skidder or clam bunk mounted on a farm tractor (skidder operator),
- Off-road transport with forwarder, clam-bunk skidder, farm tractors with semitrailers etc. on strip road (wood forwarded or skidded to the landing),
- Piled deck in road landing as prepared for truck loading
- Transportation with trucks with trailers or truck-tractor with semitrailer.

Conditions for strip road; they must be placed without wet areas, should be kept away from strong side slopes, big boulders, steep areas etc.

In thinning operations the trees are usually felled, limbed and bucked into 3...5 m lengths prior to skidding. The piles are placed at the end of skid trails with a horse, mechanical horse or some other mechanical device, where a larger machine takes over. This larger machine in thinning operations can be a tractor with the wheel formula 4WD (4 wheel drive), width of only 1,6 m and light weight, with a possibility to work in a stand without harming the remaining trees.

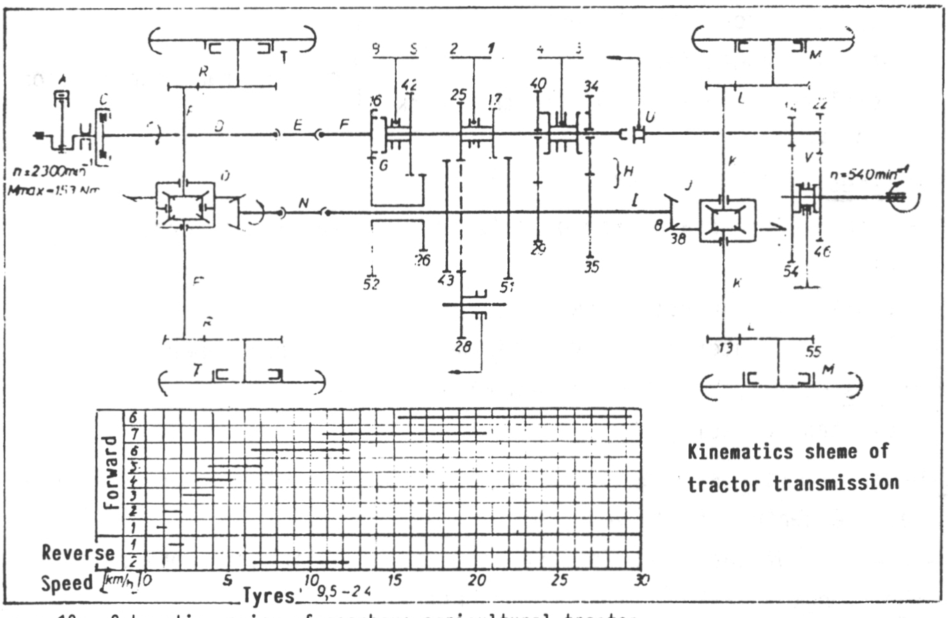
In finding adequate components we started with agricultural tractor series S-1000, type T-1033 from the "T.V." manufacturer in Bjelovar. Exept for some parts of transmission and accesories, other components were usable on forestry tractor.

Mechanical features of the designed medium-sized tractor with a selfcarrying structure;

Engine - Torpedo F 3L 912, 4-stroke, 3-cylinder in line, air cooled, diesel, direct injection, 33 kW at 2300 min^{-1}, torque 154 Nm at 1600 min^{-1} 220 g/kWh

Clutch - dry, friction, single disc, spring loaded

Mechanical transmission - gearbox with 6 speed forward (from 1,18 to 19,2 km/h) and 2 speed reverse (3,66 and 19,2 km/h); a range of speed must be changed because of a problem in the second reverse speed (insufficient pulling force); fig. 10a.



Kinematics sheme of tractor transmission

Figure 10a. Schematic review of gearbox; agricultural tractor

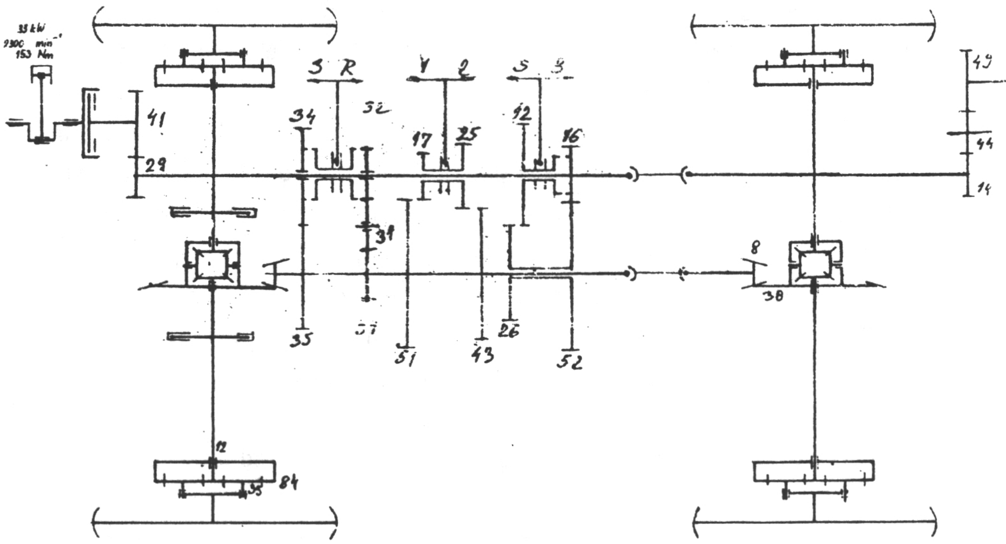


Figure 10b. Schematic review of gearbox; skidder

Differential gearing - mechanical manually locked gears hanging foot pedals, front and rear, automaticaly switch off; ratio 1:4,1

Final reduction - planetary gear in wheel hub, ratio 1:8 (!)

<u>Steering</u> - Articulated frame type, lever-operated hydrostatic steering,
e.g. orbitrol servo steering
steering angle $\pm 42^{\circ}$
vertical angle 18...20° (in the knick)
} center frame oscillation

<u>Weight</u> - 3500 kg

<u>Standard tyres</u> - 12,4/11-24 8PR

<u>Brakes</u> - main: center brake type on axles dual hydraulically controlled disc
auxiliary: exhaust brake
parking: center brake type, mechanical lock, hand operated

<u>Hydraulic system</u> - hydraulic pump, external gear pump
oil tank capacity 25 L

<u>Load capacity</u> - every axle equal to all load capacity of tractor (3500 kg)

<u>Knick</u> - at the center of the vehicle;
- locking of the knick for the time of hydraulic crane operation

<u>Protection</u> - engine, axles, other components

<u>Cabin</u> - safety, good view all around

Dimensions - wheel base 1800 mm
ground clearance 400 mm
width 1600 mm
turning radius about 5 m (outside tyre)
overall length, height etc. different for three types

Blade - on the front part of tractor

Variant A: CLAM BUNK SKIDDER; clam bunk 0,7 m²; width of jows about 1200 mm
horizontal angle 2x20^{O}, vertical: forward 15^{O}, reverse 20^{O}
hydraulic crane 25 kNm, fig. 11; grapple 0,2 m²

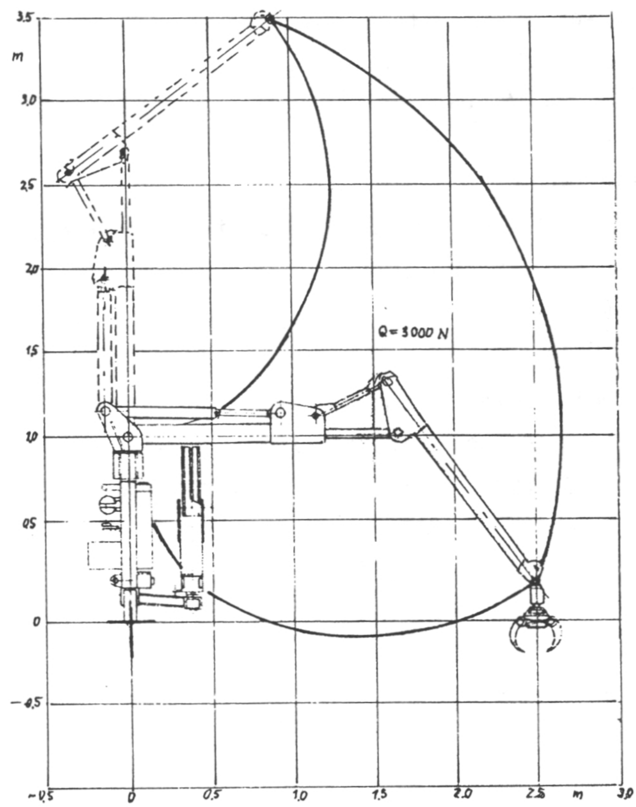


Figure 11. Diagram of hydraulic crane

height of piling 2 m
knuckle boom design
maximum reach 3,4 m
net load 400 kg
height of reach: +2 m, -1 m
slewing 220^{o}
pump 11 L/min at 600 min^{-1} of engine (separate unit)
task: to pile the logs on the landing
pressure: relieved constant pressure

Variant B - SKIDDER
winch: two-drum type with paralel axles
elec.-hydraulically controlled
line pull 2x35 kN (bare drum)
line speed to 1 m/s
drum capacity 60 m, dia. 10 mm
fair lead: 3 rollers mounted on sealed ball-bearings

Variant C - MIDFORWARDER (only project)
load capacity 5...6 t
hydraulic crane 30 kNm

At the moment variant A and B are on the field testing. Some features are important for used tractors on skidding operations; axles locked, knick locked, robust design, low torque in gearbox, low revolution of motor at the time of pump operations etc.

C O N C L U S I O N

Small scale techniques at thinning operations cause a number of construction problems which had to be solved in the course of their adaption, e.g. choosing the suitable engine, tyres, tracks, transmission components, etc., strengthening the chassis and axles, securing a particular degree of stability, realizing the most favourable arrangement of graded gear box speeds, etc.

It is important to make choice of equipment according to the following criteria: national/foreign, modality of foreign equipment.

The next task is taking part in organization of equipment manufacture, optimization of work regime, level of control, energetic consumption etc., as a legislation of products (standardization, occupational safety, typization).

The horse stays in the forest; the wish is, however, to design mechanical devices flexible and light like a horse, as the only possibility for small scale techniques for thinning, which will compete sucessfully with other equipment in certain forest operations and under certain conditions.

We wont to combine power, economy, and environmental preservation in logging. For better future generations of machines, we would like to make the equipment that will not damage the soil, is energy-saving and does not pollute the environment.

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PLANNING OF MECHANIZED THINNING IN NEW ZEALAND PINUS RADIATA PLANTATIONS

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ABSTRACT

New Zealand has had limited experience with fully mechanised thinning systems to date. Most of the experience has been gained since 1986.

Planning of mechanised thinning systems can be categorised under three broad levels - strategic, tactical and operational.

Factors considered at the strategic level include markets, silvicultural regimes, and harvesting systems; at the tactical level include terrain and tree characteristics, people, product quality, site damage, performance capabilities and capital costs; and at the operational level include the importance of the operator in decentralised planning, training operators, supervisors and foresters in logging planning and establishing reporting, control and feedback mechanisms.

Key words: Mechanised thinning, planning, Pinus radiata

I N T R O D U C T I O N

Mechanised systems account for less than 10% of the thinning volume harvested from New Zealand's forests (Galbraith and Vaughan, 1989). Because of the volume of clearfelling this equates to less than 2% of the total volume harvested.

The change in attitude of the pulpmills to Pinus radiata thinnings wood - in recognition that it's special characteristics are highly desirable for certain products - suggests that thinning volumes may increase substantially. Although traditional motor-manual harvesting systems have served New Zealand well in the past, and are continuing to do so, it is expected that mechanised systems will play a greater role in the future. The economics are delicately balanced and quite small changes in labour availability and cost could tip the scales in favour of more mechanisation.

Although highly mechanised harvesting systems were introduced to New Zealand clearfelling situations in the late 1970's and a number of valuable lessons learnt (Terlesk, 1982) it was not until the mid-1980's that serious attempts were made to mechanise thinnings. Since 1986, the following new machines have been introduced to thinnings -

- Bell feller bunchers
- Waratah delimber feller buncher
- Denis and Harricana stroke delimbers
- Lako and Waratah single grip harvesters
- Volvo forwarder.

There is currently only one fully mechanised thinning operation in New Zealand - a Waratah delimber feller buncher, a Waratah processor, and a Volvo forwarder supplying shortwood for a new reconstituted board plant in Kaitaia, Northland (Raymond, 1989a).

Although New Zealand has limited experience with mechanised systems in thinning, certainly compared with Scandinavia, we are rapidly "climbing the learning curve". This consideration of the planning aspects of mechanised thinning is is based on our own New Zealand experience, the imparted wisdom of two Swedish researchers who have worked with us at the Forest Research Institute (Stig Andersson and Assar Johansson) and detailed studies, by New Zealand researchers, of mechanised thinning systems in Australian Pinus radiata plantations.

P L A N N I N G L E V E L S

Planning, for many activities, can be broken down into three levels - strategic, tactical and operational (Hill, 1981). These are usually related to a time horizon and become more focussed as the horizon gets shorter, i.e. strategic planning is generally long term (5-10 years) in nature, tactical is medium term (0.5-5 years), and operational is short term (<0.5 years). The planning at each of these levels is often done by different people. Planning for mechanised thinning operations can also be categorised at these three levels.

Strategic Planning

In April 1989 IUFRO Division P4.02.02 held a conference on "New Approaches to Spacing and Thinning in Plantation Forestry". The conference highlighted the large differences in attitudes to silvicultural management between New Zealand and European countries. It also highlighted that considerable differences existed within New Zealand. The debate over commercial versus non-commercial thinnings was extensively covered. The debate ranged over such topics as

- stand layout
- land taken out of production by tracks and landings
- mechanical damage to final crop trees - particularly pruned trees
- the effect of delayed commercial thinning on rotation length and economics
- wind damage after commercial thinning
- supply requirements.

If, after consideration of the relevant factors, a commercial thinning is anticipated then strategic planning might address such issues as timing of thinning, what type of terrain should be commercially thinned, mill infeed requirements, transportation infrastructure, and so on. Linked with these issues is the broad selection of suitable harvesting systems (e.g. motor/manual, mechanised, cable).

A consideration which is often overlooked is the layout of the stand to be harvested. The Forest Research Institute, over the last two decades, has established a series of stand reorganisation (layout) trials in an attempt to improve the economics and performance of the commercial thinning operation. These have been described in detail by Terlesk et al (1983, 1988). The synergism of group planting and mechanised thinning has recently been suggested by Terlesk (1989). Since we believe the concept is both novel and exciting for what it promises a brief explanation will be given here.

Stand reorganisation

Figure 1 shows our current thinking on the layout and management of groups (cf. row planting layouts). Two hundred groups of four trees would be established on each hectare. At age 4 all trees would be low pruned to 2 metres. At age 6 two trees per group would be medium pruned to 4 metres. At age 7 to 8 the best tree per group would be high pruned to 6 metres. The commercial thinning would then be scheduled for age 9 to 11.

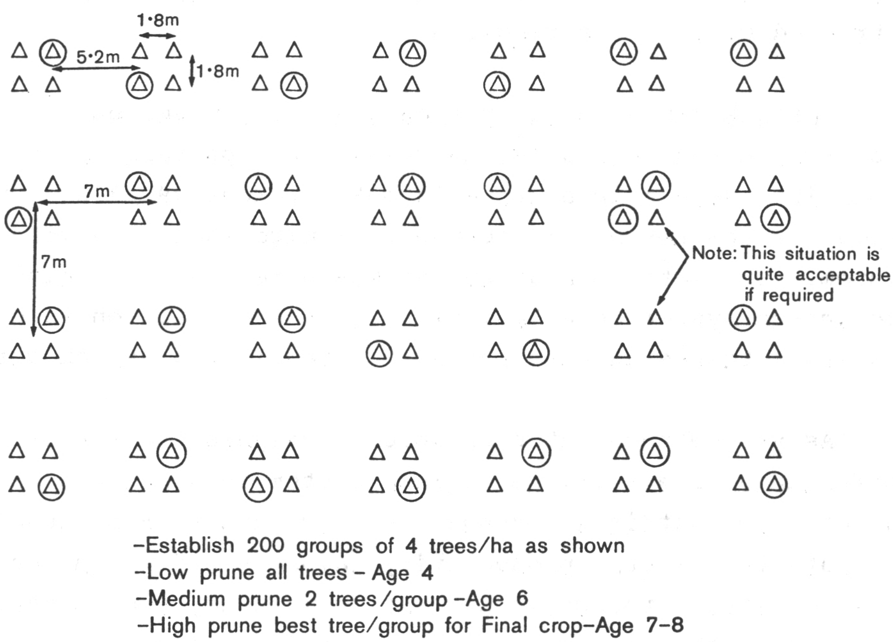

Figure 1. Group layout concept.

The objectives of the group layout are to

- improve the load accumulation phase
- minimise the mechanical damage to the final crop
- protect the pruning investment by carrying out the thinning at an early age
- cover the cost of commercial thinning.

Although conventional row planting does not stop the use of mechanised thinning systems many of the group layout stand characteristics should enhance the performance of mechanised systems. Such characteristics include clear, well defined working and concentration corridors, regular and relatively wide (c. 7 m) espacement of the final crop, concentration of the removals, a suitable tree size (0.2 to 0.3 cu. m.), delimbing slash concentrated within the corridors reducing the impact of the harvesting machinery on the site, and marking stems to be extracted will not be required.

Terlesk (1989) used synthesised data, based on information from Sweden and Australia, to compare the performance of a mechanised system in a group layout - Lokomo 990/762 single grip harvester and Lokomo 910 forwarder - with that of a motor manual system. The motor manual system was more cost effective than the mechanised system selected, although the conclusion is quite sensitive to the assumed production levels and system costs.

As yet we have not been able to compare the actual performance of a fully mechanised system in a group planting layout with that in a conventional row layout. Best guestimates indicate that system productivity gains should be in the order of 10 to 15%. Interactive simulation methods, incorporating stand maps, thinning prescriptions, and model harvest vehicles such as those described by Stuart (1981) and Fridley et al (1985), should allow us to refine these estimates.

T a c t i c a l   p l a n n i n g

A number of factors have to be considered in the tactical planning phase for mechanised thinning.

Terrain

Ground based mechanised thinning systems work on slopes up to 30 degrees in Australia but a sensible slope limit is considered to be about 20 degrees (Raymond, 1989c). The further development of "walking" backhoes fitted with feller/ /delimber/bucker harvesting heads and multi-legged walking extraction machines may see this limit extended in the future (Mann et al, 1985). Until recently cable logging thinning systems have been used on steep slopes in New Zealand but have now been abandoned because of high cost.

Tree characteristics

Tree size is one of the key characteristics affecting machinery productivity and unit costs. For example, generalised production curves for a single grip harvesters working in easy conditions are shown in Figure 2. Raymond (1989c) has presented tree size vs.long term productivity tables for a range of mechanised thinning machinery in Australia. Terlesk (1989) estimated that unit costs for a mechanised thinning system based on a Lokomo 990/762 harvester and a Lokomo 910 forwarder would be NZ$7.80 greater for a tree size of 0.2 than for 0.3 cubic metres (NZ$30.00 vs. NZ$22.20) .

Tree form (straightness, presence of multiple leaders) effects the productivity of processors. Generally slide boom delimbers work better than feed roll type processors in trees of poor form (Galbraith and Vaughan, 1989; Raymond, 1989c). Feed roll type processors are generally more productive in trees of good form however.

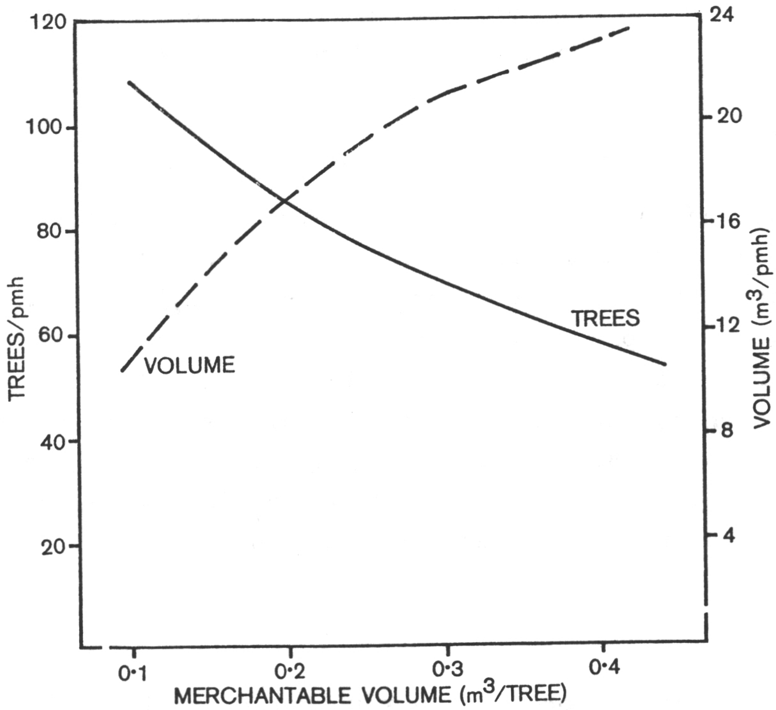

Figure 2. Generalised productivity curves for single grip harvesters.

The silvicultural regimes practised in New Zealand Pinus radiata plantations usually result in large branches even at the time of thinning. Depending on soil fertility some sites produce larger branches than others. Branch size is a very important determinant of the suitability of mechanised systems. For example, Figure 3. shows the effect of branch index on the productivity of the Lako harvester for trees of various sizes (Raymond et al, 1988). The Lako harvester performed at its best when delimbing lightly-branched (< 4cm) trees. More heavily branched trees were often difficult and at times impossible to delimb.

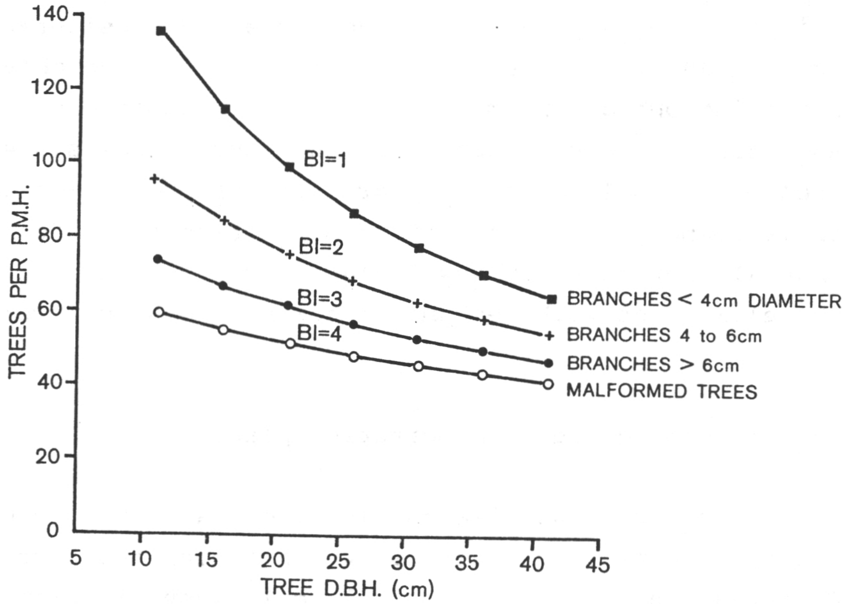

Figure 3. Effect of tree size and branch index on productivity of Lako harvester

Feed roll processors appear best suited to trees with branch sizes less than 5 to 6 cm diameters (Pinus radiata branches grow in whorls which are more difficult to delimb than individual branches). Productivity for feed roll processors drops 30 to 40 percent for malformed trees with branches over 6 cm.

Tree breeding of Pinus radiata provides larger trees with better form and more consistant form for commercial thinning. These trees can be more rapidly processed, have a reduced and less critical requirement for selection, and can be more economically harvested.

Length of harvesting season

In Scandinavia the harsh climatic conditions during winter favour mechanised thinning systems; the length of season which harvesting can be carried on has been extended considerably (Johansson, 1989). New Zealand's climate is considerably milder and harvesting operations rarely shut down completely - although wind and rain can reduce production in motor manual systems. An allowance of up to 15 days per year loss of production due to weather is commonly made in setting production goals for current motor manual operations in New Zealand. Much of this allowance could be eliminated with mechanised thinning systems (Terlesk, 1989).

Approval of logging and transportation plans

In some parts of New Zealand logging plans have to be approved by catchment authorities (which administer part of the Soil Conservation and Rivers Control Act). Many district councils also want to review and approve logging and transportation plans before they are actioned. Although it is too early to tell the number of approvals required may decrease as a result of the current restructuring of a large number of small local authorities into fewer Regional Councils.

Preparation of detailed area harvest plans

The location of harvest setting boundaries, roads, tracks and landings need to be considered if productivity is to be kept high. Experience in Scandinavia suggests that, for medium and easy terrain conditions, most of this can be handled by machine operators who are an increasingly important target group for logging planning courses (Johansson, 1989).

Considerable gains from reduced total costs could be obtained by using operations research techniques in mechanised thinning planning. The spacing of roads, extraction tracks and loading areas have considerable effect not only on construction costs but also on extraction productivity and harvesting systems costs. For example, Raymond (1989a) identified that forwarder "productivity would increase significantly" by determining the optimal combination of total distance travelled, travel on sand tracks, and travel within the stand for an operation in Northland.

Landings

With processing at the stump the need for large landings in thinning is eliminated - roadside storage is often adequate. West (1989) has shown that thinning systems which minimise the area of tracks and landings without raising extraction costs will have inherently better profitability for the forest owner - both from reduced construction costs and additional revenue at the time of clearfelling. Terlesk (1989) estimated savings in landing construction costs of $200/ha for one area he looked at on easy terrain in Kaingaroa by using mechanised shortwood thinning systems.

People considerations

As well as selecting the right equipment the tactical plan should also address people requirements. It is generally recognised that mechanised systems provide a more comfortable and safer working environment than motor manual systems. The importance of people in achieving high productivity can not be overstressed. The selection and training of operators must be planned for (Andersson, 1987).

Raymond (1989b) reports that the South Australian Logging Investigation and Training Association uses a computerised forwarder simulator "as another means of operator selection and is very effective in supplementing both normal interview techniques and in-bush forwarder training."

Spiers (1987) reported that the owner of a Waratah processor considered that his operators were still climbing the learning curve several months after acquiring the new machine. Duggan (1989) noted that the production levels of the experienced Waratah processor operators, almost a year later, varied by as much as 15% and recommended that the selection of a good operator is essential to ensure contract viability.

Recognition must be given to the time required for both the machine operators and the system manager to go through the learning curve. Johansson (1989) has suggested that this may take up to a year for the machine operators and several years for the system manager.

Product quality

The quality of the product to be produced needs to be considered in the tactical plan as it will effect the type of machinery to be selected and performance capability of the machinery. Some measures of quality might include length accuracy, delimbing quality (length of stubs), amount of non-woody material (e.g. sand, pumice, stones, mud) and wood damage. The acceptability of a given mechanised system will depend on the market or mill that is being supplied. For example, the Kaitaia Triboard mill in New Zealand requires a 2.6 metre pulpwood length (tolerance of +5cm, -2.5 cm) which is straight, cleanly delimbed and free of sand. It has been estimated that this very tight log specification is costing an extra NZ$13.00 per tonne

(c. 40%) in logging costs. Other woodlines are not as demanding of log form, delimbing quality or infeed lengths. The introduction of mechanised systems may result in a decrease in product quality (still to an acceptable level) to ensure high harvesting machine productivity.

Another important consideration in mechanised thinning is that logging residue will automatically be more concentrated, especially if the delimbing is carried out on the roadside. If the residue can be used as fuel, it may in some cases contribute to better harvesting economics (Andersson, 1987). Collection of this material for fuel has not received much consideration to date in New Zealand. Nutrient loss from within the stand also has to be considered.

Sawlog yields, as well as pulpwood, could be expected from the mechanised thinning in some instances. The ability to process and sort these products must be included in the tactical plan if needed. For example, in one Australian company's view, the only processor which satisfactorily delimbs large Radiata pine to sawlog standard is the stroke delimber (Raymond, 1989b). However, other companies find the delimbing of feed-roll machines acceptable.

Soil disturbance

The importance of minimising soil compaction and disturbance for future tree growth is now widely recognised. Considerable effort is being put into the design of machinery with the objective of reducing damage. One of the sessions at the conference for which this paper was prepared addresses this issue.

The use of forwarders carrying shortwood may eliminate the disturbance that would occur from stems dragging on the ground in a tree length operation. The greater forwarder payloads will also reduce the number of machine passes made over the ground for a given volume of wood to be extracted. There is some doubt, however, that the heavier loads do not result in more soil compaction.

Probably the greatest reduction in soil disturbance and compaction, when compared with conventional motor manual systems, occurs when the branches from the processed trees are laid down as matting in front of the harvester and forwarder.

Some forests in Australia also suspend thinning operations when soil become too wet and could be easily disturbed.

Understanding performance capabilities

The preparation of plans requires a good understanding of the performance capabilities of various pieces of machinery under a range of conditions. The balancing of production from several machines within a mechanised thinning system makes this task particularly important. Good work study data is the foundation for developing this understanding. However, as Andersson (1987) warned, the environment (social, ecological, industrial, economic, and educational, as well as physical) in which a system is being operated at a given time also effects its performance. For example, Raymond (1989c) commented that "a 30% difference in performance between operators is not uncommon, which makes it hard to really measure a machine's performance confidently. It is essential that the man carrying out the assessment of the machine's performance is experienced and can reliably 'rate' the machine and its operator. If not, the wrong assessment of the machine will be made."

Besides productivity, performance capability includes such features as how often will the machine be shifted - will it need wheels for quick shifts between processing landings or is a stable track based machine needed.

Capital cost

Many of the factors discussed above can effect equipment selection. An additional consideration is the capital cost of the machinery. It is important not to over-capitalise. High cost machines designed for working with large trees should be allocated to large tree stands wherever possible. Similarly if a machine can be built domestically for less cost than imported machinery it should be given serious consideration if it does the same job. For example, the New Zealand built Waratah Hydraulic Tree Harvester has similar capabilities to some Scandinavian equipment for a capital cost of about 20% less.

Operational planning

Operational planning, which is usually concerned with the day-to-day management of the system, entails many tasks. Features of some of these only are covered below.

Centralised versus decentralised planning

Current thinking is that the planning for day-to-day management of operations, whether it be for an accounting department or for mechanised thinning system, should rest with the individual work teams. Peters and Waterman (1982) in their book "In Search of Excellence" have shown that centralised planning rarely lives up to its expectations; decentralised planning by the small teams involved in an operation leads to higher productivity and more efficient use of resources.

Swedish researchers at Skogsarbeten have found that

> "As far as possible, the individual work-teams should be personally responsible for the planning, carrying out and follow-up of their work. This also means that everyone is actively seeking for possible ways to improve the organisation, methods and equipment - rationalization on a daily basis" (Fryk et al, 1987).

Johansson (1989) believes that the operators will play a key role in planning, operating and maintaining mechanised thinning systems in New Zealand - as they have in Sweden. He states that the planning role seems to be simpler in New Zealand than overseas since there is less seasonal variation, to some extent very favourable terrain, shorter outrow distance and lower stocking in final felling, which all contribute favourably. The reduced requirement for marking individual trees for selection, possible from improved genetic tree stock and alternative planting layouts, such as group planting, will also make the operational planning task easier.

Availability and utilisation

Harvesting systems make money when the machines are doing the job for which they were designed. An operation is losing money when the machinery is sitting idle because some part (or other machine on which it is dependent) has broken down. Similarly machines could be idle because the system is not properly balanced, e.g. scheduling of trucks may be inadequate.

To ensure that machinery has high mechanical availability many Scandinavian companies are now training mechanics to be machine operators (Johansson, 1989) or are giving intensive training in equipment maintenance to the operators. When a machine breaks down the operator quickly fixes it instead of waiting for a specialist forest machinery mechanic to come to the forest site.

Ensuring that a reliable supply of parts is readily available must also be planned for. This will be particularly important in New Zealand with the high machinery costs and long distances from the supply factories. For example, some cable logging operators in New Zealand have arranged direct communication links with overseas manufacturers to ensure a fast supply of spare parts if needed. Raymond (1989c) suggests that machines should be selected which are supported by good local agents or, failing that, those whose component parts are common and readily available.

Getting high utilisation out of machinery might mean mechanised harvesting contractors have to plan to share some resources. For example, Raymond (1989b) reported that nine independent mechanised contractors (who logged to roadside for the Australian Newsprint Mills Limited) were serviced by a separate contractor who loaded pulpwood using knuckleboom cranes mounted on six-wheel prime movers. Other contractors share worskshop facilities.

Reporting, control and feedback mechanisms

The operational plans should also include mechanisms for reporting, control and feedback. Feedback systems which show the utilisation and productivity per logging site and time period of interest can be used to answer such questions as:

(1) What production can be expected on similar sites ? (Productivity relationships with site variables can be gradually built up over time).

(2) Which machines should be (not be) bought next time ?

(3) Which machines and operators are (not) working effectively ?

(4) What volume is stored where ?

(5) Are costs acceptable ?

Other feedback which might be needed could include

(6) Is the quality of the products produced acceptable ?

(7) Is damage to the site acceptable ?

The use of on-board computers for collecting field data and providing reports on machine useage/production is becoming common for overseas mechanised systems, particularly in Scandinavia. Sensors connected to computers can provide information on volumes, lengths and diameters per assortment and whether the machine is working or idle. Some of these parameters can be readily gathered as output from bucking computers. Data can be transmitted to the office by a variety of methods (e.g. special external data cassettes, radio and telephone lines [Johansson, 1989; Raymond, 1989b]) and further analysed. To date computers have seen limited useage in New Zealand for this application - basic productivity is usually collated from weigh-bridge records.

The reports and feedback will allow the operational plans to be adjusted if required. Contingency plans need to be in place. These plans might include the location of stands to which machinery could be shifted to produce more acceptable results.

SUMMARY

(1) Although New Zealand has had limited experience with mechanised thinning systems we are rapidly climbing the learning curve. The growing interest in the special characteristics of young Radiata pine pulpwood may see an upsurge in thinning volume harvested. For a number of reasons the proportion of thinning volume harvested by mechanised systems could be expected to increase.

(2) Planning for mechanised thinning systems takes place at strategic, tactical and operational levels. The special requirements and high costs of mechanised systems demand that operators, supervisors and foresters be given some training in logging planning.

(3) When planning a commercial thinning a broad perspective must be maintained at least at the strategic level. As well as providing an intermediate yield commercial thinning is a silvicultural treatment aimed at improving the quality of the final crop and the economics of the forest enterprise. Research into such areas as multiple-stem processing, swathe processors, genetic improvement of the tree crop and alternative layouts to row planting could dramatically change the overall economics of commercial thinning in New Zealand.

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THE STATE OF MECHANIZED PRECOMMERCIAL THINNING IN CENTRAL AND EASTERN CANADA

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SUMMARY

Despite the fact that mechanized precommercial thinning has been of interest in Canada for almost 40 years, there is no operational, mechanized spacing ongoing in the country. Conclusive results from previous attempts have been hindered by a number of problems, including: cut strip width; damage to residual stems; inability to cut below the lowest live limb; inherent problems with the prime mover in terms of power, gradeability, flotation and manoeuverability; and, difficult site conditions.

FERIC is addressing the drawbacks of existing equipment in an ongoing research and development program. The program includes the modification and evaluation of off-the-shelf brush cutters and the design of new concepts. Given the present technology, the most feasible method appears to be a combination of mechanical strip thinning followed by motor-manual selective release.

Keywords: precommercial thinning, strip thinning, mechanical method

INTRODUCTION

Regeneration systems that rely on advance growth, natural seeding, and direct, broadcast seeding are in widespread use across Canada. These techniques have limited control over the amount of regeneration, resulting in stands that are often overly dense. Young stands originating from wildfires also add to the area in need of spacing. At the present time, the main sites involved are balsam fir (Abies balsamea (L) Mill.) and jack pine (Pinus banksiana Lamb) stands. However, mills that utilize hardwoods are becoming more prevalent and thus, spacing of certain hardwoods, such as white birch (Betula papyrifera Marsh) and trembling aspen (Populus tremuloides Michx.) is also done.

Precommercial thinning or spacing is a well-established and growing practice in central and eastern Canada. Presently, motor-manual methods using either conventional chain saws or more commonly, purpose-built brush saws predominate. Manual methods, involving axes, brush knives and clippers, still are used but usually on small-scale and make-work type of projects.

At first glance, the mechanization of precommercial thinning would appear to be a promising alternative. High costs are incurred with motor-manual methods because of low man-day productivity, especially in very dense stands. Despite this apparent incentive and the fact that mechanized spacing has been of interest in Canada for almost 40 years, there is no operational, mechanized spacing ongoing in the country.

Past attempts at mechanized precommercial thinning are numerous but have generally been on an experimental level (Ryans 1989). Since the beginning of the 1980's, trials of off-the-shelf brush cutters have been sporadic and have often gone undocumented. However, they do provide insight into promising methods and equipment and on the limitations and constraints that must be tackled in trying to mechanized this practice.

METHODS

Suitable stands

High motor-manual treatment costs occur at the higher stand densities since the productivity of a brush saw operator is primarily dependent upon the density. The sensitivity of a machine to density will be less, so the target sites for potential mechanized spacing likely are in dense stands. As the density rises above 20 000-25 000 stems/ha, the ability of a machine to reduce costs is enhanced. Below this level, the potential to reduce costs is less, and there is a danger that too many of the crop trees are removed or damaged. Moreover, balsam fir often occurs in dense clumps and a strip thinning machine may remove entire clumps leaving large openings. Therefore, the exact stand density where strip spacing becomes feasible will depend upon the distribution of the stems, machine width, treatment pattern and percent area removed.

Detailed operational criteria for strip precommercial thinning of balsam fir have also been developed by the Precommercial Thinning Working Group for Eastern Canada and can be found in Smith (1987). Some of the criteria include: candidate stand conditions; site conditions; treatment area; and desired row thinning characteristics.

Design parameters, and target stand descriptions and conditions for strip thinning of lodgepole pine have also been developed (Hedin 1986, Hedin 1988).

Geometric pattern

Given present technology, the potential of a totally-selective mechanized system to reduce the cost appears low. Mechanized cleaning is being accomplished with boom-mounted flails in Sweden. However, the effectiveness of these mchines for precommercial thinning under Canadian conditions is doubtful because of restricted visibility, a lack of row integrity, and the onus on the operator to make the crop tree selection.

The most advantageous pattern therefore is in strips. The width of the leave strips will depend upon the density of the stand and the width of the cut strip. To decrease the cost of treatment, a higher percent of the total area can be mechanically thinned. Treatments where greater than 50% of the area is cut mechanically, however, would be limited to very dense stands, and the width of the cut strip would have to be less than the prescribed distance between crop trees. Otherwise, the distance between crop trees in adjacent leave strips would be too great after a follow-up motor-manual operation. In addition, narrow leave strips with a consistent width of less than 1 m are difficult to achieve because the operator must avoid obstacles. If a rectangular spacing between crop trees is acceptable, there would be more flexibility in strip widths and the percent that could be removed with a machine.

Checkerboard patterns are less productive since one half of the second pass has been cut before. They are also more terrain limited since one half of the passes take place on side slopes in sloping and broken terrain. Moreover, expansive areas of balsam fir on flat terrain are rare in eastern Canada. Jack pine stands do occur on sandy flats, but with both species, there is the possibility of losing too many crop trees.

Follow-up motor-manual treatment

Long-term growth and yield studies that investigate precommercial thinning in strips have shown marginal benefits of strip thinning alone. Bella (1974) and Bella and DeFranceschi (1977) recommend a combination of strip and selective thinning for jack pine and lodgepole pine, respectively. Piene (1981) also recommends spacing in the leave strips for balsam fir on the Cape Breton Highlands.

Mechanical strip thinning, as preparatory to motor-manual spacing, provides both advantages and disadvantages. Some potential advantages are:

- access to the site is enhanced;
- layout and supervision should be facilitated;

- if crews follow a year later when the needles on the felled trees have browned, the operators should be able to spot and cut any lower live limbs while working back and forth across the strips.

The disadvantages include:

- a higher productivity requirement is put on the mechanical strip thinning since only approximately one-half of the area can be treated mechanically and the cost of motor-manual operations is added to the total treatment cost;
- if a large amount of lower live limbs and wounded trees are left by the mechanical thinning, the productivity of the motor-manual operators will be reduced. The cost advantage of strip thinning will thus be reduced or negated;
- bent trees along the edges of the leave strip or trees pushed into the leave strip may reduce the productivity of motor-manual operators.

Seymour et al. (1984) found that the inherent efficiency of the brush saw operations was not improved in the residual strips, but the total thinning cost including the mechanical treatment would be reduced, compared to motor-manual spacing alone in a stand density of 49 400 stems/ha. Mechanical strips appeared to have a positive psychological effect on the brush-saw operators.

E Q U I P M E N T

Equipment of potential application or used in past attempts in strip thinning are either nonpowered or powered.

Nonpowered equipment has been tried over many years and consists of brushland discs, front-mounted straight and V-blades, drum choppers, and drags. They have the advantages of being relatively cheap and can be readily found or made locally. All are attachments than can be easily mounted onto available prime movers. However, their use usually has been ineffective primarily because of inconsistent mortality in the cut strip and excessive side damage. Choppers have been the most successful but are limited to flat, rock-free terrain, and performance quality if also inconsistent.

Powered cutting mechanisms have the greatest potential for precommercial thinning. The majority have cutting heads of a set width that are directly mounted onto the front of the prime mover, and thus, produce a cut swath of consistent width. Some have cutting heads that are mounted on a boom, and can cut a corridor of variable width up to the reach of the boom. Some selection may be possible with this type but the main intention is to produce a cut strip. The intention with all this equipment is to produce a relatively straight cut swath and leave a residual strip of a consistent width. In practice, the ability to produce a residual strip of consistent width will depend upon the operator, visibility and site conditions.

The cutting mechanisms can be classified by the type of cutters, either fixed or free-swinging, and by the direction of the main powered shaft, horizontal or vertical.

Fixed cutters include circular saws and cutting blades with fixed teeth. Free-swinging cutters consist of knives, blades or chain that are loosely attached to a revolving disc or drum. They flex back upon impact with an obstacle and return to their original position by centrifugal force. The advantage of the fixed type is that they are much more efficient cutters, requiring much less power or capable of cutting larger diameter material with a similar power input. The main advantage of the free-swinging type is that there is less damage upon hitting a rock or boulder. This is especially important on horizontal shaft mechanisms where the blades must be sharper and can be difficult to change.

Machines with either vertical-shaft or horizontal-shaft cutting heads have been tried for strip thinning in Canada. Both types of cutting mechanisms have apparent positive and negative qualities, and it is difficult to define the optimum configuration for strip thinning based on the experience to date. Some of the inherent advantages and disadvantages of both types are listed in Table 1.

Table 1. Comparison of vertical- and horizontal-shaft cutting heads (from McKenzie and Zarate 1984)

Advantages	Disadvantages
VERTICAL SHAFT	
1. Low power requirements	1. Can leave high stubs
2. Long blade life	2. Large safety zones required
3. High kinetic blade energy	3. Small bearing area at blade attachment points can accelerate blade wear at these points
4. Cuts, even when blades dull	4. Can have poorer operator visibility
5. Low power-hr/ton (energy per ton) expended	5. Can be longer machine overall
HORIZONTAL SHAFT	
1. Capable of cutting close to ground	1. Higher power needed to drive cutters
2. Can be a closer coupled machine	2. Usually low kinetic blade energy
3. Can have good operator visibility	3. With low kinetic energy, poor cutting when blades dull
4. Can have large blade bearings	4. Blade changing can be difficult
5. Both ends of blade usually supported	
6. Can have high kinetic drum energy (flywheel effect)	

The following is a brief review of the equipment used in recent strip thinning trials during the 1980's, and machines of potential use. Included are the more promising off-the-shelf machines and some recent development efforts: vertical shaft equipment.

Vertical-shaft equipment has been used in the form of attachments or integral with a prime mover. Machines, such as the Kershaw and Hydro-Ax, have been tested in most regions across Canada.

The **Kershaw 10-8** has a twin vertical-shaft, flexible-knife cutting head. The operator has excellent visibility of the cutting head. The prime mover is only slightly wider than the 2.36-m wide cutting head. Ground pressure is fairly high. Unfortunately, the 10-8 model is no longer in serial production and the next model, the 10-10, is much too wide to create a suitable cut strip. A model 10-8 was used operationally for strip spacing of balsam fir on the limits of International Paper in Maine in 1986. Herring (1981) also reports experimental use of the machine in British Columbia for precommercial thinning.

The **Hydro-Ax Rotary-Ax** is available in various models. All models have a single vertical-shaft cutting head. A flexible knife is mounted on each end of a rotating blade. Some users have replaced the blade with a disc. The smaller 300 model is underpowered (Ross 1985). Models with suitable power, the 520, 620 and 720 series, have a 2.45-m wide cutting head but the prime mover is wider than the cutting head unless equipped with narrow tires (18.4 in.) that result in high ground pressure.

Trials of the machine in Canada over the past 10 years are reported by Herring (1981) and Hedin (1987) in British Columbia, and Ross (1985) in Nova Scotia. Seymour et al. (1984) studied a 520 series used in balsam fir stands in Maine. A machine was still in operational use on the limits of Scott Paper, Maine in 1986.

A **Rotary-Ax** attachment has also been installed on modified tracked, front-end loaders. The **Track-Ax** was tested in 1987 and 1988 by the B.C. Ministry of Forests and Lands (B.C. M.O.F.L.) to examine the performance of a tracked machine on slopes of 30% or more (Forrester 1989). The machine demonstrated the ability to meet the B.C. M.O.F.L. standards.

The **Crabe Combine** (Sutherland 1985) is a Canadian version of the Pallari Swath Harvester developed in Finland (Hakkila and Kalaja 1980). The Crabe Combine consists of two, sickle-shaped knife cutters and a drum chipper. The machine was developed under the Enfor program by the Canadian Forestry Service to harvest brush for biomass energy, but it could be adapted for harvesting precommercial thinings. There has also been some interest in the concept for safety reasons, since it does not rely on high rotation speeds to generate cutting force. However, the drum chipper restricts the production capacity of the machine in the tested configuration. The viability of systems that remove the thinnings are dependent upon the value of the product. At the present time in Canada, the cut material is more valuable as a fertilizer for the crop trees than for energy.

There are a number of boom-mounted vertical-shaft cutting heads that have been tried in precommercial thinning.

A **FERIC concept-testing machine** for plantation cleaning and precommercial thinning was evaluated in 1985. The machine was designed so that it could cut strips as narrow as 1.8 m and up to 2.5 m. The concept consisted basically of a circular saw mounted on a straight boom with a tilting head.

In dense balsam fir, 135 000 stems/ha, the cut trees bunched up in front of the machine, hampering visibility and productivity. Another major limitation was the stability of the carrier during the tests. Further development of the concept has been postponed until a suitable carrier has been identified of built (Ryans 1985).

The **Canterra CT-268** brush cutter has a 2.36-m wide carrier which makes it suitable for strip thinning. The ground pressure is low because of the low operating weight. The cutting head consists of a 1.54-m diameter cutting disc mounted on a straight boom. Sharkfin cutters, welded on the disc, break up the severed stems while the disc is swung back and forth to cut a strip.

The machine has been used and observed on various brush cutting operations but has never been tested for precommercial thinning. The Canadian manufacturer has dropped production of the machine, and the only unit produced was bought by a contractor and taken to the U.S. for hydroline right-of-ways.

The cutting head of the **Weldco-Beales boom-mounted flail** consists of a rotating disc on a vertical shaft with three free-swinging blades. The flail was mounted on the conventional articulated boom of a Caterpillar 205 excavator.

A brief trial was conducted in the fall of 1986 on a steep slope with heavy debris in interior British Columbia (Hedin 1987). Productivity was poor but it was felt there may be some future potential for the concept. Cutting heads, similar to the Weldco-Beales units, are produced by a number of manufacturers.

Presently, excavators with flail and saw-type cutting heads are being used for precommercial thinning on an experimental basis in Québec and Maine.

Horizontal-shaft equipment

Horizontal-shaft cutting heads are usually available only as attachments. As well, the majority of these heads are made to be mounted on a farm tractor. The availability of this equipment has been limited, and more extensive modifications are required for it to be mounted on a suitable carrier. Thus, the experience with horizontal-shaft cutters in Canada has been limited.

In an operational development trial initiated through the Canada-Saskatchewan Forest Resource Development Agreement, the Canadian Forestry

Service tested a **Seppi Forst** brush cutter to demonstrate the potential of precommercial strip thinning with motor-manual follow-up in fire-origin jack pine stands. The machine was observed cutting strips through an 11-year-old stand with an average height of 2 m and densities ranging from 30 000 to 40 000 stems/ha.

The Seppi model 175 was hydrostatically driven from a modified Versatile 276 bidirectional tractor. The 75-kW (PTO), 4-wheel drive tractor has a hydrostatic-mechanical transmission. The width of the tractor is 2.4 m, and the cutting head is 2.1-m wide including belt-drive housing and skids. Side damage was being caused during the operation, primarily by the tires, but the damaged stems will be removed during the following motor-manual operation.

Although not designed for brush cutting, a **Hydro-Ax chain flail** delimber has been used for precommercial thinning on an operational basis in Maine. The cutting head consists of short lengths of chain spaced along a horizontal drum. The flailing chain concept has the potential to remove limbs close to the ground and is less sensitive to damage when striking rocks. It could be used as the main cutting head in front of the machine or as a trailing, secondary head to clean off the lower live limbs.

CONSTRAINTS ON MACHINE DESIGN

There are a number of constraints facing the mechanization of precommercial thinning. Many of the problems are interconnected but the primary ones are:

- width of cut;
- stand damage along edges of the leave strip;
- incomplete mortality within the cut strip; and
- difficult site conditions.

Width of cut

To meet the spacing prescriptions in central and eastern Canada, the width of the cut strip should ideally be 1.83 to 2.44 m. Cut strips much wider than the prescription will decrease the use of a machine to denser stands, otherwise only a small percent of a stand can be cut mechanically to avoid losing too many crop trees. Most off-the-shelf brush cutters do not meet the width criteria because they were designed for other brush cutting applications where a narrow width of cut is a detriment to productivity.

Finding or designing an off-road vehicle for forestry applications with suitable width and power is a difficult task. The added necessities of low centre of gravity for stability and high ground clearance to avoid obstacles are opposing features that are difficult to achieve when the width is a restriction.

Stand Damage

Injury to stems along the edge of the leave strip can be caused by both the cutting head and the prime mover. Damage includes trees pushed aside and badly leaning, stems with the bark removed and branches broken, and injury to the roots. However, since motor-manual spacing is to follow the strip thinning, trees damaged along the edge can be removed at that time.

The cutting head can cause damage because its entire width is not actually cutting. Thick metal plates and guarding along the sides for safety purposes can cause damage with vertical-shaft cutters. Horizontal-shaft cutters have other problem areas such as the side-mounted hydraulic pumps, chain drives and bearings. Feed rails can help minimize this kind of damage by directing the stems inward to the cutting mechanism, but these have rarely been tried because of the short duration of most of the trials.

A major contributor to stand damage by most integral brush cutting machines is a prime mover that is wider than the cutting head. Usually, the wheels protrude past the cutting head, thus knocking down stems and peeling off bark.

Other causes of side damage created by the prime mover include: backing up into the leave strip; articulating while stuck on an obstacle or while turning around at the end of a pass; and, off-tracking while steering caused by the rear of the machine which does not follow the path of the front. On slopes, the entire machine can also slip sideways into the residual strip while climbing over windfalls.

Root damage can be caused by high ground pressure on wheeled prime movers or by skid steering with tracked machines. Many existing integral brush cutters on the market have excessive ground pressure ratings. The consequences of this type of damage and soil compaction have yet to be investigated in Canada.

Incomplete cut-strip mortality

A lack of complete mortality within the cut strip occasionally can take the form of undamaged stems, but more often partially-damaged stems and live limbs remaining on the stump. Some rotary cutting heads are composed of two or more cutting mechanisms adjacent to each other to decrease the length of the cutting head, e.g., two vertical-shaft, flexible-knife cutters on the Kershaw Klearway. If the cutters do not overlap, a line of undamaged or partially-damaged trees is left, especially in very dense stands.

Trees are also missed when the cutting head stops but forward progress continues. The cutters may jam if the machine is underpowered for the stand conditions or if cut stems bunch up around the cutting head.

The lowest live limb problem is the most difficult one to solve. Rotary cutters are sensitive to impacts with large obstacles, especially boulders and rocks in the soil. The cutting head is one of the main causes of mechanical breakdown on brush cutting operations. Thus, the head must be kept high enough off the ground so as not to risk impact. Moreover, the rugged microrelief in most balsam fir stands makes it difficult to follow the contours of the terrain. In older, very dense stands, this problem may not be too serious because the lowest live limbs are fairly high off the ground. However, the treatment of younger stands from 7 to 12 years in age is being recommended (Piene 1982); thus, the problem will be increased because live limbs will be closer to the ground.

The extent of the low live limb problem for various species and sites, in terms of their ability to compete with the crop trees, has received little investigation in Canada.

Difficult site conditions

The last problem, difficult stand and terrain conditions, is aggravated because the machine is required to cover 100% of the area while keeping relatively constant spacing and cutting straight strips. The machine must be capable of traversing various ground strength conditions, climbing slopes, and negotiating ground roughness obstacles like boulders, heavy debris, and high stumps. In addition, white birch is generally not being utilized but is a natural component of most balsam fir stands. Thus, a major obstacle is large residuals and a high percent are windfalls by the time spacing is done.

Windfalls and heavy debris conditions, especially in fire-origin pine stands, also restrict the ability of the cutting head to cut below the lowest live limb and to reach young, low-lying regeneration.

Varying stand densities, species compositions, and tree heights and diameters occur in stands of natural origin. The cutting head must have sufficient power to handle very dense stands and harder, larger-sized deciduous species such as pin cherry, red maple and white birch. For example, along the western coast of Newfoundland, over 50% of the sites are in the 85 000-plus stems-per-hectare class. Densities in excess of 200 000 stems per hectare are not uncommon. The ability of a cutting head to macerate the trees will be an advantage in taller and denser stands where they may bunch up if only cut once at the butt.

Sufficient and constant power to the cutting head must be supplied independent of changing ground speeds. Thus, the prime mover must be equipped with hydrostatic drive or an auxiliary engine must be used. Other desirable characteristics of a prime mover for precommercial thinning are adequate power, good visibility and low ground pressure. A machine that is very limited by terrain or stand factors will not be viable in mechanized precommercial thinning on an operational scale in Canada.

ONGOING DEVELOPMENTS

Both the Eastern and Western Divisions of FERIC are developing concepts for strip thinning machines, designed to overcome the drawbacks of equipment tested to date.

i) a vertical-shaft, twin-saw cutting attachment has been built by Weldco-Beales in cooperation with the Western Division, and is undergoing preliminary testing in British Columbia in fire-origin lodgepole pine stands. The cutting head is mounted on a hydrostatic drive tracked loader to better negotiate steep slopes and difficult debris conditions.

ii) the preliminary design of a versatile prime mover concept for silvicultural operations has been made by the Eastern Division. The machine has been designed to meet the criteria for a precommercial thinning machine: 2.5-m wide; hydrostatic-mechanical drive; high engine power, etc. The machine also suits the requirements for light drawbar pull applications in site preparation, such as brush cutting, and raking. Efforts to secure outside financial support for the development are underway. Extensive field testing of the prototype is anticipated to take place in 1990, if the unit is built as planned.

iii) in cooperation with Stora Forest Industries and the provincial government of Nova Scotia, a chain flail is being tested for early precommercial thinning (age 3-4) in understocked but overly dense balsam fir stands. The strip thinning treatment is to be followed by in-fill planting in the openings and along the cut strips. Modifications to the flail will be tried to increase the mortality along the cut strip if the conventional chain configuration is ineffective. A motor-manual spacing will be done at approximately year 10. Trials are ongoing to determine the feasibility of this method to treat partially-stocked sites.

CONCLUSION

Mechanized techniques must meet both economic and biological objectives. This must be considered both in the use and modification of off-the-shelf equipment and in the design of a new machine. A mechanized operation must decrease costs, whether used on its own or as preparatory operation to motor-manual crews. Many of the positive silvicultural effects of spacing will be lost if there is excessive crop tree removal and damage, and if there is incomplete mortality within the cut strip.

Mechanized precommercial thinning has been of interest for years but has not received much research and development effort. None of the existing machines meet the present criteria, and an ideal machine is not on the immediate horizon. However, many of the problems with off-the-shelf equipment, such as low, live limbs and side damage, can be addressed when designing a purpose-built machine for strip precommercial thinning. A long-term commitment will be required for the development of suitable machines and systems for precommercial thinning.

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MANIPULATORS WITH TELESCOPIC BOOM FOR THINNING AND THEIR INFLUENCE ON FORMABLE STAND

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SUMMARY

Nobody disputes the necessity of thinnings from the forestry aspect and they are an additional source of timber. However, old-fashioned methods of tree cutting and selection cannot satisfy the developing society. The main direction must be mechanization of operations. The machines being constructed should follow three basic requirements - ecological, ergonomic and economic. In the Lithuanian Research Institute of Forestry, a range of manipulators are being constructed and technologies for their implementation developed, primarily, from the ecological point of view.

Key words: thinning, mechanization ecology, ergonomics, economics

INTRODUCTION

Some of the main objectives of thinning a forest include:

- perfection of stand composition in a preferable direction;
- raising of viability and improvement of stand sanitary state;
- shortening of the time to growing technically mature wood;

- increase of total wood recovery by decreasing natural losses by mortality or reduced growth from competition
- increasing the protection, water-protection, sanitary-hygienic and other beneficial functions of forests.

The forest sector of the USSR has found itself in a paradoxical situation: having vast forest reserves and voluminous harvesting, it does not satisfy the requirements in raw material for its products. The yearly deficiency of timber amounts to more than 25 mln m^3. Although 15 mln m^3 of raw material can be purchased from outside, there is a 10 mln m^3 per year shortage of raw material. In addition, the exporting possibilities of the enterprises of "Minlesprom" are not utilized by at least 7 mln m^3.

At the same time, in the European-Ural zone of the USSR, requirements for timber are growing. However, they should be satisfied from local reserves, if the timber harvesting from thinning cuttings reaches 50-55 mln m^3 and the harvest from cleaning cuttings and non-clear cuttings provides an additional 60-70 mln m^3 by the year 2000, as predicted.

The forest requiring cleaning cuttings in the USSR covers a vast territory. The area of the country covered with young, middle-aged and under-mature forests amounts to 242,8 mln ha including softwoods - 163 and hardwoods - 79,8. The area of stands requiring treatment comprises approximately 134,5 mln ha. Under an average rotation of thinnings every 12 years, the area treated should reach 11,2 mln ha/year; current 8 mln ha/year are thinned.

The main factors restraining more extensive thinnings are as follows:

- absence of requirement for small-scale commodity timber (about 140 mln) which includes 70% of softwood species;
- diversity of stands;

- insufficiently developed net of forest roads;
- complication of the technological process of cutting;
- shortage of working power; and
- low mechanization level of thinnings, especially in young stands.

Mechanization of thinnings

One of the main factors still restraining extensive thinning is poor mechanization of the work. Even with existing technical means, labour-consumption for thinning and other kinds of non-clear cuttings is 2-3 times greater than for clear-cutting. While the proportion of mechanization in thinnings and non-clear cuttings remains less than 20%, and while there is a shortage of labour, extension of non-clear cuttings is restrained.

Thinning cuttings will not be fully mechanized in the near future because of their great diversity and complexity in biological, technical and technological aspects.

Advancement of native and foreign practice shows that the systems of combined machines each of which performs several operations and substitutes two or even more unioperational machines display themselves as more effective economically than unioperational ones.

Nevertheless, despite the way which the development of mechanization of thinning operations would take, it should keep to three main E's: Ecology, Ergonomics, Economics.

Only then can this or that system or concept be considered viable. It is difficult to draw a line between these three factors, because they are very close and cannot exist one without another. Nevertheless, we shall try, as far as it is possible, to analyze them separately.

Great contradictions in correlations of three spheres: man-machine-forest in the Soviet Union and even world-wide have began in the last decades, and especially after man started turning from traditional harvesting techniques to intensive mechanization of operations. It is a great pity that these contradictions make greatest impact on forest environment which has no real possibility to protect itself.

Ecology

The work of the technically armed man in a forest may cause the following types of damage as characterized here in a sequence of decreasing importance:

- damage to stems and bark of residual growing trees;
- damage to surface roots;
- extinction or damage of undergrowth-future forest!;
- ground compaction and changes of its water - physical properties;
- damage to crowns and tops of residual trees;
- damage to ground structure on skidways and strip roads and as a consequence of this - water or wind erosion;
- damage to forest litter;
- damage to deep roots;
- pollution of surrounding environment by exhaust gases;
- soil contamination by oil products and harmful liquids;
- changes in the impact of wind, sun and water after cutting operations.

First of all, let's analyze operations of non-clear cuttings with the traditional technique.

In the Central Urals, after consequential cutting in a spruce stand on loamy soil, the soil density increased only by 20%, porosity decreased by 5%, and water permeability by 25%. This is many times less than after clear-cutting. Non-clear cuttings of average and little intensity (20-30%) in the highlands of Caucasus, South Urals and forests of the Baltic region, Byelorussia and Ukraine are characterized by slight increments in soil density and decreases in porosity and water permeability. Damage increases together with increasing intensity, but still is considerably less than clear-cutting performed by multioperational units.

Therefore, the traditional technique ensures harvesting operations with allowable negative impact on the ecological environment. For this reason there was no necessity to study the impact of such cuttings on soil earlier.

The only negative factor of the traditional technique was its low production capacity. This spurred the introduction of mechanization in the forest.

Harvesting techniques changed with the introduction of unioperational and multioperational machines. New technologies for their implementation were worked out resulting in a sharp increment in harvesting productivity during the last two decades. However, along with this, mechanization of cutting operations and afforestation has drastically worsened the state of soils and ecological conditions of forest renewal and growth on vast territories. From an ecological stand point, the use of unioperational machines in clearcuttings is especially questionable. There is a necessity to speed up the construction of machines less harmful to ecological environment. New cutting methods maximally corresponding to forest nature technologies are needed in order to preserve undergrowth and soil.

One way to diminish the harmful impact of harvesting on forest environment is to use multioperational units. They pass along a skidway less times and therefore, the ground and root systems of trees are correspondingly less damaged. Nevertheless, multioperational units have greater weight and size. In this case the use of widened tyres is very important. It raises the capacity of skidding operations by 60%, fuel expeditures of tractors are reduced by 20-70% depending on soil conditions (average 40%), resistance to rocking is reduced, rate of speed increases, as well as the service time of tyres, working conditions of the operator are improved, and most importantly the soil compaction is considerably decreased as is soil and litter disturbance, and damage to the root systems of growing trees. Tractors with broad tyres do not sink as much on ground with poor bearing capacity and are more stable on steep slopes. The analysis of experimental results with tyres of high flotation has shown that there was no practically difference between soil compaction before and after harvesting. Measurements performed showed that the rate of soil compaction increment on a skidway after 20 tractor passages was 2%, and after 100 of passages, 10%.

Ergonomics

According to the data of studies carried out in the USSR, the quantity of accidents in mechanized operations compared to traditional ones has decreased by 29,3 times in felling operations (on account of 1 mln m^3 of ready timber), skidding by 12,3 times, delimbing by 18 times and automized cross-cutting by 3,9 times. The sick rate of cutting technique operators has decreased by 25%, and delimbing by 20%.

Mechanization has changed the character of work in the forest. First of all, physical loading of man has been greatly reduced, but it has been substituted by mental loading. Operating a machine may be simple physically, but it requires a definite decision and its realization.

For example, during operating a harvesting machine of high horse-power performing several operations, the operator uses mechanical, hydraulic and electronic systems. During one cycle working with his hands and legs an operator performs 22 movements over a period of 15 seconds. During a shift including removings and normal delays, he makes approximately 15 thousand comprehended coordinated movements.

It is generally accepted that in the process of mechanization, special attention must be paid to the operator of a machine. In most cases operator and his attitude towards work are the main factors determining the growth of productivity and reliability of a machine. Very often an interested and active operator means much more than technical perfections.

Complete mechanization leads to safe working conditions. Machines help protect a worker from the impact of harmful climatic phenomena. Nevertheless, according to a series or ergonomic parameters (operation efforts, noise, vibration, microclimate, presence of gases in a cab) the machines do not correspond to contemporary requirements, and therefore need further perfection in order to create normal working conditions.

Economics

Implementation of the new technique is retarded because of the use of the old technique untill the very last moment that it is economically justified. Besides, much time and means are needed for organized implementation of new machines, preparation of workers and technical personnel for operation under new conditions.

Abroad, it is thought that mechanization for the sake of mechanization as such without getting corresponding economic benefits is harmful. Such an benefits should, first of all, be expressed in reduced operation expenditures and costs.

While construction of one or another machine takes a definite amount of time. This presupposes the necessity to accurately account for a complex of factors among which outstanding ones are those of economics.

At present harvesting has abruptly become more expensive. But the growth of costs for machinery abroad is practically followed by the same proportion of growth of costs for timber. Thus, in Sweden the costs for harvesting machinery since 1968 till 1978 increased average by 1,83 times, while costs for pulpwood increased by 1,88 times. However, nothing of the kind is going on in the USSR where harvesting machinery is becoming more expensive, while costs for timber are stable. Therefore, raising of mechanization level in the USSR undermines financial basis of timber enterprises and mechanization is non-profitable to them.

Mechanized labour requires a deeper understanding of the whole production process, payment system, evaluation results, etc.

The data of foreign investigations into production with wheeled tractors shows that 30-40% of a labour productivity increment can be attributed to the experience of workers and the labour organization.

Our outlook

Summing up the experience of thinnings in the republic and taking into account world-wide achievements in the sphere we have come to the conclusion that to maximally preserve forest environment during mechanization the following is necessary:

a) strip roads aiming at a more uniform stand cutting must be not broader than 4 m;
b) distances between strip roads should be not less than 25 m;
c) technological machinery should be based on energetic means

of minimal size, adequate power, perfect manoeuvrability and maximal practicality, as well as minimal pressure of the working part on the ground;

d) to construct technological equipment on booms of maximal length with the simplest movement trajectory;

e) aiming at reliable stability of an aggregate, to make support of working parts with the tree being processed on ground in cases of great boom outreach, and to loosen automatically from the support when a guaranteed stability is reached;

f) to cover skidways with cutting residues in order to minimize soil compaction and water permeability while passing with normal (available in the USSR) tyres;

g) to seek, as far as it is possible, to perform cutting operations in dry periods, and even better in winter on frozen ground.

Taking into account the requirements for lightness of a construction, maximalization of attainability, simplicity of operation and ability to predict the trajectory of movement, so that the damage to the residual stand is reduced and the forest environment preserved, the mechanization laboratory of the Lithuanian Research Institute of Forestry has constructed a range of manipulators with telescopic booms from 5 till 15 m in lenght, mainly for use on forestry tractors (Figure 1). For the first very important operation they are equipped with a working part: a claw which is situated at the end of the last section, as well as with packing equipment and may be used for collection, hilling, dragging up, packing and skidding of timber. The boom functions can be greatly expanded when with other working parts, such as grappling-cutting, delimbing-bucking, crushing, milling, and mounting-grappling aggregates.

When operating with the equipment for grappling and dragging up of large and heavy trees or logs, in order to ensure the stability of energetic means (with great boom outreach) removement is performed by having support on the ground and only after the aggregate has reached stable state with the hugged tree or log, as well as guaranteed firmness of the boom. The working part is then moving in a slightly lifted manner (Figure 2).

When a tree is already on a strip road and the tractor is moving ahead, while the manipulator is in front, then delimbing is performed directly when lifting the tree. The branches then fall down on to the strip road and cover the surface. If the manipulator is situated behind the cab of a tractor, then the tree is placed along the axis of a strip road, hugged at the base of boom and delimbed by claws on a length corresponding to the length of the boom. After this the stem is cut, dragged up to the tractor, taken by the grappling equipment and the cycle of delimbing is repeated once more. In this case branches are also scattered on a strip road, but the aggregate with every bunch moves backwards till the edge of the cutting area (Figure 3) along the strip road covered with branches.

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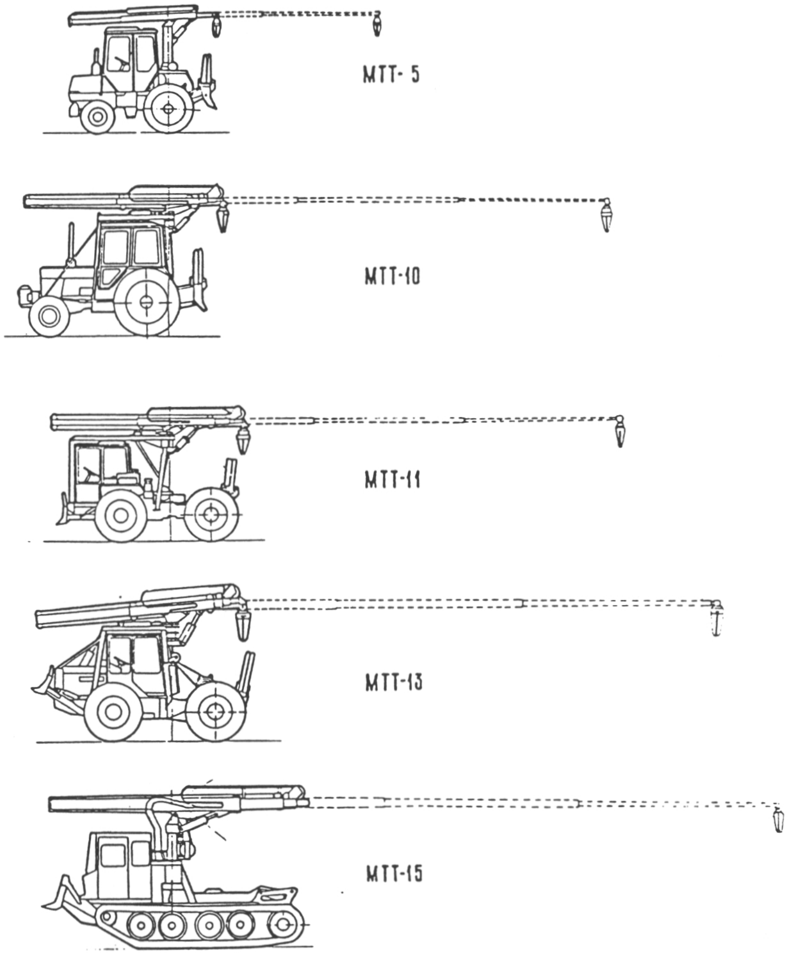
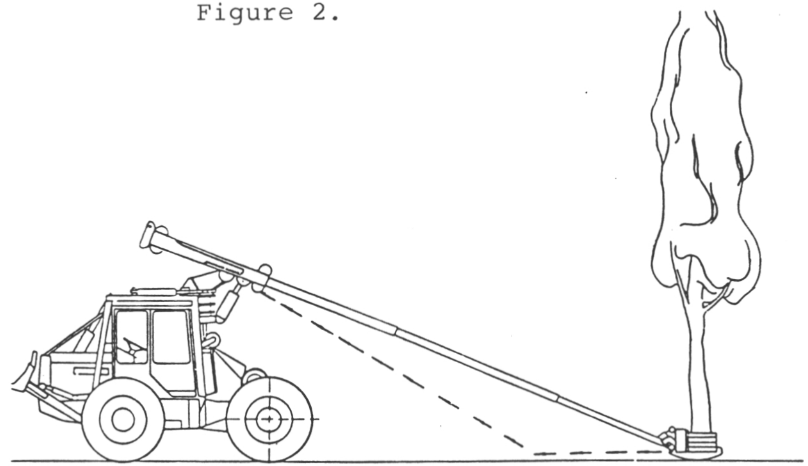
MANIPULATORS WITH TELESCOPIC BOOM

Figure 1.



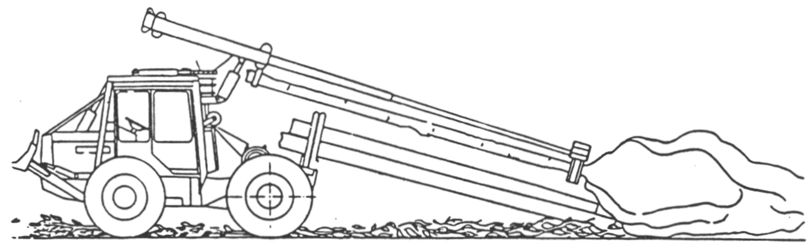
APPROACHING A TREE

Figure 2.



DELIMBING AND BUCHING

Figure 3.



DIE TECHNOLOGISCHEN VERFAHREN DER JUNGBESTANDSPFLEGE UND DÜNNHOLZGEWINNUNG UNTER DEN FORSTLICHEN BEDINGUNGEN DER DDR

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Das in der Folge des II. Weltkrieges gestörte Altersklassenverhältnis der Wälder der DDR führte seit vielen Jahren zu einem übernormal hohen Anteil junger Bestände der II. und teilweise III. Altersklasse. Die Notwendigkeit der Pflege dieser Bestände im Interesse ihrer zukünftigen Stabilität und mengen- und qualitätsgerechten Zuwachsentwicklung sowie der Bedarf der Volkswirtschaft an der dabei anfallenden Menge Rohholz in einem Umfang von etwa 15% am Gesamtjahreseinschlag erfordern die Ernte und Bearbeitung dieses Materials, das zum überwiegenden Teil in der Baumart Kiefer anfällt.

Der spezifische Arbeitsaufwand für die Ernte und Aufbereitung von Dünnholz ist etwa fünfmal so hoch wie bei der Durchforstung der Bestände im späteren Alter und etwa zehnfach gegenüber der Endnutzung. Dazu kommen sehr ungünstige Arbeitsbedingungen in der Kiefer immer noch 4000 bis 6000 und bei der Fichte 2500 bis 2800 Bäume/ha aufweisen. Diese Umstände sind Anlass zur Jungbestandspflege und Dünnholzgewinnung und dabei insbesondere zur Mechanisierung von Arbeitsgängen.

Im Gegensatz zur Vornutzung in mittelalten Beständen weist Holz aus der Jungbestandspflege ein sehr geringes Stückvolumen auf. Es beträgt im Durchschnitt der Erstdurchforstung, die bei Kiefer optimal zwischen 7 und 10 m Bestandesmittelhöhe Verwertbarkeit verbunden, aus der zusätzliche Anforderungen an die Rationalisierung des Gesamtprozesses erwachsen, um durch Sortierung und teilweise Veredelung eine möglichst weitgehende Anpassung der aus den Baumteilen zu bildenden Sorten an den volkswirtschaftlich optimalen Verwendungszweck zu erreichen.

Eine sehr rationelle Methode der Aufbereitung ist zwar das Hacken ganzer Bäume; die dabei entstehenden Hackschnitzel mit Grüngut (HSmG) können aber von der Industrie nur in sehr geringen Mengen aufgenommen werden. Auch die nach der Entastung durch Hackung im Wald entstehenden Hackschnitzel mit Rinde (HSmR) sind territorial unterschiedlich, insgesamt aber nicht unbegrenzt absetzbar, wohingegen ein grosser Bedarf an dickeren Schichtholzsorten und an entrindetem Holz besteht.

Daraus ergibt sich die Notwendigkeit, verschiedene Sorten aus Dünnholz auszuhalten und ihren veredelten Anteil zu erhöhen.

Im Laufe der Forschungs- und Entwicklungsarbeiten der Letzten Jahre wurden verschiedene technologische Verfahren und Mechanisierungslösungen zur Jungbestandspflege geschaffen und zur praktischen Anwendung gebracht, wie die nachstehenden ausführungen zeigen.

Ausserdem wurde die Aufbereitung des Dünnholzes sowohl auf stationären Anlagen als auch im Wald weiterentwickelt, und es wurden auch neue Wege dabei beschritten.

Die <u>kombinierte Kiefernjungbestandspflege</u> ist entwickelt und allseitig wissenschaftlich begründet worden, um in solchen gesunden Kiefernjungbeständen im optimalen Höhenbereich von 7-10 (12) m, die einen Bestockungsgrad von mindestens 1,2 aufweisen, durch schematische Entnahme jeder 5. oder 7. Reihe günstige technologische Bedingungen für den Einsatz von Entastungs- und Fällmaschinen sowie Rücketraktoren zu erreichen. Entsprechend dem üblichen Reihenabstand entstehen dabei im Mittel 3 m breite Arbeitsgassen, auf denen etwa 2/3 der Holzmenge des ersten Pflegeeingriffes anfallen. Sie werden bei der Erstdurchforstung, bei allen späteren Eingriffen, bei Forstschutz- und Düngemassnahmen und zum Unterbau benutzt.

Zur Mechanisierung des arbeitsaufwendigsten Teilprozesses, der Entastung, der nach herkömmlichen, vorwiegend manuellen Verfahren mit etwa 100 min/m^3 an die zwei Drittel der Gesamtzeit zur Dünnholzbereitstellung benötigte, wurde die Entastungspaketiermaschine EPAK 4 entwickelt und produziert. Sie ist auf die allradgetriebene Grundmaschine TT 80 mit 1,82 m Breite montiert, die aus einem tragfähigen Rahmen besteht, an dem die 4 Räder über Bogies pendelnd aufgehängt sind. Als Antrieb ist ein komplettes Traktorentriebwerk mit 33 kW Motorleistung eingebaut. Der Entastungsgreifer erfasst die am Boden liegenden Bäume oberhalb des Stammfusses, führt sie neben der seitlich angeordneten Fahrerkabine den Durchzugswalzen zu und trennt die Äste ab, die vor der Maschine zu Boden fallen. Durch eine Automatik gesteuert, werden die Stangen bei eingestellter einheitlicher Länge gezopft, auf dem heckseitigen Tisch gesammelt und zu rückefähigen Bunden von ca. 0,5 m^3 Volumen abgelegt. Längere oder dickere Stangen werden ungezopft einzeln seitlich abgeworfen. Bezogen auf die Operativzeit beträgt die Produktivität 80-90 Bäume/h, was je nach Stückvolumen 2-4 m^3/h entspricht. Zum Rücken der Stangenbunde aus den Arbeitsgassen werden kleine Standardtraktoren mit Rückezange (1 Bündel) oder der Durchforstungstraktor DFU 451 mit Chokerseilzug (2 Bündel) eingesetzt.

Die ökologischen Vorteile dieses Verfahrens bestehen im Verbleib des Reisigs im Bestand, das auf der Arbeitsgasse verteilt anfällt und gleichzeitig den spezifischen Bodendruck der Maschine verringert.

Eine technische Weiterentwicklung der Entastungsmachine EPAK wird gegenwärtig als Forschungsmuster realisiert und untersucht, indem ein längerer Zuführmanipulator montiert und mit einem kombinierten Fäll-Entastungskopf ausgerüstet wird, womit die Bäume der zu fällenden Reihe der Arbeitsgasse und die selektiv zu entnehmenden Bäume bis zur 3. Reihe beiderseits der Gasse vom Stock getrennt und dann den Entastungswalzen zugeführt werden können.

Eine technologisch weiterentwickelte Form der kombinierten Kiefernjungbestandspflege und damit eine Erweiterung ihres Anwendungsbereiches wird praktisch angewendet, indem nur jeweils die 9. bis 13., vereinzelt 15 Reihe entnommen wird und die im selektiven Teil mit Motorsäge gefällten Bäume mittels leichter fernbedienter Traktorenseilwinde spitzwinkelig auf die Arbeitsgasse gezogen werden, wonach alle Bäume mit EPAK-4 entastet werden können (Bernauer Verfahren). Die Reihenentnahme mit diesem grösseren Abstand ist bis zur Bestandesmittelhöhe 14 m und bereits bei einem Bestockungsgrad von 1,0-1,1 anwendbar.

Eine Variante dieses Verfahrens ist die Bearbeitung in zwei Stufen: Zuerst wird nur das ganz dünne Material entnommen und zu Faschinen verarbeitet oder nach Zopfung gehackt. In dem so leichter begehbar gewordenen Bestand werden sodann die dickeren Exemplare, insbesondere die Protzen, gefällt, auf die Gasse gerückt und entastet.

Für den Gesamtprozess von der Fällung bis zur abfuhrgerechten Lagerung der Stangen wird eine Normzeit von 103 min/m^3 benötigt.

Ein in der kombinierten Kiefernjungbestandspflege versuchsweise eingesetzter Kranharvester vom Typ FMG 0470 erbrachte infolge des hohen technischen Reifegrades der Maschine und der Perfektion des Bedieners eine hohe Produktivität beim Fällen und Aufarbeiten (80-110 Bäume/h im Tagesdurchschnitt). Dieser Vorteil ging aber durch die für das Rücken ungünstige Ablage sehr kleiner Schichtholzhaufen (im Mittel 2-3 Bäume zu insgesamt etwa 0,06 m^3) in dem auch nach der Durchforstung noch dichten Bestand teilweise wieder verloren.

Den wesentlich grösseren Anteil an den Verfahren nimmt die selektive Kiefernjungbestandspflege ein. Sie wird auch bei der ersten Pflege der aus dem optimalen Höhenbereich herausgewachsenen Bestände und bei den Folgedurchforstungen der nicht durch Reihenentnahmen dicht aufgeschlossenen Bestände sowie fast ausschliesslich bei Fichtenjungbeständen angewendet.

Allen Verfahren ist gemeinsam, dass die mit Motorsäge abgeschnittenen Bäume aus zwei benachbarten Reihen durch Chokerseilzug mit leichten Traktorenwinden oder mit Kleinseilwinden zu Boden gebracht und bündelweise an die meist quer zu den Baumreihen verlaufenden Rückegassen gezogen werden. Diese "Queraufschlüsse" sind 4 m breit und im Abstand von 60-80 m angelegt.

Werden nun entastete Stangen zur Weiterverarbeitung auf zentralen Holzausformungsplätzen benötigt, so folgt das Rücken der Baumbündel auf Gestelle oder Abfuhrwege zur Entastungsmaschine EA 20, die an der 3-Punkthydraulik eines leichten Standardtraktors angebaut ist. Mit einem leichten Manipulator werden die vor der Maschine abgelegten Bäume den Durchzugswalzen und dem Dreimesseraggregat zugeführt, mit hoher Geschwindigkeit entastet (6 m/s) und dann von einer Aufgestellten Prallwand abgebremst. Dadurch entstehen abfuhrgerechte Stangenpolter. Infolge der relativ engen Kopplung zwischen Rücketraktor und Entastungsmaschine entstehen dabei öfter Kopplungsverluste. Dennoch können mit diesem einfachen Maschinensystem durch 2 Arbeitskräfte 300-500 Stangen pro Schicht mit einem Durchmesser im Bereich der Äste bis zu 15 cm angerückt und entastet werden.

Da ein grosser Teil des Dünnholzes bereits im Wald zu 2 m langem Schichtholz eingeschnitten werden muss, wurden die Bedingungen für einen speziellen Dünnholzprozessor erforscht und anhand eines Forschungsmusters näher untersucht. Dabei zeigte sich, dass im Interesse einer Anpassung an Absatz und Verwertung eine automatische Sortierung nach zwei variablen Durchmessergruppen erforderlich ist. Wegen des geringen Stückvolumens (0,025 m^3/Baum) ist ferner ein Sammeln der ausgeformten und sortierten 2 m-Stücke auf der Maschine in getrennten Behältern und die Ablage in grösseren rückegerechten Haufen eine wichtige Voraussetzung für eine effektive Gestaltung des Gesamtprozesses. Der Staatliche Standard schreibt darüber hinaus vor, dass eine Längentoleranz von $\pm$ 2 cm nicht überschritten werden darf.

All diese Forderungen sind erfüllbar, wie am Forschungsmuster DP 25 mit seinen Prinziplösungen nachgewiesen werden konnte. Bei einer Operativzeit pro Zyklus von 0,66 min/Baum, entsprechend 90 Bäume/h, können somit in den unteren Stückvolumengruppen 2-3 m^3 Dünnholz je Stunde bearbeitet werden.

Um den Einsatz auch in etwas älteren Beständen mit einzelnen dickeren Bäumen zu ermöglichen, wurde der max. Berarbeitungsdurchmesser mit 25 cm realisiert, so dass in solchen Beständen trotz längerer Zykluszeiten bis zu 5 m^3/h ausgeformt werden können.

Dieser Dünnholzprozessor arbeitet auf den "Queraufschlüssen". Das Ergreifen der einzelnen Bäume aus den am Ende der Reihen zusammengezogenen Baumbündeln mit dem Hydromanipulator wird einzeln gesteuert. Das Entasten, Zerschneiden, Sortieren und Sammeln bis zum eingestellten unteren Grenzdurchmesser erfolgt vollautomatisch. Sobald ein Behälter mit 0,4 m^3 Schichtholz gefüllt ist, wird es auf den Boden entleert. Das Rücken dieser Haufen erfolgt mit einer darauf abgestimmten Schichtholzrückezange am kleinen Standardtraktor oder einer doppelt so grossen Zange am stärkeren Traktor. Infolge der kurzen Zeit zum Ergreifen und Ablegen einer oder zweier solcher vorbereiteten Rückelasten ist dieses Verfahren auf den kurzen Entfernungen bis etwa 100 m produktiver als ein Forwarder, unter allen Entfernungen aber wesentlich billiger.

Sind aus dem Dünnholz der selektiven Pflege Hackschnitzel mit Rinde zu produzieren, so werden die zusammengezogenen Baumbündel gezopft und dann vom Traktorenanbauhacker, der auf den Queraufschlüssen operiert, aufgenommen. Beim Einsatz leistungsfähiger Grosshacker werden häufig wegen ihrer besseren Auslastung die Teilbäume vorher auf Wegen und anderen holzfreien Stellen in grösseren Mengen konzentriert.

Während das aus den Durchforstungen mittelalter Bestände anfallende Holz zu etwa 70% auf zentralen Holzausformungsplätzen aufbereitet, sortiert und verladen wird, werden für die Dünnholzausformung gegenwärtig noch zahlreiche stationäre und schienengebundene Anlagen auf zentralen Plätzen errichtet. Sie werden mit entasteten Stangen, vereinzelt mit gezopften Bäumen, beliefert.

Eine Hauptlinie der <u>zentralen Dünnholzaufbereitung</u> besteht in der einzelstammweisen Bearbeitung durch Messeinrichtungen, Sägen, Längs- und Querförderer, Rotorentrindungsmaschinen, Sortier- und Sammelanlagen, um eine optimale Sortenaushaltung für unterschiedlichste Verwendungszwecke zu sichern. Spezielle Ausrüstungsvarianten enthalten in wenigen Fällen eine vorgeschaltete Feinentastung, häufig das Hacken aller Reste. Eine grosse Bedeutung besitzt die Ausformung speziell dimensionierter Sorten und ihre Weiterverarbeitung zu Produkten für Landwirtschaft, Bauwesen, Siedlerbedarf, Erholungsbauten usw. An Massenprodukten fallen Schichtholz für Zellstoff- und Plattenindustrie und weisse Hackschnitzel an.

Als zweite Hauptlinie befindet sich in der Überführungsphase die Aufbereitung von Dünnholz und weiteren Holzreserven wie Stückreste, Stockholz, Schadholz, Schwarten u.a. zu hochwertigen Hackschnitzeln ohne Rinde für die Sulfit- oder Sulfatzellstoffindustrie. Dazu wurde in der DDR eine Trockenentrindungstrommel-, Hack- und Siebanlage (TEHSA) entwickelt und produziert, deren Kernstück die Entrindungstrommel mit 10 m Länge und 3 m Durchmesser ist. Sie ist mit speziellen Messern und Auslassöffnungen versehen, wodurch auch die Bearbeitung von Baumteilen mit Ästen ermöglicht wird.

Zur Anlage gehören ferner eine Einschnittsäge für Stangen- oder Baumbunde, eine Rückführung für ungenügend entrindete Holzstücke, der Hacker, die Siebanlage mit Rückführung zu grosser Hackschnitzel in den Hacker sowie die Fördereinrichtung. Bei entsprechender Fahrweise kann der im Hackgut verbleibende Rindenanteil je nach Bedarf bis auf unter 0,5% reduziert werden, z.B. bei Fichtenhackschnitzeln für die Sulfitzellstoffproduktion.

Es deutet sich an, dass die projektierte Jahreskapazität von 24 000 m^3 Hackschnitzel im dreischichtigen Betrieb mit 4 Bedienungskräften wesentlich überschritten werden kann.

Zusammengefasste Erkenntnisse

- Der grosse Umfang der Jungbestandspflege in der DDR und die unterschiedlichen forstlichen Absatzbedingungen erfordern eine Vielfalt technologischer Verfahren der Gewinnung und Verarbeitung von Dünnholz. (Zusammenstellung der Wesentlichsten produktiven Verfahren siehe Schema 1.)

- Die Mechanisierung nur des Fällvorganges lässt sich nicht ökonomisch gestalten; eine Kombination von mindestens zwei Arbeitsverrichtungen ist erforderlich.

- In jedem Fall ist in den dichten Jungbeständen das entnommene Material in langem Zustand (mit oder ohne Äste) mindestens bis an den Rückeweg zu bringen.

- Der Einsatz von Prozessoren in der Jungbestandspflege ist besonders dann effektiv, wenn sie automatisch sortieren und das Schichtholz sammeln und in rückefähigen Haufen ablegen.

- Das Rücken mit Standardtraktor und Schichtholzrückezange ist dann bei den vorherrschenden kurzen Rückeentfernungen ökonomisch wesentlich günstiger als mit Forwarder.

- Die aus anderen Ländern bekannten Prozessoren entsprechen unter den spezifischen Bedingungen der Jungbestandspflege in der DDR nicht den technologischen und ökonomischen Erfordernissen.

- Ein Harvestereinsatz in der Jungbestandspflege erscheint aus gegenwärtiger Sicht nicht möglich oder ökonomisch nicht tragbar.

- Es existiert jedoch keine begründete scharfe technologische Grenze zwischen der Dünnholzgewinnung in der Jungbestandspflege und der Durchforstung mittelalter Bestände.

- Bei der Weiterentwicklung der Verfahren und Maschinen zur Dünnholzgewinnung sind die vielfältigen Anforderungen der Ausformung und Verwertung zu berücksichtigen.

Schema 1: Wichtige produktive Varianten der Dünnholzgewinnung in der DDR

Bereitgestelltes Sortiment / Art der Gewinnung	Ganzbäume, grob entastete Bäume	Stangen (L1/L2)	Hackschnitzel mit Rinde	Hackschnitzel mit Grüngut	Schichtholz (m. R.)
Kombinierte Jungbestandspflege – Entnahme 5. - 7. Reihe		. MKS . EPAK . FEPAK	→ Mobilhacker		
– Entnahme 9. - 13. Reihe		. MKS . SW . EPAK FEPAK	→ Mobilhacker		
Selektive Jungbestandspflege	. MKS . Tr/SW	. MKS . Tr/SW . EA 20		. MKS . SW . Mobilhacker	. MKS . Tr/SW . DP 25
Bestandesaufschluß	. MKS . Tr/SW	. Makeri . FEPAK			. MKS . DP 25 . Kranproz.
frühe Vornutzungen		. Makeri (FEPAK)			. MKS . Kranproz.

MKS - Motorkettensäge
Tr/SW - Traktor mit Seilwinde
EPAK - Entastungspaketiermaschine
FEPAK - Fäll-Entastungspaketiermaschine
EA 20 - Dünnholzentastungsmaschine am Standardtraktor
DP 25 - Dünnholzprozessor

WORKING METHODS IN THINNINGS
LOGGING SYSTEMS AND WORKING TECHNIQUES

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SUMMARY

In 1988, thanks to a very favourable economic conjuncture in France, and at the European level, with an important economic resumption, new investments are made, specially in forest industry, with the modernization of mills and new softwood projects.

Sofwood forest, alone, represents a standing volume in excess of 640 M m^3, with an annual increment of about 27 M m^3 (or on the average, 5.7 m^3/ha/year). Only 60 % of the increment is presently harvested.

The autor gives an insight into the logging of first thinning and the foreseeable evolution for the coming years.

Concerning silviculture, selective thinning is no more practiced because of logging difficulties and growing mechanization. A more progressive silviculture is taking place with line thinning removing every third or fifth row. Marking of the first thinning, though still in use, is more and more questioned. In some regions, it is left to the feller or machine operator.

Concerning logging of first thinning, it is still a manual operation in 95 % of the cases, only 5 % of wood being mechanically harvested, but a more pronounced interest is appearing for harvesters, replacing a scarce manpower. Machines ar being adapted to the forest, and silviculture is adapting to logging machines.

Thus, new thinning methods, taking every fifth or third row, or up to 50 % of the trees , develop rapidly. On the other hand, the sales of harvesters well adapted to French conditions increased by 50 % within a year, SIFER machines being the most frequently sold.

Extraction is fully mechanized and forest machines with 6 or 8 driven wheels are presently very successful for they reduce soil damages. In 1988 these machines accounted for 80 % of the forwarders sold in France.

As a conclusion, the first observations since the mechanization of forest logging, which is now in a period of fast evolution, showed the importance of the training of manpower, as well as managers or loggers.

INTRODUCTION

French forest, with 14 millions ha, is the most important one of EEC countries. Softwood occupies 34 % of the wooded area, or more than 4,500,000 ha. Maritime pine and Scots pine account for over the half of this area.

The annual increment of softwood forest is of about 26,700,000 m^3, or 6 m^3/ha/year. In 1988, logging produced 16,500,000 m^3 softwood timber. France has an important softwood potential.

Pulp and paper projects in France (capacity increase and new mills) create a change in forest logging, the first effect of which are becomming evident.

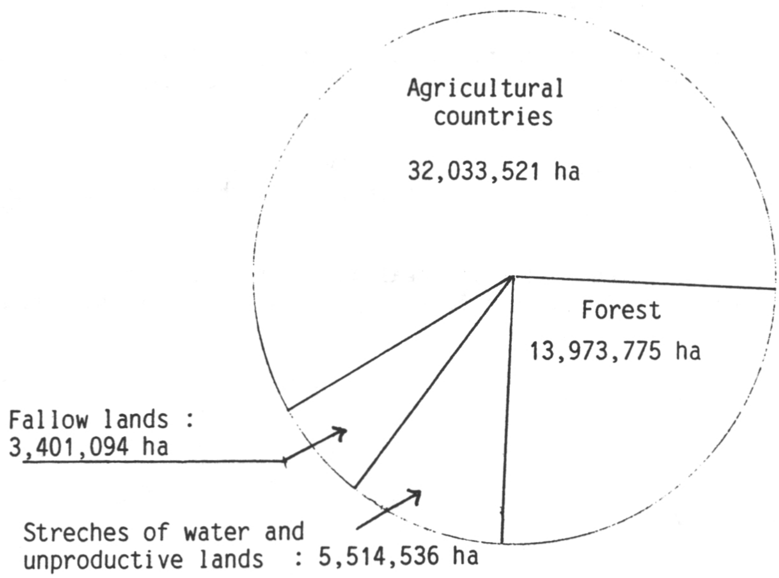
With this context in mind, we shall deal about first thinning in this country, as it is done in 1989 and the foreseeable evolution for the coming years.

1 - INTRODUCING FRENCH FOREST

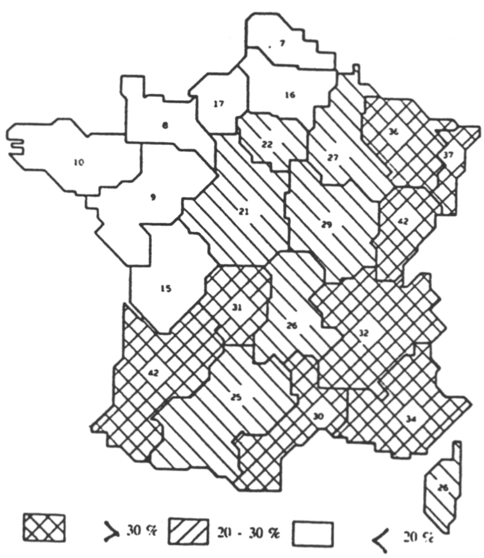
1.1 - Area

French forest (production and protection forest) covers 14 millions hectares, on a forested ratio of 25 % of the total area. This area is increasing for the middle of the XIXth century.

- Distribution of the national area (54,923,000 ha)



- Percentage of the wooded area in each economic region



1.2 - Species

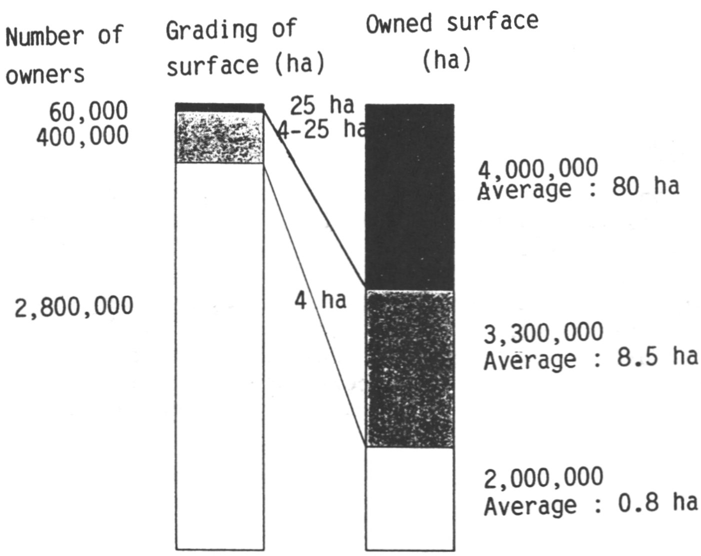
Hardwoods are the most important species, with 66 % of the area, 34 % are planted with softwoods. The following tables show the importance of each species :

Hardwoods : 66 %	
Oak	33 %
Beech	9 %
Chesnut	4 %
Misc	20 %

Softwoods : 34 %	
Maritime Pine	10 %
Fir. Spruce	9 %
Scots Pine	8 %
Misc	7 %

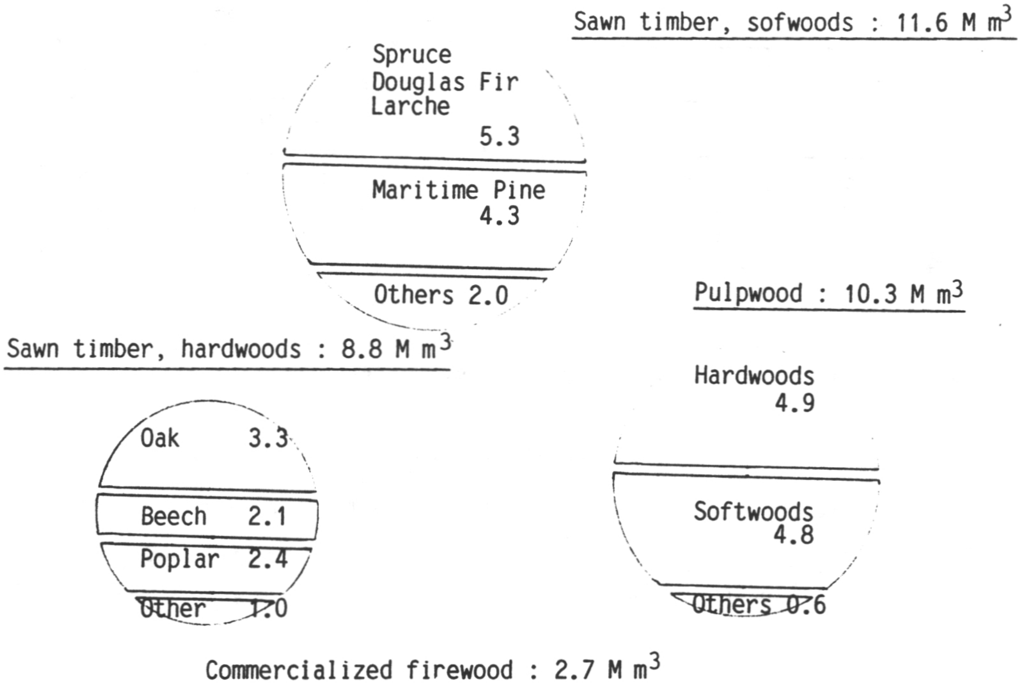
1.3 - Distribution and structure of forest ownership

- The state owns 2,500 forests, or about 1.7 million hectares.
- Communities own 14,000 forests, or about 2.6 millions hectares.
- Privates owners : 3.3 millions owners for 10 millions hectares. The following table shows the structure of private forest :



1.4 - Production

The total increment amounts to about 66 millions m³ a year. In 1987, logging amounted to 33.4 millions m³. It should be added to this figure timber logged for self consumption, which is not sold via the usual commercialization network. Its estimated volume is 10 millions m³.



2 - FIRST THINNING

2.1 - Introduction

The development of a stand depends on the time of the first thinning. For determinning the time of the first thinning, foresters use one among several methods :

- The increment borer for extracting increment cores, on which the width of rings can be measured and a possible decrease in diameter growth be observed. But this method necessitates the taking of a great number of cores and the effect of competition appears only after two or three years of reduced growth, that is too late.

- The hart-becking spacing factor : a ratio between the average distance between stems and the dominant height :

$$S\ \% = \frac{a\ (cm)}{h\ dom\ (m)}$$

Successive thinnings will increase the value of "a", so as to maintain a roughly constant spacing factor. The usually recommended values, after thinning, are the following :

Larch $24 \leq S \leq 26$ %

Douglas fir $22 \leq S \leq 24$ %

Scots and laricio pines $20 \leq S \leq 22$ %

Norway spruce and grand fir $18 \leq S \leq 20$ %

- The ratio height/Diameter (h/D), which is a very good stability index. This ratio increases if no thinning is done. Values often cited as an indication of the moment of the first thinning are 80-90 for Norway spruce and 60-70 for Douglas Fir ; in the most frequently only late thinning is done, for obtaining commercial product, and with a low intensity for not endangering the stand stability.

- The basal area : from 25 m^2 onward, it should be thinned to reduce this value to 15 m^2.

The following table shows the extreme densities, the age of the stand at the time of first thinning and the percentage of merchantable stems (DBH > 8 cm) :

	Theoretic density		Age	Harvested percentage
	Mini.	Maxi.		
Spruce	2,000	6,000	15-30	85-80
Douglas Fir	1,000	2,500	13-25	95-75
Scots Pine or other	3,000	8,000	18-30	85-40
Maritime Pine (South West)	1,000	1,500	15-20	95-70

Planting density is different according to the species and the region. In eastern France, density are very high (up to 10,000/ha) while plantations in Limousin and western France were done at much lower densities. From the point of view of mechanization, dense plantations are difficult to tend because of a too narrow spacing between rows and the first thinning yields products with a small diameter which is not easily sold.

2.2 - Different types of thinning

- Line thinning

It is done in young stands, at the time where competition between trees appears. The method consists in systematically cutting each n line, usually each third one. Trials conducted by AFOCEL showed namely that when cutting each fourth line, the remaining middle line does not profit by the thinning. On the other hand, there is no easy access to all trees at the time of the second thinning.
Openings created by cutting on line must be sufficiently wide for an easy access of machines without wounding the remaining trees.
In dense plantation, two lines must often be cut.
From a pratical point of view, this type of thinning gives an easy access to all stems and makes manual or mechanical logging easier. No marking is needed.

- Thinning each third line and selective thinning

Line thinning, which is very favourable to logging, has the drawback, from a silvicultural point of view, of making no selection in the contiguous rows and the second thinning will still produce an important quantity of pulpwood.

In order to overcome this drawback, while harmonizing logging and modern silviculture, we are conducting, for some years, a line thinning taking each third row and a selective one in the contiguous rows. From a pratical point of view, this method has the same advantages than the line thinning. For not loosing the benefits of line thinnings and increasing the costs of logging, selective thinning must not be a mere cleaning but should take at least 25 % of stems in the contiguous lines. For a good distribution in the stand and a maximum increment, there should not be four consecutive stems left after logging. Marking of the trees is not useful. Precise indications to the feller and a careful survey of the stand should be sufficient.

- Selective thinning with strip roads

It consists in opening a corridor each fourth, fifth line, or more, and conducting a selective thinning between these corridors. Conducted in stands with high or heterogenous trees in which a line thinning would be dangerous or inadapted, it presents no interest in young stands where the average volume of trees selectively thinned would be too low. This type of thinning can be mechanized to some limits (often every fifth row), except on strong slopes.

Marking is not needed, a well trained feller can easily perform it for he has a good visibility as the felling of trees progresses. (The selection of crop trees will be made after the first thinning.) Constraints bound to logging should nevertheless always be taken into consideration.

- Selective thinning

Mechanization is not possible when applying this method except when corridors were planned at planting time for the circulation of machines or when spacings are wide. This is the case of numerous maritime pine stands in south western France and of low density plantations (L 1,000 stems/ha).

In the other cases, mechanization of logging will be possible only for the second or third thinning. Marking is difficult and time consuming, felling is a very hard work and logging costs are prohibitive. This method is no more applied to first thinning.

2.3 - Intensity and production of a first thinning

Volume collected in a first thinning is directly related to the intensity of thinning and to the average volume of the stem.

In a line thinning, taking each n line, 1/n of the number of stems and 1/n of the standing volume is harvested. Stands thinned in due time were generally thinned in this way (usually 1/3) and produce 40-60 m^3/ha.

In a line thinning, taking each third row followed by a selective on with a 25 % intensity, the selective thinning takes 15-20 % of the volume of the two remaining lines.

In selective thinning with striproads, the volume harvested depends on the width between striproads and on the intensity of the selective thinning.

Production generally varies between 70 and 120 m^3/ha.

2.4 - Marking

Who performs it ?

- In state forest, it is performed by a forester of the National Board of Forests.

- In private forests, it is much more complex. Few owners were trained to marking and are able to perform it, in fact, private forest owners are rarely foresters. They often commit an experience person with marking. More rarely, there is no marking at all and the logger just receives some more or less precise indications.

How is marking performed ?

There is a silvicultural aspect and another one concerning the method of marking. Let us consider two externe cases :

<u>1st case</u> : First thinning is only selective, with a few, distant striproads. Each tree to be cut is marked with a blaze on the stem and receives a stamp, the operation is repeated on the stump (for an easier control after logging). A survey is then carried out : the diameter of all marked trees is measured and trees are classified. Competing species (as hardwoods in a softwood plantation) are also marked.

<u>2nd case</u> : First thinning is a line thinning taking each third line, only the first tree of the lines to be felled will be marked with paint.

The first cases is rather rare, the second one occurs more frequently. All intermediary cases are possible.

One observation should be made concerning marking a selective thinning with striproads, specially when striproads are laid by taking each fifth row : marking the selective thinning is a real difficulty if striproads are not carefully set. It occurs namely frequently that the marker working in the stand is no more able to recognize which line was set as a striproad. Practically, each stem of the striproad should be marked, a rather time consuming operation ! A solution would be to log first the trees of the striproad, then to mark the selective thinning, but it is generally impossible to apply.

What does a marking operation cost ?

The time spent in marking a first thinning is variable : according to the stand itself (species, density, undergrouth, pruning, topography), to the type of thinning to be marked (selective, selective with striproads, line thinning), to the method (blaze only, blaze and stamp on the stem and the stump, paint ...) and in some cases to the time spent in serveying the marked trees.

On the average, for a selective thinning with striproads, the time spent is about 0,75 day/ha.

For a forester with an annual salary of 100,000 FF (160,000 FF including social charges), the cost of a working day amounts to 750 FF, travel and lunch expenses should be added : 1,000 FF can be considered as a minimum.

Thus, marking costs about 1,100 - 1,350 FF/hectare. With a yield of 40 m^3/ha in first thinning and an average cost of 1 200 FF/ha, marking costs 30 FF/m^3 or 10 FF/ton.

How is logging conducted ?

Two cases may occur :

- Logging is manual, realized by fellers with chainsaws.

- Logging is mechanized or semis mechanized, with logging machines which, in the case of a full mechanization, fell, trim, top, crosscut and stockpile. This last working technique is not yet usual, but these is a fast evolution because of the lack of loggers for thinning.

In both cases, marking can be performed by the feller as his work progresses, but he must always take the logging machines into account to prevent damages to the remaining stand. This is possible thanks to some elementary rules :

- Striproads must be sufficiently wide for an easy circulation of machines : at least 4 m,

- On slopes, striproads must follow the slope,

- Machines, and more particulary forwarders, must have an easy access out of the stand,

- Striproads must be opened at both ends,

- Access to selectively thinned trees, must be easy,

- Etc ...

3 - LOGGING FIRST SOFTWOOD THINNING

Supervision of thinning is done :

- Either by the owner, eventually with the assistance of a private cooperative which logs and for sells timber,

- Or by as company which buys standing timber (forest logging compagnies often own a sawmill),

- Or by subsidiaries from by mills.

Logging methods, in a first thinning, may vary but are nevertheless a function of the machines used and of the market :

- Short length billets,

- Full length stems,

- Full trees,

- Chips.

Only the first two methods are used in France :

- short length logs (2-3 m) as pulpwood or small sawnwood,

- 3-6 m long logs sawmills.

3.1 - Harvest methods

3.1.1 - Manual felling

95 % of the volume harvested in thinning, or 4 500 000 m^3 is hand felled by loggers with chainsaws.

Loggers are often independent workers because present legislation incities forest owners to turn to independent workers rather than salaried employees. This is the reason why the number of salaried employees was reduced by the half for ten years while the number of contractors inversely increased.

Manpower is more and more reluctant to work in thinning, for logging big logs is a better paid and less hard job. And with the industrial development of C.T.M.P., thinning is becoming a much harder job with log length of 2,5 m for a better loading of waggons.

Usual costs for softwood thinning :

Norway spruce (East)	70 - 110 FF/m^3
Douglas Fir (Center)	60 - 80 FF/m^3
Maritime Pine (South West)	45 - 70 FF/m^3

Costs of logging are not set according to defined rules, as is some countries. They are often discussed with the foreman and vary according to the region and the species.

3.1.2 - Semi-mechanized logging

Mechanization in first thinning began with processors, trimming and crosscutting are namely the more time consumming operations in manual felling.

Semi-mechanized logging systems associate one or several fellers, which fell and trim the butt of the trees, and a processor.

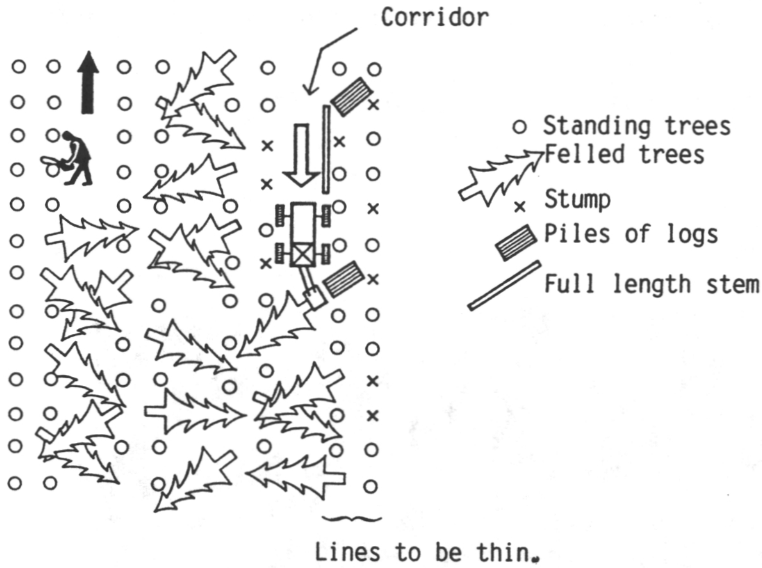
The first processors appeared in France at the beginning of the '80s. Their use developped after the windblow in central France in 1983.

SIFER 103 processors had then a big success.

Processor SIFER 103

With a 35 cm capacity, this machine can work in first and second thinning in line thinning or selective with striproads 1/3 or 1/5 and process pulpwood or small sawnwood. If spacings between striproads are wider, the machine can difficulty access to the trees to be selectively thinned.

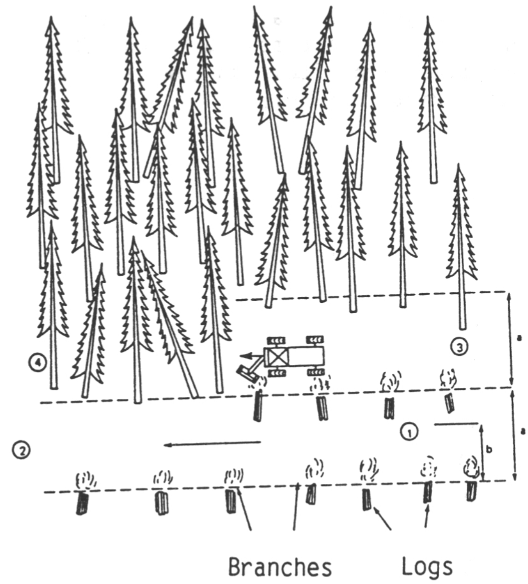
Example : second selective thinning after a first line thinning taking each third line.



The following table gives average figures for 6 processors SIFER 103 observed in 1988.

Annual output	7,400 m^3
Operating time	1,500 h
Yield	5 m3/h
Cost/hour	434 FF/h
Cost/m3	88 FF/m^3

SIFER machines were also very performant in windblows. Thanks to their conception, they can easily process windthrown trees.



1 —> 4 : working direction of the team

Organizing the work in a windblown stand.

Among semi-mechanized systems, let us also mention processor heads mounted on agricultural tractors (VIMEK), some units are use in France, but their production and costs are not yet well known.

3.1.3 - Mechanized logging

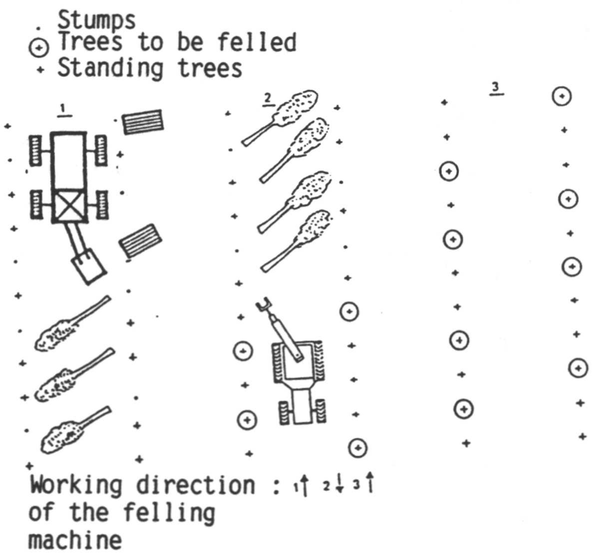
3.1.3.1 - Association of mono functional machines

Two types of machines are needed :

- One shearing head adopted to a crane mounted on a agricultural or specific tractor. The felling machine SIFER 725, with a 25 cm capacity, was launched in 1984 and was adapted to the IH agricultural tractor and to a Manitou tractor (adapted from a fork lift).

- One processor SIFER 103.

  Several units of this type are working in first thinning of maritime pine in Southwestern France. Plantations are made with 4 m wide corridors for the circulation of machine. The felling machine progresses backwards between the rows where it lays the felled trees. The processor stockpiles logs from two rows in the same one for an easier forwarding.



Selective thinning

These units are producing over 13,000 m^3/year, essentially in first thinning.

The costs per hour of a team are about 700 FF/h or 61 FF/m^3.

3.1.3.2 - Multifunctional or combined machines

The drawback of the former system lies in the investment for two machines.

Since 1987, multifunctional machines are more frequent. To date, the most commonly used are the SIFER 204 machines. They are followed by MAKERI 33 and 34T, SOGEDEP, OSA and TAPIO.

By the end of 1988, 22 such machines were in use :

- 6 fellers with chain,
- 9 fellers with shears,
- 4 processors crane mounted,
- 3 heavy duty machines for clear cuts.

They produced over 150,000 m^3, or an average 6,800 m^3/machine.

The following table sums up the data for 5 SIFER 204 logging first thinning in 1988 :

Production	7,500 m^3
Operating time	1,577 h
Yield	4,8 m3/h
Cost/h	355 FF/h
Cost/m^3	74 FF/m^3

3.1.4 - Forwarding

This operation was the first to be mechanized. To date, it is exclusively done by machines.

First thinning produces pulpwood in 2 or 2.5 m length and small sawnwood in length to 6 m. These products are skidded :

- Either by agricultural tractors with a crane and a trailer,

- Or by forwarder with 4, 6 or 8 driving wheeles.

Agricultural tractors are less expensive but they have a lower yield on forest soils. They are essentially used on flat and bearing soils. Their number is difficult to evaluate, for if a number is used all year round for this job, others are also used in agriculture.

Articuled forwarders appeared in France in 1969 and are largely used. The total number of skidding machines is estimated at more than 1,000 units. An estimation of the number of these machines working in softwood thinning is difficult for they also often skid hardwood.

The annual production varies between 8,000 and 13,000 m^3 for the smaller models and 18,000 to 25,000 m^3/year for the bigger ones.

The following tables shows the usual price for skidding in France :

- All France, except South West

<table>
<tr><td rowspan="2">Forwarders</td><td>Small capacity</td><td rowspan="2">Pulpwood</td><td>6,000 à 10,000 m^3</td><td rowspan="2">25 à
50 FF/m^3</td></tr>
<tr><td>Big capacity</td><td>10,000 à 18,000 m^3</td></tr>
</table>

- South West France :

<table>
<tr><td rowspan="2">Forwarders</td><td>Small capacity</td><td rowspan="2">Sawn wood
and
pulpwood</td><td>8,000 à 13,000 m^3</td><td rowspan="2">15 à
30 FF/m^3</td></tr>
<tr><td>Big capacity</td><td>18,000 à 25,000 m^3</td></tr>
</table>

Skidding using skylines may also be encountered in moutainous regions, but this type of skidding is generally not adopted to the silviculture as it is practiced.

3.1.5 - Parameters which influence the costs of logging first thinning.

ARMEF conducted an analysis bearing on 8 consecutive years with a semi-mechanized team. The two main factors influencing yield are :

- The organization of the working site

- The aptitude of the operator

The other ones are :

Concerning mechanized felled

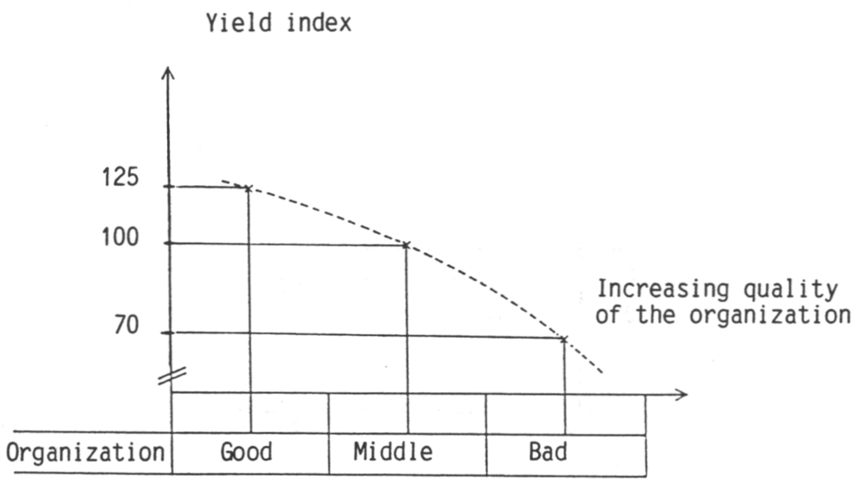
- The unit volume of trees

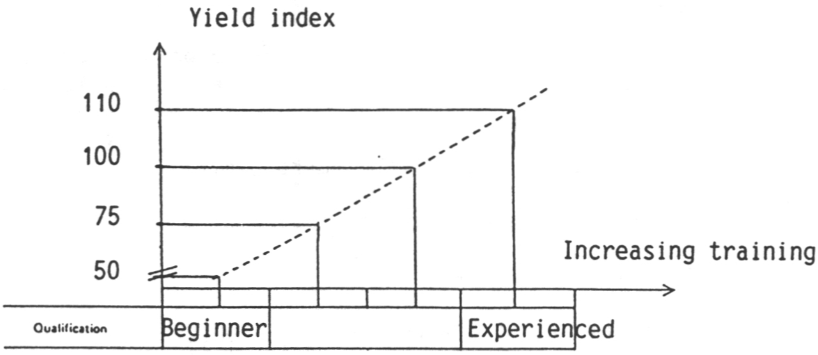
- The spacing between rows

- The volume harvested per hectare

- The type of thinning

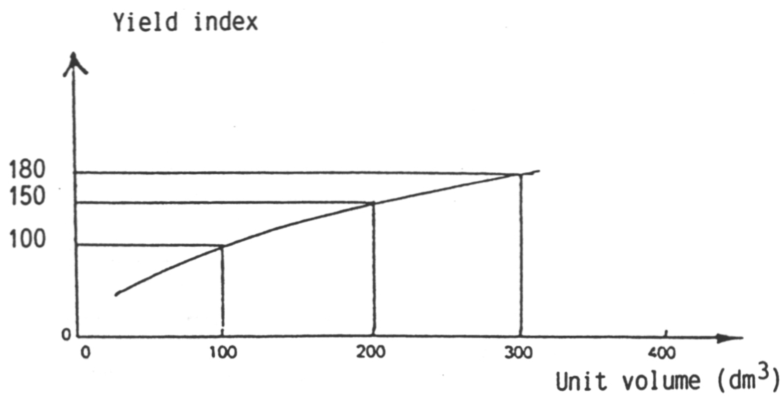
- Soil conditions





These two schemes show the importance of a good organization and of training of the operator. The production of an experienced operator is twice as high as that of a beginner.

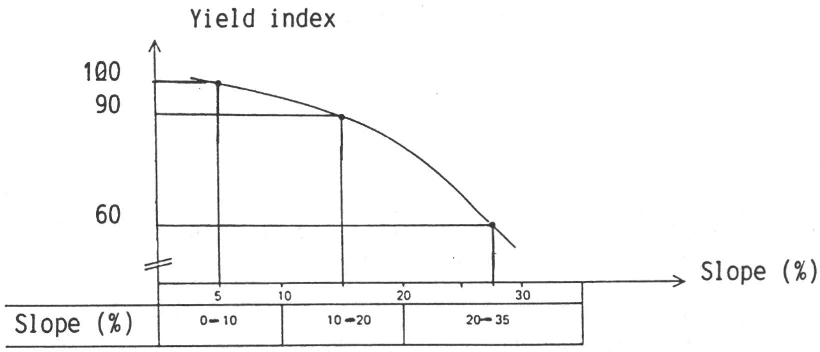
Instant yield according to the volume of stems (cut in 2 m length) :



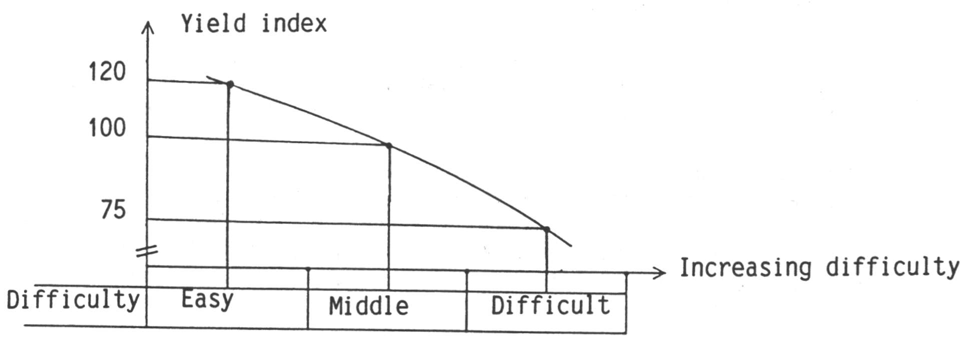
The productivity of felling machines in increased by 1,8 when the unit volume of stems is 300 dm^3 instead of 100 dm^3.

- At forwarding, the following factors are also important :

  . Slope :



  . Trail conditions :



NOTE :

We do not wish to conduct here a detailed study of all parameters which influence the costs of logging, but only to show, with some examples, the importance of the qualification of operators and of ground conditions in the formation of the logging costs.

CONCLUSION :

About 60 % of the increment of the softwood forest is harvested. There are, in fact, important variations according to the species and the regions, but this figure shows that France has an important potential.

Mechanization of forest logging with specific machines began at the end of the '60s for skidding. To date, it is fully mechanized.

Concerning felling, mechanization is more new. The mechanization level for the harvest of softwood is only of 5 % (230,000 m^3 mechanically harvested on a total 4,800,000 m^3).

Presently, industrial projects or capacity extentions are provoking an evolution in forest logging : the sale of skidding machines was doubled in 1988, and essentially machines with 6 or 8 driving wheels are sold. The sale of harvesters is also strongly increasing.

The development of mechanization necessitates a number of evolutions :

- In silviculture, where first selective thinning is no more in use (except in stands planted with corridors for circulation of machines) and is replaced by selective thinning with striproads. Marking of the trees to be thinned is questionned in first thinning and often realized by the feller or machine operator. With a well trained manpower, this method gives very good results.

- In forest logging, studies showed the importance of well trained operators. Concerning the machines, new evolutions beared on a better adaptation of machines to the conditions of french forests.

Mechanization has a broad future in France. It is the only solution for maintaining the costs of pulpwood at a level compatible with industrial constraints. It will ensure a regular supply in spite of manpower scarcity. But a better training of foresters and loggers is needed as well as a more important rapport of small contructors who are becoming more numerous.

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POSSIBILITIES OF MULTI-TREE PROCESSING IN THINNINGS

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The working conditions in thinning stands are in many ways difficult for machines. Size of stems to be removed is small, removal per hectare is small, remaining stems are hindering the work of the machine etc. The productivity of a machine is therefore usually much lower in the first thinnings than in later thinnings or clearcuttings. Thus the harvesting costs are also much higher in thinnings than in clearcuttings.

The working method for the main machine type in Finland, the single grip harvester, is to handle one tree at a time. Single grip harvesters are highly-developed and their ability to handle different size stems is very good. So the difference in the time consumption with different size of stems in primary conversion is getting smaller and smaller. The influence of the stem size on productivity is thus increasing and harvesting costs in stands with small tree size, like first thinnings, are rising in comparison with later thinnings and clearcuttings with bigger trees (Figure 1).

One way out of this is to develop the single grip harvester to be able to handle several small trees at the same time. It means stems with Dbh of about 7-13 cm which share of the total number of removed stems is very high in first thinnings (Figure 2).

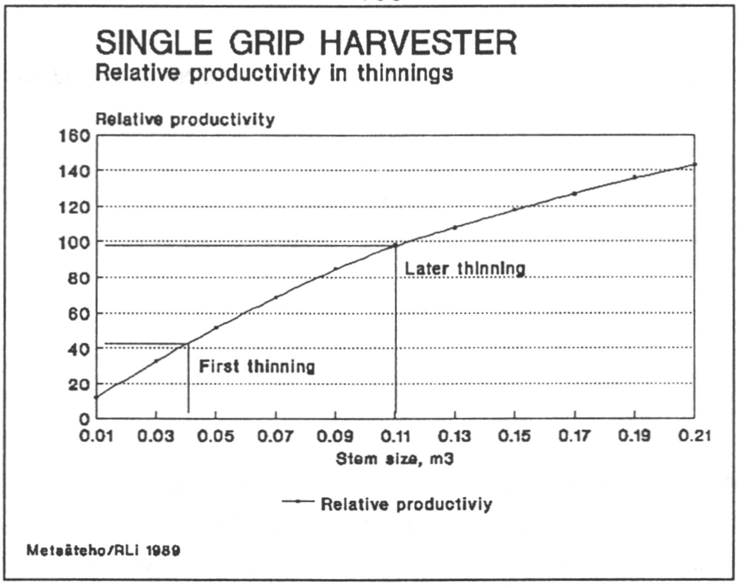

Figure 1. Relative productivity of single grip harvester in different thinnings by stem size.

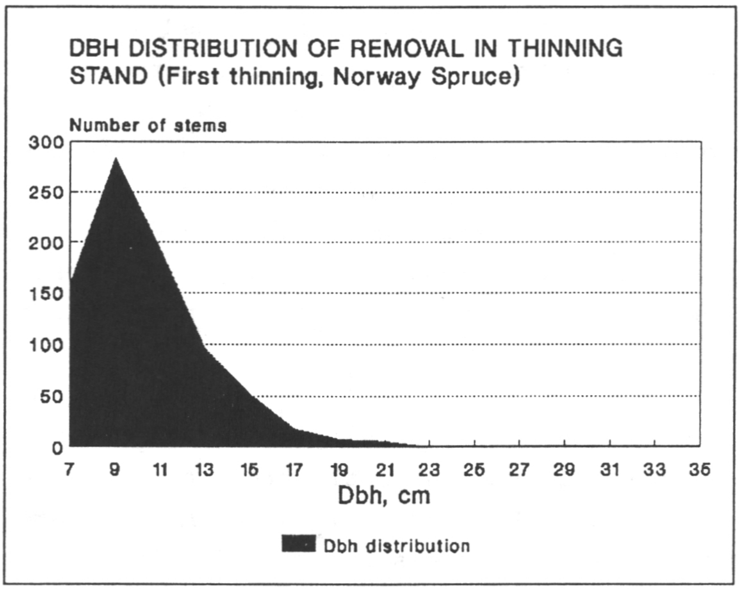

Figure 2. Dbh distribution of removal in first thinning (Norway Spruce).

Developing a machine able to multi-tree processing is very problematic. In a joint nordic project we have started by studying different feeding systems in multi-tree processing by single grip harvesters. Time studies have been made from delimbing and bucking by different single grip harvesters (Lokomo 750 H, Keto 150 and Tapio 400). Results of time studies by Lokomo 750 H are shown in Figure 3.

The main result was that multi-tree processing with a single grip harvester is a promising way to increase productivity but the machine needs special feeding systems and also the delimbing knives have to be developed to be more suitable.

A feeding system with three tracks (Keto 150) does not work in multi-tree processing well enough. The amount of stems can be maximum four but two stems is already quite difficult. It is also very sensitive to differences in diameters of stems in the bunch to be processed at the same time. The stepfeeding system with two rollers is not much better (Tapio 400).

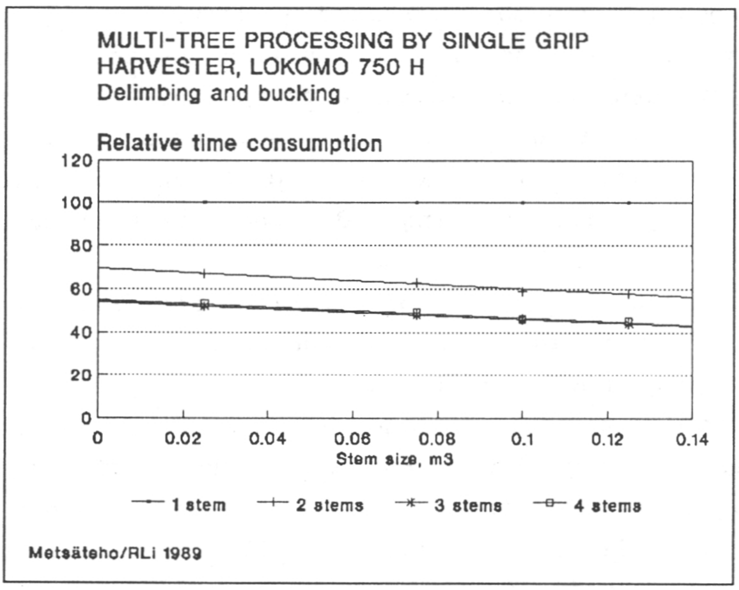

Figure 3. Relative time consumption in multi-tree processing (delimbing and bucking) by Lokomo 750 H.

The best feeding system was with four feeding rollers (Lokomo 750 H). Four trees can be processed at the same time and the time consumption per tree is lower than in processing three stems at a time.

The delimbing quality in multi-tree processing by different single grip harvesters did not differ much but the delimbing quality was much lower than in single tree processing. The solution to a better delimbing quality can be to use delimbing knives which each are designed to be steerable.

The time consumption per tree by multi-tree processing with single grip harvesters was lower than in single tree processing. So multi-tree processing seems to be a potential way to increase productivity when harvesting small trees.

There are many problems to be solved and one is felling for multi-tree processing. Felling has to be done by the single grip harvester including primary conversion. A separate felling machine or manual felling for the processor will be too expensive and the increased productivity in multi-tree handling will be loosed. The felling system on single grip harvester has to be designed to accumulate 2-4 trees for processing. In accumulating all movings of trees have to be done in vertical position. Different techniques for accumulating, cross cutting and crane work will be tested.

The base machine has to be stabile and its crane strong enough to move many stems at the same time. Base machines like those we now have in our medium sized harvesters are very stabile and their cranes are strong enough but smaller machines will have great problems to use multi-tree technique in primary conversion. So the size of machines used in thinnings will not become smaller if the multi-tree processing is going to be used.

LOGGING TECHNOLOGIES AND UTILIZATION OF BIOMASS FROM THINNINGS

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1. Introduction

Technologies of timber logging in thinnings are taking into consideration natural conditions, tree species composition and the structure of stands. Predominantly mountainous character of the terrain with long and steep slopes limits the utilization of technologies which comprise machines moving in stand during their operation. Density of stands precludes the movement of machines in stand. This is the reason for developing of technologies with machines moving on skid roads.

2. Technologies of logging in thinnings

Felling is performed by one-man powersaw. With regard to mountainous character of terrains logging machines or harvesters have only limited usability. Stands, especially which were after logging regenerated through natural regeneration, are very dense. Therefore the greatest problem is to ensure directional felling in such way that trees are lying in the direction optimal for following yarding to skid roads. The technology with double-drum winch attached to agricultural tractor has proven the best. Each drum of winch has independent radio remote control. Each winch is controlled by one feller. Tractor stands on skid road. From first winch cable is led forward and from second winch backward from tractor. Directional pulleys lead first cable into working field to the right from road and second cable into working field to the left from road. One feller works in each working field. He fells tree by powersaw, clamps tree in cable and switches on winch by radio remote control and skids tree to skid road.

After the cable is disengaged from tree yarded to road it is led to another tree and technological process is repeated. In thinner stands several trees can be led simultaneously to skid road. Through this technological process the greatest effectivity is reached and losses to remaining trees and soil are the smallest. Schema of the technology is in figure 1.

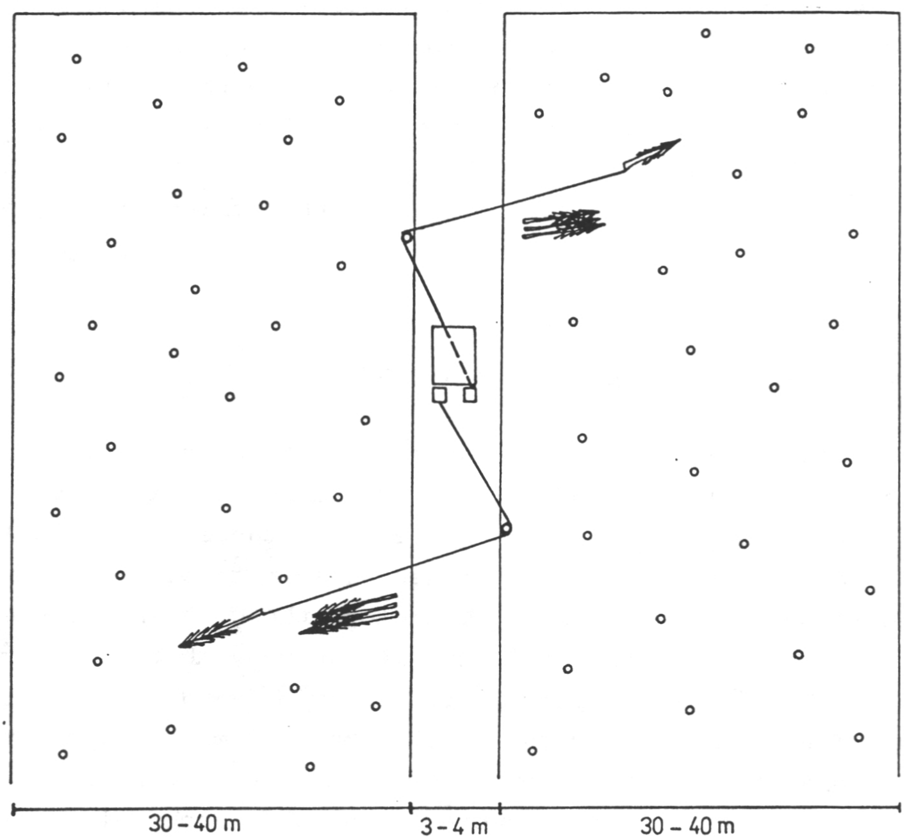

Figure 1. Schema of felling and yarding of trees with the use of tractors with double-drum winch. Drums are radio controlled.

Whole trees are skidded from stand to landing and they are limbed and bucked here by limbing maschines or by processors. Large amount of branches is consolidated at landings. These branches were recently burned without any effect directly at landings. In the case that burning of branches was not possible due to near stands, buildings, or other reasons, the storage capacity of landings was reduced for long period ahead and these heapes of branches became suitable place for the spreading of forest pests. Therefore it was necessary to solve the processing of this raw material from the viewpoint of its utilization, as also from technological viewpoint.

The utilization of branches consolidated beside limbing machines made possible the introduction of chipping technology by mobile chippers. By chipping of branches we get more homogenous material suitable for further transport and handling.

Next step was to solve the utilization of this raw material. With regard to known problems of its processing in woodworking and pulp and paper industry we looked for nontraditional method of the utilization. The utilization for feeding and energetic purposes was chosen to be further studied, verified and introduced into production.

3. The technology of tree foliage utilization for feeding purposes

Branches collected beside limbing machines are chipped by mobile chipper. Chips are blown out from chipper directly into containers and then they are transported into the mill for the production of feeding flour. This mill was constructed on the basis of agricultural machines and equipment manufactured in serial form.

Chips are unloaded in intake hall and they are carried by a system of conveyers into sorting machine SIKO-2. Wood is unrequired part of feedstuff since it reduces its digestibility and therefore it must be sorted out from the chips. Sorting machine is operating on pneumatic principle. Lighter tree foliage in vertical pipe is sucked into bin and heavier wood fractions in upper part of pipe on the conveyer. Tree foliage includes not only needles but also all lighter particles of bark, wood, non-woody thin branches and buds.

Sorted tree foliage is transported by system of conveyers into drum drier where it is dried, reaching the moisture contents 10-12 %. Dried tree foliage falls into grinder where it is milled into feeding flour. Flour can be transported by pneumatic system on packing line and dispatched in sacks to consumers, or it is transported to bins which are part of granulating line. On granulating line hay, straw, groats, molasses, vitamin-rich components, biofactors and other feeding components are added into flour and granulated feedstuffs are produced according to receipts for particular kinds of animals. Annuals capacity of pilot plant with one shift per work-day is 500 tons of flour and 2500-3000 tons of granulated feedstuffs.

Energetic requirements of flour drying were one part of this solution. With artificial drying of agricultural products heating oils or gas are used as a source of energy. With aim to eliminate the use of these sources a furnace for the burning of sorted wood fraction was finished. Offtake of combustion gases is conveyed through drier and whole regime of heating is connected to automated regulation of drying.

At present another technological part of tree foliage distillation is added to pilot plant. According to opinions of specialists from the field of livestock physiology (Gallo et al. 1987) with high doses of flour rumen digestion of animals can be affected by ethereal oils from tree foliage.

Therefore tree foliage will be distilled before drying and in such way ethereal oils will be removed from it. These oils will be used in chemical industry.

With produced flour feeding trials of farm animals and forest game were made.

As to farm animals trials were made with lambs feeding. Control group was fed by traditional feedstuffs and in experimental group 9 % of flour from tree foliage was added to feedstuff. During additional feeding by flour from tree foliage mean daily increments increased by 11,5 % and the utilization of feedstuff improved by 7,9 %. During commissional evaluation of cooked meat, cooked liver and meat both any negative effects of flour from tree foliage were not found.

Feeding experiments of suckling sheep with lambs were made too. 4 % and 8 % of flour from needles was used as an additive into traditional feeding dose. In experimental group with 4 % addition the increment of lambs increased by 12,8 % in comparing with control group. In experimental group where 8 % of flour was added the increment of lambs increased by 16,7 % in comparing with control group. It is supposed that these differences resulted from the positive effect of flour on health state of mothers, production and biological value of milk, and thus on good health state of lambs (Gallo et al. 1987).

5. Conclusion

Tree foliage was recently unused raw material. Modern logging technologies make possible to utilize also this material. The results of experiments have shown that flour produced from tree foliage can be valuable feeding addition with specific, effective substances for additional feeding of farm animals and also forest game.

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THE DEVELOPMENT OF FOREST MACHINE TRAINING IN FINLAND

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Forest machine training is composed of a one year introductory course in forestry (general studies) followed by basic vocational training in operation of forwarders and machines for forest improvement and forest machine mechanics. Logging machine operators are trained in a follow-up course organized for forest machine operators with some work experience and for anyone who has already completed basic forest machine training. In addition, currently employed forest machine workers can take part in short upgrading courses and business training.

The state forestry colleges introduced basic training courses in

- forest machine operation in Rovaniemi in 1966;
- operation of machines for forest improvement in Taivalkoski in 1967;
- forest machine mechanics in Rovaniemi in 1969;
- logging machine operation in Jämsänkoski in 1988

In Finland, the mechanization of forest work began in the mid-1950s with the use of farm tractors, and then the forwarders came onto the scene in the 1960s. The degree of mechanization in logging is about 34% at present and nearly 100% for forest improvement and soil preparation. The mechanization of logging is still increasing rapidly, being at its highest in central Finland, nearly 60% in some areas. Mechanization in artificial regeneration and nursery management is still at the experimental stage.

Of the 25 forestry institutes in Finland, 7 provide forest machine training: Jämsänkoski, Kullaa, Kuru, Mikkeli, Rovaniemi, Taivalkoski, and Valtimo. The forestry colleges in Jämsänkoski, Rovaniemi and Valtimo offer courses in forwarder operation and forest machine mechanics. The college in Taivalkoski offers training in operation of machines for forest improvement. Training in logging machine operation is offered at all forestry colleges except Taivalkoski. Short training courses are also given at all seven forestry colleges.

The number of recruits needed is gauged to the demand in the labour market. There are 300 machine operator recruits, 60 forest mechanics and 48 logging machine operator entrants.

The Central Board of Vocational Education ratifies the national basic curriculum of forest machine training, from which the colleges may deviate 30% at the most. The course curriculas at the Jämsänkoski forestry college are presented in appendix 1, 2 and 3.

Partly due to the location of the forestry colleges, there are presently difficulties in filling the total recruit quota for machine training. The most difficult problem, however, is getting state grants budgeted to acquire new modern forest machinery, service and transportation vehicles. Some of the forestry colleges offering logging machine training lack sufficient observation forests for field work. Forest colleges own an average 1000 ha of observation forest land, but at least 5000-10000 hectares are actually needed.

Future aspects of forestry training

Although renovation took place at the vocational school level in Finland in 1984, we can already verify that further revision is needed, especially in forest occupational training. This is needed for the drastic changes in forestry as a result of mechanization. Forestry has been forced to mechanize because of costs and labour politics. In the future we may have to leave the separate training of loggers and forest machine operators, and adopt a broader training of forest technicians. This fall, the Kuru forestry college began an experimental training course for forest technicians with a new curriculum (Fig. 1).

The training of forest technicians will be adopted in the future most probably because forest jobs will be hired out on a turn key basis, assuming that the logger has skills and know-how inforest management, planning, supervision, logging and forest machine operation.

It has been predicted that by 1995 the degree of mechanization in Finland will be an average 70% and total forest labour output could be carried out by 17500 permanently employed workers.

Metsäteho, the Forest Work Study Section of the Central Association of Finnish Forest Industries, has predicted that by the year 2050 forest work will be completely (i.e. 100%) mechanized and 8000 forest workers will be required. Nevertheless, since labour productivity will increase and forest machines will develop rapidly, the labour demand will further decrease and only 3000 permanently employed forest machine operators will be needed. The predictions have taken into consideration the growth in Finnish national harvestable timber.

Because forest machine training is very expensive, more consideration will be given to the appropriate number of recruits and their suitability to the field through selective entrance examinations. The effectiveness of training will be increased with more use of practice machines in field work.

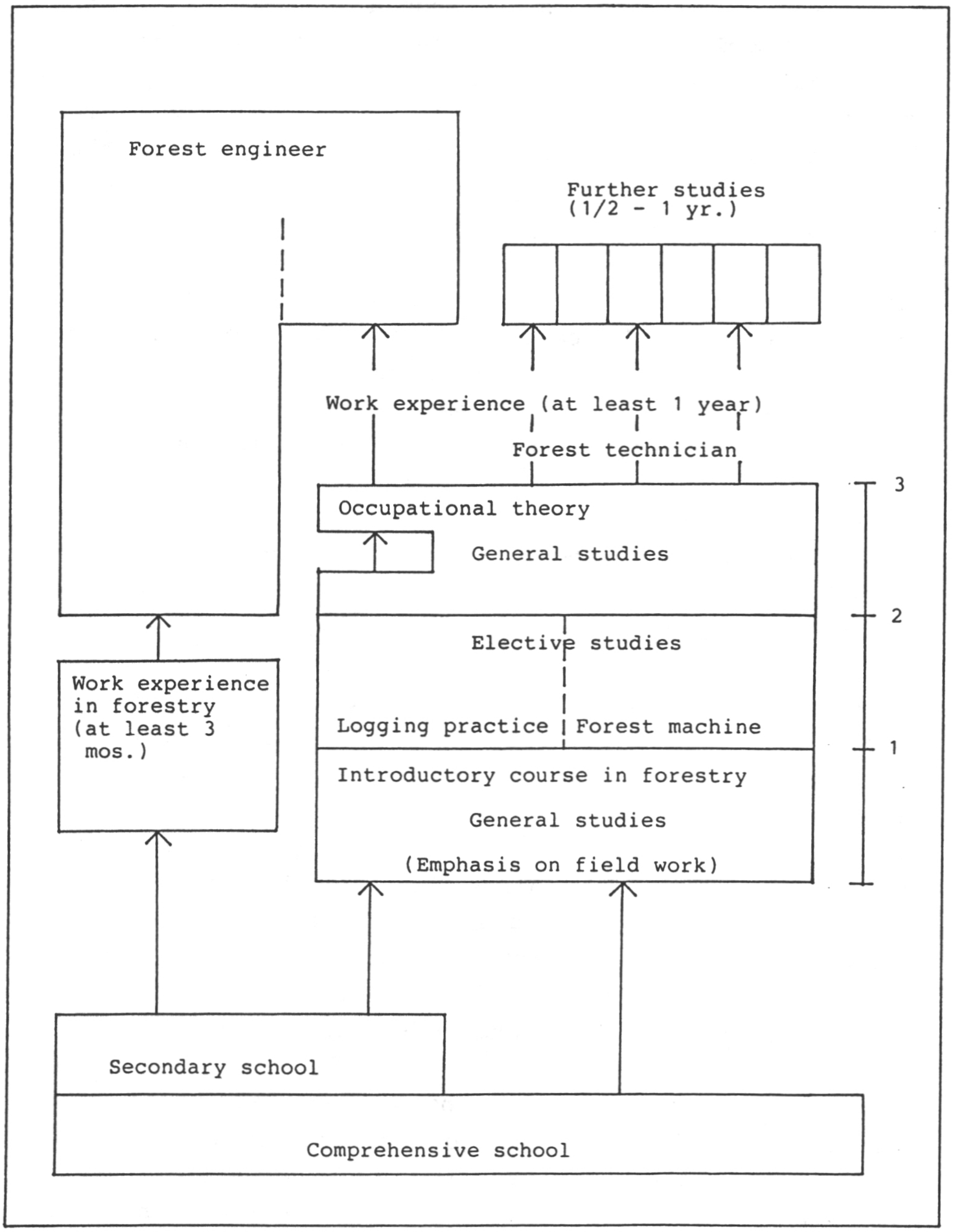

Figure 1. Forest technician training in Kuru Forest Training Institute (with focus on field work) beginning in the first year of general studies.

Appendix 1. The curriculum for forest machine operator training in Jämsänkoski Forestry Training Institute.

Course description		Forest machine operator specialization, hrs
General studies		
Finnish	76	76
Swedish	55	55
Mathematics	50	
Cost calculation		50
Civic education	58	
Labour legislation		20
Labour protection		38
Health and physical ed.	60	60
Occupational courses		
Forest Machines	381	
Diesel engine		70
Transmission		70
Electrical equipment		70
Hydraulics		110
Accessories of forwarder		61
Use of forest machines	530	
Principles of forest haulage		70
Loading and operating techniques		80
Forwarding of timber		380
Maintenance and repair	210	
Science of materials		20
Welding		60
Maintenance and repair		130
Student counselling	20	20
Total	1440	1440

Appendix 2. The curriculum for forest machine mechanic training in Jämsänkoski Forestry Training Institute.

Course description	1 yr	2 yr	Total hours	Mandatory
<u>General subjects</u>				
Technical physics	90/40	40	130/80	2)
Mechanics and strength of materials				
Strength of materials				
Machine drawing	40	20	60	2)
Trade economics				
Cost calculation				
Trade economics				
Languages	40	20	60	2)
Finnish				
English				
Swedish				
Civic education	20	20	40	2)
Student counselling				
Labour legislation				
Health and Phys. Ed.	66	30	96	2)
First aid				
Phys ed.				
<u>Vocational courses</u>				
Forestry, timber trade and industry	20/70	70	90/140	2)
Forest and timber trade				
Forest machinery				
Multi-process machines				
Machine operating technique				
Internal-cumbustion engines	70	50	120	2)
Piston engines				
Liquid fuel equipment				
Transmission	70	50	120	2)
Clutches				
Gear systems and shafts				
Hydraulic transmission				
Steering and brake equipment				
Accessories	34	0	34	2)
Hydraulics	160	60	220	2)
Principles of hydraulics				
Hydraulic auxiliary devices				
Pumps and regulating units				
Valves				
Hydraulic systems				
Maintenance of hydraulics				
Electrical equipment	80	70	150	2)
Principles of electrical equipment				
Ignition systems				
Charging systems				
Electrical steering systems				
Electrical auxiliary devices				
Maintenance of electrical equipment				
<u>Margin</u>	320	500	820	2)
Total	1270	1220	2490	
Supervised apprenticeship, days	12	30	42	

Appendix 3. Further studies on the use of logging machines in Jämsänkoski Forestry Training Institute (course duration approx. 20 wks = 750 hours)

	hours
1. Use of timber harvesting machines	410
2. Maintenance of forest machinery	200
3. Business economics	40
4. Automation	40
5. Work techniques and phys. ed.	20
6. Field trips	40
Total	750

1. Use of timber harvesting machines	
- Principles of forest management	(100)
- Mechanized primary conversion	(190)
- Forwarding	(100)
- Environmental conservation	(20)
2. Maintenance of forest machinery	
- Hydraulics	(60)
- Diesel engine	(15)
- Electrical equipment	(50)
- Transmission	(15)
- Equipment and accessories	(60)

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