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The procurement of timber to the forest industries in the Nordic countries is based on the log-length or shortwood system, and employs load-carrying forwarders and chainsaw or single-grip harvesters. This technology is characterized by high productivity, safety, suitability for small-sized trees, high recovery of timber, and environmental friendliness. About one fourth of the industrial timber in the whole world is harvested using the log-length system. The challenge of ecological sustainability, multiple use of forests, adoption of thinnings as a tool of management, trend toward improved utilization of forest biomass, and shift from natural forests to plantations all increase the global interest in the log-length system.

The paper presents a review of the Finnish forest sector, the technology of timber harvesting and transport, productivity of logging work, and costs of timber at the mill. The highly mechanized logging systems of the forest industries and the lighter technology of self-employed forest owners are discussed separately. Furthermore, the use of residual biomass as a source of clean and renewable energy, the Finnish logging machine industry, and forest operations research in Finland are also reviewed.

Keywords: Timber procurement, logging, log-length system, shortwood system, logging machine industry, Finland

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TABLE OF CONTENTS

Page

Preface

Finland is known as an industrialized country which lives off its forests. The national economy and exports are highly dependent on forestry, forest industries and the entire forest cluster.

Many foresters, customers of the forest industry and researchers visiting Finland want to gain a comprehensive understanding of timber procurement as a link between wood production and utilization. To fill a gap in the information readily available for a foreign reader, the Finnish Forest Research Institute published in 1989 a review titled Logging in Finland (Hakkila 1989). The paper was translated into Japanese by Dr. Masao Shishiuchi and published by the Forest Engineering Research Institute in Joyoma, Japan (Finland no bashutugizutu 1991).

Although only five years have passed, a radical change has taken place in Finnish timber procurement since then. Cutting has been mechanized, the cost of procurement has been reduced, and environmental considerations have been given much more emphasis. Consequently, the FFRI has decided to update the review and expand its theme from logging to the entire procurement system from stump to mill. A timely reason to revive the study is the XX IUFRO World Congress in Tampere in August 1995, bringing to Finland some 2000 forest scientists, many of whom are specialists in forest operations research. The FFRI wishes that this synthesis will help the visitor to appreciate the problems and solutions of timber procurement to the Finnish forest industries in a changing society, as well as the past and ongoing forest operations research and development toward environmentally sound and efficient technology.

The manuscript was skilfully typed by Ms. Maija Heino and Ms. Essi Puranen. Mr. Hannu Kalaja, Mr. Erkki Oksanen and several machine manufacturers contributed photographs. The English language was checked by Dr. Ashley Selby. The manuscript was reviewed by Professor Rihko Haarlaa, Professor Matti Kärkkäinen, Dr. Jari Parviainen, Mr. Olli Eeronheimo, and Mr. Erkki Verkasalo.

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Puuksanharju, June 1995

Pentti Hakkila

1 Introduction

Procurement of timber to the forest industries, i.e. purchase, planning, logging, measurement and long-distance transport to the mill, is a vital function of forestry and an essential link between the production and utilization of wood. *Logging*, i.e. the cutting and off-road transport of timber from stump to road side or landing, is the central operation in timber procurement. *Harvesting*, on the other hand, refers to the aggregation of all operations, including preharvest assessments, related to the felling of trees and the extraction of their stems or other usable parts from the forest for subsequent processing into industrial products (Dykstra & Heinrich 1995).

Up to World War II, timber harvesting all over the world relied on simple hand tools, human labour and draught animals (Figs. 1 and 2). The mechanization of agriculture in the 1950s and 1960s resulted in rural depopulation and a shortage of loggers and work horses. It therefore became necessary to mechanize forest operations as well. The introduction of tractors as forest transport vehicles made tree-length skidding a feasible alternative to the traditional shortwood system in North America, whereas in the Nordic countries the physical logging conditions and environmental considerations still favoured the traditional short-wood system.

The Nordic countries considered it necessary to develop a completely new technology for their specific conditions and to meet the public's growing concern over the forest environment. The course of technology development was marked by the predominance of non-industrial private forest small-ownership, strict ergonomic standards and the strong influence of environmental considerations. Initially Sweden was the innovator, but when Finland gradually recovered from two defensive wars, both countries became world-leaders in ergonomically and environmentally sound technology, mountain logging and cable yarding systems up till now excluded.

Independently of the degree of mechanization and scale of operation, Nordic timber procurement is based on *the shortwood system*, presently referred to as *the log-length system, cut-to-length system* or *product-length system*. It is a characteristic of this technology that the stems are bucked to assortments at the stump and subsequently transported to the road side in load-carrying tractors, i.e. forwarders, completely off the ground. A wide range of machines and methods adapted to the system are available for small-scale farm-owner operations and large-scale industrial operations, both for thinnings and regeneration cuttings.

Figure 1. Until World War II, timber was cut by simple handtools and often processed to products at site (Photo Paavo Aro).

Figure 2. Even in the early 1950s over 100 000 Finnish horses hauled timber from forests in the winter time (Photo FFRI).

The concept of efficiency is not restricted to reliability and economic performance. Efficiency is also affected by social and environmental issues (Sundberg & Silversides 1988). The appropriateness of a system is dependent on its operating environment and the established infrastructure. It is therefore self-evident that other solutions than the log-length system are often more feasible in other environmental, industrial and socio-economic conditions. Nevertheless, the Finnish timber procurement system enjoys a world-wide reputation, and interest in the Finnish know-how in the changing world is increasing because of:

- the requirements of ecological sustainability
- the increasing public interest in landscape management and multiple use of forests
- the introduction of thinnings as a tool of forest management
- the trend toward intensified recovery and improved value utilization of wood and other forest biomass
- the need for ergonomic improvements in methods and machines
- the shift from natural forests to plantations and smaller trees

Although wood is a renewable material, harvesting tends to disturb the ecological balance of a forest stand and change a familiar landscape. It therefore only too often creates an image of “dirty business”. Consequently, it is not sufficient to evaluate *the performance of a timber procurement system* on the basis of operation costs and labor productivity alone. Forest management and harvesting have become more complex. Environmental considerations such as avoidance of soil compaction and damage to trees, maintenance of the biological diversity of the ecosystem, and multiple use are an equally important challenge to timber procurement organizations. Furthermore, the value utilization of wood is largely determined during the procurement process.

The forestry and the forest industries continue to be vital for the national economy of Finland, but in the changing society, forest policy can no longer be aimed at sustained production of wood only. *Ecological sustainability* has become an equally important requirement, and it has to be recognized in the goal setting of forest management. It follows that since the beginning of the 1990s an increasing emphasis has been given to environmentally sound technology in the procurement of timber to the Finnish forest industries (cf. Haarlaa 1995).

2 The forest sector

2.1 Forest resources

Only 20 000 years ago northern Europe *was covered by 2 km thick continental ice*. The heavy ice cap flowed from the high Norwegian mountains, eroding away the original topography and creating the low, undulating peneplain covered by glacial moraine and fluvial sands and gravels. As the climate became milder, the ice retreated about 10 000 years ago. When the retiring of ice periodically stopped, huge amounts of coarse material were accumulated forming gravel ridges along the ice edge.

The removal of heavy load of the ice resulted in a land lift phenomenon after the release of the ground. At the narrow strait in the Gulf of Bothnia between Vaasa and Umeå the ground level today is 300 m higher than during the Ice Age, and land lift still occurs there at a rate of 9 mm per year, causing drainage problems in agriculture and forestry.

Finland, like Alaska, is located between the 60th and 70th parallels. A large part of the country lies north of the Arctic Circle at the limit of human habitation. *The mean effective temperature sum* (threshold +5°C) of the thermal growing season is 1200 day degrees in the south but only 600 day degrees in northern Lapland just south of the timberline. A narrow zone in the north is treeless tundra and used for the reindeer husbandry only.

The North Atlantic Drift brings warm water from the Gulf of Mexico to the Atlantic coast of the Scandinavian peninsula and makes the climate suitable for growing coniferous timber. In fact, Finland is the most forested country in Europe. On the world map, Finland is located *in the zone of boreal forests*.

Forestry land, covering 26.4 million ha or 87 % of the total land area, is composed of forest land, scrub land, waste land and areas under forestry roads and landings. To be classified as *forest land*, the potential annual increment of the site must be at least 1 m^3/ha. *Scrub land* is exposed bedrock, scree or mires, where the potential annual increment is below 1 m^3/ha but over 0.1 m^3/ha. *Waste land* is composed mainly of open mires and northern tundra producing annually less than 0.1 m^3/ha. The total area of forest land is 20.1 million ha amounting to 4 ha per capita, more than anywhere else in Europe (Table 1).

Only a few tree species are adapted to the boreal climate and edaphic conditions. There are only 23 natural tree species in Finland. It is not

Table 1. Land use in Finland in the 1980s (Yearbook...1994).

	South Finland	North Finland Area million ha	Whole country	Whole country %
Forest land	11.5	8.6	20.1	65.9
Scrub land	0.6	2.5	3.1	10.2
Waste land	0.4	2.7	3.0	10.0
Roads, landings	0.1	0.0	0.1	0.4
Forestry land, total	12.5	13.8	26.4	86.5
Agricultural land	2.6	0.4	3.0	9.9
Built-up areas	0.6	0.1	0.7	2.4
Transport routes etc.	0.3	0.1	0.4	1.2
Total land area	16.1	14.4	30.5	100.0
Inland watercourses	2.3	1.0	3.3	
Total area	18.4	15.4	33.8	

uncommon that a natural stand is composed of a single species. Approximately 45 % of the growing stock is Scots pine (*Pinus sylvestris*), 37 % Norway spruce (*Picea abies*), 15 % birch (*Betula pendula* and *Betula pubescens*) and 3 % other hardwoods, mainly grey alder (*Alnus incana*) and aspen (*Populus tremula*). Fortunately, from the wood quality point of view, slow-growing, straight-stemmed pine, spruce, and birch produce excellent and uniform raw material for the forest industries. From the management, procurement, and processing points of view the scarcity of tree species can be seen as an advantage.

In the early 1950s, *the annual increment* of the Finnish forests was 54 million m^3 (Yearbook...1994). According to preliminary results of the 8th National Forest Inventory, the growth currently exceeds 80 million m^3 per year. This great growth increase is a result of intensive silviculture. The drainage of about 6 million ha of wet forest lands alone is responsible for an annual growth increase of more than 7 million m^3 (Paavilainen & Tiihonen 1988). Regeneration of unproductive over-aged stands also has enhanced the growth considerably, especially in northern Finland. The increase in the nitrogen depositions and the carbon dioxide content of the atmosphere also contribute to this development.

During the late 1980s, *the annual drain* from Finland's forests, including wood harvesting, pre-commercial thinnings and natural mortality, was 55 million m^3 (Yearbook...1994). The preliminary estimate of drain for 1994 is 63 million m^3. New production capacity of pulp, lumber and spruce plywood is being constructed, but a surplus of industrial stemwood will remain. In addition, unmerchantable small sized trees from pre-commercial and early commercial thinnings with their crown mass, and logging slash from regeneration cuttings, form a large renewable reserve of clean bioenergy of which 10 million m³/year is considered technically harvestable (Hakkila 1992).

Nature conservation areas protected by legislation cover 2.8 million ha, a majority of them located in the northern part of the country (Maintenance of... 1994). It is estimated that *the conservation areas* so far established or proposed, and *the protection plans* for endangered species and habitat reserves, all combined account for a setting aside of about 3 million m^3 of the annual growth. According to the Revised Forest 2000 program, the impact of the non-commercial values attached to environment, and the multiple-use of forests, result in 6-7 million m^3 of the annual increment being left outside commercial use. Given that the current total annual growth in Finland's forests amounts to 82 million m^3, the aforementioned reductions would still leave about 75 million m^3 potentially available for commercial utilization, which is considerably more than the expected demand for timber (Fig. 3). The annual fellings could be increased in the 1990s sustainably to 70 million m³ and during the following decade to 75 million m³ (Finnish Forestry...1992). Thus, the new environmental approach will not necessarily jeopardise the future supply of wood raw material to the forest industries on a national scale, but it may cause serious local problems to forest owners, forest workers and saw milling especially in northern Finland.

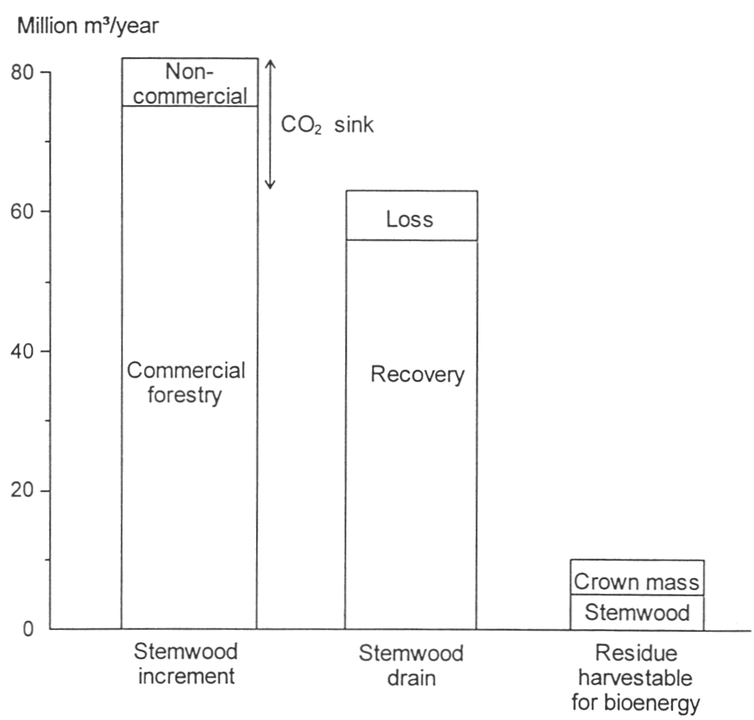


Figure 3. The annual increment of stemwood, the drain of stemwood in 1994 and the technically harvestable energy reserve of unmerchantable forest biomass.

One family in five owns forest land in Finland. There are 284 000 private forest holdings of 5 ha or more. About 56 % of the private forest land is owned by farmers, and 66 % of the private owners reside on the holding. Thus, *the forestry is closely bound with agriculture* (Fig. 4). However, among the forest owners the share of urban people is increasing.

Private citizens own 63 % of the forest land and, because of the more favourable location of the private forests in the southern part of the country, they produce 80 % of the domestic timber. The state owns 24 % of forest area, administrating it through the *Finnish Forest and Park Service* (FFPS). Forest industry companies own 9 %, and municipalities, parishes, and foundations the remaining 4 % of the forest land (Yearbook...1994).

The predominance of *non-industrial private family forestry* strongly influences the principles, care and intensity in which the Finnish forests are managed and utilized. The average area of a private non-industrial forest holding in South Finland is only 33 ha. The fragmented ownership tends to increase the cost of timber procurement and affects the constraints placed on forest machines with respect to their mobility from site to site and friendliness to the forest environment and landscape. On the other hand, *the ownership structure, together with the heterogeneous and small-patterned nature of the forest sites, helped to maintain the mosaic nature* of the forests during a time when ecological considerations and *the concept of biodiversity* were not yet stressed as a goal of forest management.

Figure 4. Forestry in Finland is closely bound with agriculture (Photo Erkki Oksanen).

2.2 Forest management

Trees mature slowly in the boreal climate. Accordingly, the forest management regimes are based on *long rotation periods*, generally 70-100 years in the south and 100-140 years in the north. Under these conditions, the formulation of long-term forest policy is not easy. The value of *the forest heritage to rising generations* will be affected by the future technology and preferences of the forest industries, society's priorities between wood production and other values of the forest, the global energy situation, and even climatic change.

Soon after the declaration of independence in 1917, Finland was the first country in the world to perform a national forest inventory. The state of the forests was poor due to earlier slash-and-burn cultivation near villages, extensive tar production and dimension-tree selection for saw milling. New goals were required, and sustainability became the guiding principle. *Exploitation was replaced by the sustainable production of wood.*

Nordic forest management imitates the natural cycle of forest succession. Stands are first treated with *repeated selective thinnings from below* and finally with a regeneration cutting. The purpose of the thinnings is to:

- allow more space for trees and prevent the crowns from excessive reduction, so as to maintain the vitality of the stand
- regulate the spacing of trees for faster diameter growth and, consequently, for a larger share of sawlogs in the total yield of timber over the rotation period
- regulate the composition of tree species in a mixed stand
- improve the quality properties, such as uniformity, reduced branchiness and better stem form, of the remaining stand and subsequent timber production
- salvage suppressed, damaged and dying trees which would be otherwise lost through natural mortality
- improve the physical logging conditions of future cuttings with respect to mechanization
- provide earlier incomes to the forest owner

In addition to trees suppressed through natural competition, larger dominants may also be removed selectively in thinnings primarily for their inferior quality. All trees must be removed systematically from 4 m wide strip roads which have to be opened to allow machines to move in the stand.

The general preconditions for the profitability of thinnings are: demand for small-sized wood, high stumpage price level of timber, and a well developed and disciplined logging organization which is able to carry out the work according to approved silvicultural goals and without causing damage to forest soil and remaining trees. Since these conditions occur in only few parts of the world, the practice of thinning is not common to all forest industry countries.

In Finland, *thinnings have been a standard silvicultural practice* since World War II. In southern Finland, nearly all stands are thinned commercially twice or three times and in northern Finland once or twice during the rotation period (Figs. 5 and 6). The commercial thinnings are preceded by a pre-commercial thinning, where timber is not recovered because of its small size. In southern Finnish conditions, a typical management regime is as follows:

Treatment	Stand age, years	Stem volume, m^3	Timber yield, m^3/ha
Precommercial thinning	10 - 20	- 0.02	-
1st commercial thinning	25 - 40	0.03 - 0.08	30 - 50
2nd commercial thinning	40 - 55	0.09 - 0.15	40 - 80
3rd commercial thinning	55 - 70	0.15 - 0.25	60 - 90
Final cutting for regeneration	70 -100	0.20 - 0.70	200 - 300

Compared to final or regeneration cuttings, the productivity of work in thinnings is lower and mechanization more complicated. Therefore, in an over-supply situation, industry prefers purchasing its raw material from regeneration cuttings. It follows that *the thinning targets of over 400 000 ha per year are not being fully realized.* The first commercial thinnings, especially, are a great challenge to machine manufacturers and logging organizations, since a large area of young stands established in the 1960s is reaching this phase. The average annual area of various types of commercial cuttings during 1989-1993 was as follows (Yearbook... 1994):

	Area, ha/year
Regeneration cuttings:	
For artificial regeneration	103 000
For natural regeneration	42 000
Removal of seed and shelter trees	37 000
Thinnings	166 000
Cuttings on scrub land	3 000
Other cuttings	6 000
Total	357 000

About 70-80 % of all timber is derived from *regeneration cuttings*, mainly from stands which were naturally regenerated in the early 1900s. The size of a typical regeneration area is 1-4 ha in the private forests. In the state and company forests regeneration areas are larger, but seldom more than 10 ha.

Figure 5. The first commercial thinning of a pine stand (Photo Erkki Oksanen).

Figure 6. The second commercial thinning of a pine stand (Photo Erkki Oksanen).

Regeneration takes place either naturally or artificially. Plantations are established with native pine, spruce or birch, and supplementary natural seedlings of mixed species also occur. Consequently, *plantations do not usually differ radically from managed, naturally regenerated stands*. By the year 2000, artificially regenerated stands will account for 30 % of the total area of productive forests, but because of their young age their role in timber production will still remain modest.

Results from the practice of intensive silviculture and repeated thinnings can be seen everywhere in Finland. Successive national forest inventories, which have been carried out by the Finnish Forest Research Institute 8 times over a period of 74 years, indicate a favorable development in the structure of the forests from the viewpoint of wood production; steadily increasing growing stock and growth, higher proportion of sawlog-sized timber and decreased amount of unmerchantable residue in cuttings.

However, until recently the concept of sustainability was limited to wood production, and the goals of forest management were set somewhat biasedly for increased volume growth. A policy aimed solely at the *sustained production of wood* for the forest industries is no longer sufficient. An ecologically wider perspective is being adopted, and *the maintenance and enhancement of biological diversity* is becoming an integral issue of the forest management planning. The expansion of the concept of sustainability, balancing between the competing uses of the forests, and protection of rare biotypes introduce a new challenge to foresters responsible for the timber procurement to the industry (Parviainen 1994, Parviainen & Seppälä 1994). The importance for biological diversity of dead trees, rare non-commercial tree species such as aspen, trees providing nesting holes for birds, ancient trees, etc. was not properly recognized in the past. In the new forest policy, they are valuable retention trees and therefore protected in cuttings as vital components of the ecosystem. Since the principle of everyman's rights *allows to every Finn free access* for walking, skiing and picking berries and mushrooms, the multiple-use of forests must be taken into account.

Finland's commitment to the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992, and to the Ministerial Conference on the Protection of Forests in Europe in Helsinki in 1993, require the adoption of wider approach. Increasing emphasis is being placed on the management of *forest ecosystems in their entirety* and on the maintenance of biodiversity. New Environmental Programme for Forestry in Finland, confirmed jointly by the Ministry of Agriculture and Forestry and the Ministry of the Environment, provides the guidelines for the environmental and forestry policy. The sustainable management and use of the forests require, that (New Environmental... 1994):

- the vitality of forests and their ability to regenerate are ensured
- the production of wood raw material required by the economy of the nation is ensured
- natural resources are managed and used without leading to diminished biodiversity of forest, wetland and water ecosystems
- forestry is practised so that the resultant variability can support an abundance of flora and fauna
- the multiple-use functions of forest, wetland and water ecosystems are ensured
- the livelihoods of local populations are not endangered
- the possibilities for future generations to use forests, wetlands and water ecosystems in diverse ways locally, nationally and internationally are not endangered

2.3 The timber

The Finnish softwood timber is known for its even texture. *The average tree-ring width* of industrial timber is 1.4 mm in southern Finland and only 0.8 mm in northern Finland (Hakkila 1966, Rikkonen 1987). These slow-growing trees are characterized by rather homogeneous wood density, straight stem form and good self-pruning.

The size of the trees remains small. Only 20 % of the softwood volume and less than 10 % of the hardwood volume in the southern Finnish growing stock exceeds 30 cm in diameter at breast height (Fig. 7). Therefore, the Finnish

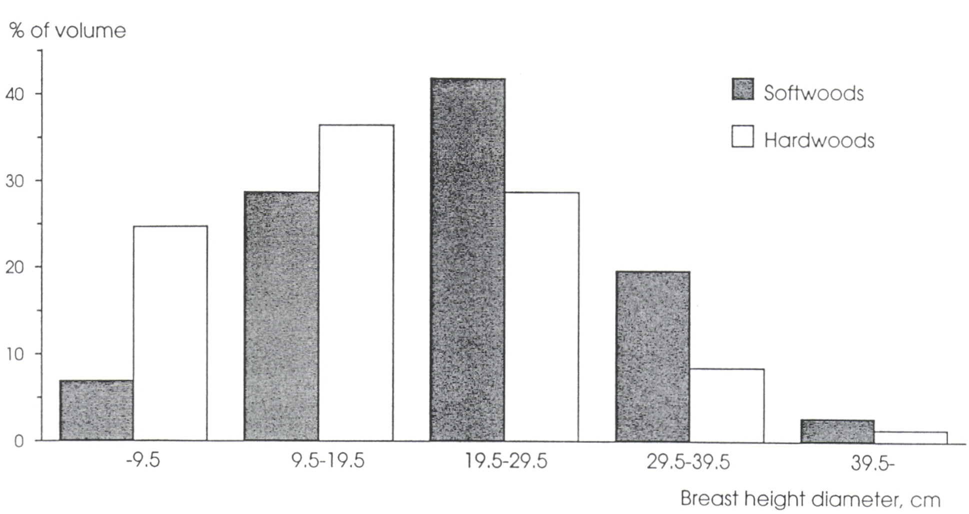


Figure 7. The breast height diameter distribution of the softwoods and hardwoods in the Finnish forests (data from Yearbook...1994).

solutions for timber harvesting and processing typically represent *small-tree technology*, the basis of which is the log-length system. The average top diameter of sawlogs is 21 cm over the bark and 20 cm under the bark. The average volume of a sawlog with bark is 0.21 m^3 for pine and 0.23 m^3 for spruce and birch (Rikkonen 1987).

When timber is cut with a chainsaw in southern Finland, the proportion of bark is 10-12 % in sawlogs and 13 % in pulpwood (Heiskanen & Rikkonen 1976, Saikku & Heiskanen 1976). In mechanized logging, the delimbing knives of a harvester tend to hew a part of the bark from the logs, and therefore the proportion of bark is 1-2 percent units smaller. In Finland, and also in this report, the diameter and *volume of standing trees and timber are given always with the bark.*

The basic density of wood, showing the dry mass in kilograms per a cubic meter of fresh wood, is the most important indicator of wood quality. The global trend is that the basic density is higher for hardwoods than softwoods, and higher for southern species than northern species. In southern Finland the basic density of softwood is around 400 kg/m^3 and that of birch 500 kg/m^3 (Hakkila 1966). The *green density* of timber, which shows the green mass in kilograms per a cubic meter of wood, depends on the season and length of storage time. For softwood timber it is generally less than 900 kg/m^3 and for birch timber more than 900 kg/m^3 when the timber arrives at the mill (Marjomaa 1992).

	Basic density of wood without bark	Green density of unbarked timber
	kg/m^3	
Sawlogs:		
Pine	430	850
Spruce	380	800
Birch	500	915
Pulpwood:		
Pine	405	875
Spruce	385	865
Birch	470	915

The dimensional requirements of timber depend on the end product, industrial process and the market situation. Differences occur between companies, but typically the minimum diameter is 15 cm for pine sawlogs, 16 cm for spruce sawlogs, 18 cm for birch veneer logs and 6-8 cm for pulpwood.

Pine and spruce sawlogs are used primarily for the production of export lumber. Grading rules are strict in terms of defects such as dead knots, sweep, crooks or rot. To produce a cubic meter of lumber, 2.25 m^3 unbarked logs are needed on average, depending on log size and quality, and on sawing equipment and patterns.

Large birch logs are used mainly for the production of export plywood, characterized by its light colour and thin plies. With the modern production technology, 2.9 m^3 unbarked birch logs are required for a cubic meter of plywood. Due to shortage of high-quality birch wood, recent expansion of the Finnish plywood industry is based on the use of spruce for the production of mixed birch-spruce plywood or pure spruce plywood. Compared with birch, spruce logs are straighter, rounder in cross-section, larger in diameter and contain less bark, deformations and defects. Therefore, the consumption of raw material for a cubic meter of spruce plywood is lower, 2.4 m^3 unbarked logs (Verkasalo 1995).

Spruce pulpwood is used for the production of mechanical pulp. Quality requirements are strict for freeness of pathological infections and for freshness. Even a small spot of rot leads to rejection and sorting the bolt into the pile of pine pulpwood. The consumption of unbarked spruce wood for a tonne of mechanical pulp is 2.6 m^3. To ensure high quality of mechanical pulp, wood must be kept fresh and delivered to the mill in the summer within three weeks from felling. As the ground is soft in spruce sites and rut formation and root damage are not allowed, the harvesting of spruce pulpwood in summer time is problematic and presupposes careful planning and timing.

Pine and hardwood pulpwood is used for sulfate pulping. Quality requirements are not especially strict, and storage over the summer season is not uncommon. To produce a tonne of unbleached sulfate pulp, 5.4 m^3 unbarked pine wood or 4.0 m^3 unbarked birch wood is needed (Verkasalo 1995). A considerable part of the raw material of sulfate pulp is received in the form of process residue from sawmills and plywood mills.

2.4 The forest industries

The national economy of Finland is highly dependent on the renewable forest resource, the green gold of Finland, and the products made from it. In 1994, *the value of forest products export* was 52.7 billion FIM, accounting for 34 % of the country's export earnings. Since forest industries are supplied by domestic raw material inputs to a greater extent than other branches of the export industries, its share of the net export earnings is over 40 %.

The flow of wood to the Finnish forest industries in 1994 is shown in Fig. 8. The total drain from the Finnish forests was a record high 63 million m^3. The share of the domestic forest industry used almost 50 million m^3 or 78 %. With an additional 8 million m^3 imports from foreign countries, the total industrial consumption of roundwood was over 57 million m^3.

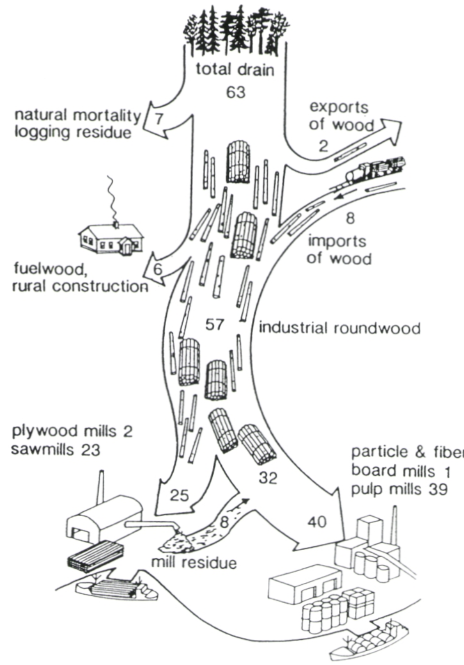


Figure 8. The flow of wood (million m^3) in Finland in 1994 according to unpublished preliminary data from FFRI. The chart modified from Annual Ring 1992-93.

In 1994, the forest industries operated almost at full capacity. *The production of pine and spruce lumber* was 9.5 million m^3, three quarters of which was exported. *The production of birch and spruce plywood* was 0,7 million m^3, almost entirely for export (Table 2).

The production of pulp was 10.0 million tonnes, composing of 2.8 million tonnes of long-fiber bleached pine sulfate pulp, 2.3 million tonnes of short-fiber bleached birch sulfate pulp, 3.6 million tonnes of long-fiber spruce mechanical pulp, and 1.3 million tonnes of unbleached sulfate and semi-chemical pulps. The bulk of the production was used for paper manufacturing, and only 15 % of the pulp was exported.

The production of paper and paperboard was 10.9 million tonnes, 90 % of which was exported. The primary products are mechanical and woodfree printing and writing papers, so that Finland accounts for about 25 % of their global export trade. Other major products are paperboard and newsprint. The paper and paperboard machines employ the world's most modern technology with an average machine capacity of 110 000 t/a. That is considerably higher than the 80 000 t/a in Canada and Sweden, 70 000 t/a in the USA or 30 000 - 40 000 t/a in Japan and Germany (The Finnish... 1995).

The Finnish forest industry is *characterised by integration.* With a part of the production abroad, the integration transcends the national borders. For example, pulp is supplied to the paper mills of the foreign subsidiaries.

During the 1990s, the number of forest industry companies has been reduced through mergers. Presently, the Finnish producers of printing and writing papers are among the biggest in the world, and the producers of lumber and plywood are among the biggest in Europe (Table 3). In spring 1995, a decision was made to merge the two state-owned companies, Enso Gutzeit and Veitsiluoto. The new company will be the largest producer of lumber and the second largest producer of paper in Europe.

Collaboration between the customers, manufacturers of machines and chemicals, universities and research institutes supports the development and transfer of technology for the forest sector. *The entire forest cluster of Finland* is involved in this arrangement, the success of which stems from close links between forestry, forest industry, the metal industry, energy technology, consulting services, education and research. Among the OECD countries, the share of forest cluster of the national exports was, in 1992, the largest in Finland (41 %), followed by Sweden (24 %), Canada (16 %) and Austria (14 %) (Lammi 1995).

Table 2. The production and exports of the Finnish forest industry in 1994 (The Finnish... 1995).

Product	Unit in millions	Production	Exports	Share of exports, %	Number of plants
Pulp	Tonne	10.0	1.5	15	43
Paper	Tonne	8.6	7.8	91	29
Paperboard	Tonne	2.4	2.0	83	16
Lumber	m^3	9.5	7.2	76	160
Plywood	m^3	0.7	0.7	98	20
Particle board	m^3	0.5	0.2	42	6
Fiberboard	Tonne	0.1	0.06	63	2

Table 3. The production and sales of the largest Finnish forest industry groups in 1993 (The Finnish... 1995).

Company	Sales bill. FIM	Lumber mill. m^3	Principal pulp and paper products	Paper & board Mill. t	Paper & board Abroad, %
United Paper Mills	16.0	0.9	Newsprint, SC	3.1	19
Kymmene	16.0	0.9	Fine paper, LWC	2.9	45
Enso-Gutzeit	13.0	1.6	Newsprint, board	3.6	19
Metsäliitto	11.8	1.2	Printing p., board, pulp	1.3	0
Veitsiluoto	4.5	0.3	Printing paper, pulp	1.0	20
Myllykoski	3.6		Mech. printing paper	1.1	64

3 Harvesting timber crops

3.1 The operating environment

The forest and its intangible values are part of the way of life in Finland. General environmental and *ecological considerations and the multiple use of forests* put increasing pressure on forest management and logging operations (Fig. 9). Maintenance of biological diversity, avoidance of damage to standing trees and forest soil, use of seed and shelter trees for natural regeneration as the primary option where possible, and recreation are gaining importance. The ongoing change has to be acknowledged in the development and application of forest technology.

In Finland the forests generally lie below the altitude of 200 m. *The terrain configuration is of low relative relief*, characterized by small hills. Unlike in many other forestry countries, cable yarding systems are not needed, since slopes are seldom steeper than 20-30 %, and the Finnish forwarders and harvesters are able to operate on up to 40 % slopes.

As a result of the Ice Age, the prevailing forest *soil type is moraine*, with an abundance of boulders. On typical pine sites the ground is bearable and summer logging is generally possible without serious soil compaction. Spruce sites are moist and soft, and since spruce has a superficial root system, thinning cuttings of spruce stands are avoided in the summer.

The average annual precipitation varies between 550-700 mm. Excessive stagnant water is a common problem in the low terrain, resulting in *peat formation and bogs*. Peatlands account for as much as one third of Finland's land area. Since large areas of drained peatlands are now reaching the phase of the first commercial thinning, harvesting small-sized timber from soft sites is a great challenge to timber procurement organizations. Machine manufacturers put considerable effort into the development of machines which can operate on peat soil without causing excessive rutting and breaking the ditches, but peatland logging remains a problem (Fig. 10).

The winter snow cover levels the ground surface and protects the soil and tree roots. Snow facilitates timber haulage in uneven terrain, but at a depth of 60-120 cm it can seriously reduce the productivity of cutting and transportation of timber. *In the winter the ground generally freezes*, thus facilitating timber haulage from soft sites. However, this does not happen each year, and the winter weather has become erratic during the 1990s.

Figure 9. Picking lingon berries in an old pine forest beyond the arctic circle (Photo Hannu Kalaja).

Figure 10. Harvesting small-sized timber from drained peatlands requires special equipment. Forwarding with a light rubber-tracked Farmi-Trac crawler (Photo Hannu Kalaja).

A major factor affecting the productivity and cost of motor-manual and mechanized logging is *the size of the trees*. The average stem volume of trees removed is in southern Finland only 0.03-0.08 m^3 in the first commercial thinnings and 0.2-0.7 m^3 in the regeneration cuttings (see page 13). Trees larger than 1.5-2 m^3 in volume are uncommon. This is why the Finnish technology is specially designed for efficient recovery and utilization of small trees but is not suitable for large trees selectively cut in native forests in the tropics.

Although the number of commercial tree species is low, *several timber assortments* are produced in a single logging operation. A typical sale of 500 m^3 is frequently composed of pine and spruce sawlogs, birch veneer logs, and pine, spruce and birch pulpwood, and may include other assortments as well. For the optimum value utilization, all assortments are kept separate in roadside piles and transported directly to their specific mill destinations.

The state stimulates forest road construction on private lands with investment support, low-interest loans and free planning. Altogether, more than *110 000 km of permanent forest roads* have been built during 1952-1993 in private, company-owned and state-owned forest lands for multiple functions (Fig. 11). About 4000 km of new forest roads are built annually (Yearbook... 1994). These roads can be used free of charge for recreational activities such as berry and mushroom picking, and as access roads to summer cottages. Due to the forest road network the damage caused by forest fires has been reduced to only 300 ha per year in the whole country. Unlike the usual practice in North America, the cost of road construction is considered an investment in forest land and is not written off as a cost against the timber removed, because the roads are useful not only for timber transport but also for forestry planning, silvicultural operations, fire protection and multiple-use.

During most of the year, a substantial part of the forest road network is able to carry truck-and-trailer units of 60 tonnes, which is the maximum allowable total mass on public roads. The forest road building program has reduced the average off-road haulage distance in southern Finland to less than 300 m (Kuitto et al. 1994).

3.2 The log-length system

A procurement system consists of a sequence of individual operations performed to reduce a standing tree into logs and transport the timber from the stump to the place of utilization. The main phases of timber procurement are purchase, cutting, off-road transport from stump to roadside, measurement and secondary transport from roadside to mill.

Each operation is related to the others in time and space, so that any interference at any stage of production destroys the sequence, and production falters or comes to a halt. In any harvesting system each step thus affects subsequent steps and in turn is affected by the preceding steps. The efficiency of a system is, therefore, dependent upon the efficiency of the system components, and is the product of the component efficiencies (Silversides & Sundberg 1989).

Three major system options are defined below. Deviations from these basic solutions occur frequently.

- In the *whole-tree system,* the trees are felled typically with a chainsaw or feller-buncher and then dragged by a skidder, on or partially off the ground, to the road-side with the branches intact. Manual or mechanized delimbing and cross-cutting into assortments take place after the off-road transport at the landing prior to trucking, or alternatively at a terminal or mill yard after the truck transport.
- The *tree-length system* is identical to the former, except that delimbing is carried out at the stump. Compared to the equipment used in the modern log-length system, tractors are usually simpler and therefore require fewer mechanical skills.
- In the *log-length system* both delimbing and cross-cutting into assortments are carried out at the stump. A larger proportion of the work is thus performed in the forest. Timber is transported to the landing completely off the ground with *load-carrying tractors, i.e. forwarders*, which are typically self-loading.

Many analyses have been made of timber harvesting systems to establish which is the most economical for a given situation. No system has universal acceptance, since none can operate at optimum capacity and cost under all circumstances. Normally the stand and terrain characteristics are determinant. In any specific case, the system with the weakest concept, if it were well designed and engineered and operated at maximum performance achievement, might produce wood at a lower cost than the conceptually best system operated with its performance factors at the minimum level (Silversides & Sundberg 1989).

The efficiency of a procurement system is highly dependent on the environment and infrastructure in which it is operating. Economic, social, ecological, industrial and educational factors, as well as local traditions and the prevailing systems also have an affect (Andersson & Laestadius 1987). The appropriateness of a certain solution may change with the priorities of the society.

When a harvesting system is selected, high productivity, reliability and the lowest possible cost of procurement are the traditional aims. However, in the course of time, criteria such as strain on workers, work safety, intensive

Figure 11. Permanent forest roads serve timber harvesting, silvicultural operations, and the multiple use of forests (Photo Hannu Kalaja).

Figure 12. Forwarders are capable of piling timber by the roadside. No specific landing site is needed (Photo Erkki Oksanen).

recovery of timber or biomass, wood quality, environmental quality, multiple use of forests, and landscape management have become more and more important.

When *forestry began its process of mechanization* in the post-war years, it was not possible for the Nordic countries to fully rely on the technical advances made in a different operating environment in North America. The development of technology more appropriate to the local forestry conditions and small private forest holdings was necessary. In the 1950s, Finland lagged behind Sweden in technological development, and Sweden therefore initially attained the lead in the Nordic forest technology and forest machine industry. Furthermore, a higher wage level in Sweden motivated the mechanization process.

It did not take a long time after the first real forest tractor, an articulated cable skidder, was imported from North America to Sweden in 1961, before manufacture was begun in the Nordic countries. The first Finnish cable skidder, the 4-tonne Valmet Terra, came onto the market in 1963.

In northern Europe, however, timber is traditionally bucked at the stump. Skidding of whole trees or stems is not easily applicable to the Nordic forest management system which is characterized by small-ownership, shortage of landing sites, a high standard of silviculture, and selective thinnings from below. For these reasons, it was necessary to develop a forest tractor more suitable to Nordic conditions and traditions. The solution was found in the four-wheel-drive, load-carrying forwarder, which was equipped with a hydraulic knuckle boom loader. The first forwarder prototype was built in Sweden as early as in 1962, based on a farm tractor which had had its front wheels removed. The Valmet Company built the first Finnish forwarder in 1965.

While the North American forest industries thus chose the tree-length system, the log-length system still remained the most efficient under northern European conditions. *The northern European and North American harvesting technologies have therefore diverged..*

The log-length system and load-carrying tractors have proved their superiority under the Nordic conditions. The tree-length system today represents less than 1 % of the off-road transport of timber in Finland. *The factors favouring the log-length system* are:

1. Skidders are an economic solution when the trees are large and distances short. Because the stem volume is small in Finland, the loads and productivity of skidders tend to remain low. The productivity of load-carrying tractors, on the other hand, is *less sensitive to stem size*.
2. Because of their shorter load, forwarders cause considerably *less damage to standing trees* in thinning cuttings. In chainsaw operations less than 2 % of remaining trees are damaged, including root damage (Sirén 1987). In

1993, the proportion of damaged trees was below 3 % in 88 % of chainsaw operations and in 55 % of mechanized operations (Jaakkola 1994a). Research results from other countries indicate that tree-length skidding tends to cause more serious damage to standing trees.

3. *Soil compaction and rutting are reduced.* Skidders have to produce much higher tractive forces in the ground contact than the forwarders, resulting in more damage to the ground (Wästerlund 1992). The ground pressure and shear effect are lower in forwarders because of the larger number of wheels, bogie axles, optional tracks, improved traction, more uniform load distribution, and ability to travel on a protective bed of logging slash. Compared to skidders, forwarders travel less owing to their higher load capacity in small-log operations, and fewer machine passes result in less ground disturbance even if it means heavier loads (Sirén et al. 1987). The long-reach boom helps to reduce the travelling of the forwarder during loading and unloading.
4. Boulders and stumps cause the tractor to swing, resulting in whole-body vibration and health problems for the driver. The forwarders drive with a larger load but move slower, have ergonomically designed cabins and a larger number of wheels, and their load is well balanced. Therefore, drivers' *vibration-induced health problems are less serious* with modern forwarders.
5. Forwarders stack the logs at the roadside into 3-4 m high piles, thus *saving landing space* (Fig. 12). Piles act as temporary buffer stores, and facilitate the subsequent loading of trucks. *Tight schedules are avoided,* and due to cold decking the forwarder can continue working even if the truck transport is interrupted.
6. *The forwarders sort the timber* according to assortments in conjunction with loading in the forest and unloading at the road side. This makes it easy for the trucks to deliver different assortments to different mills. Criss-cross transport is reduced, and handling of timber at the mill yard becomes easier.
7. When dragged along the ground with skidders, trees and stems sometimes break and tend to pick up contaminants. Grit wears out mill equipment, lowers the quality of the end product, and creates ash and slag problems in the combustion of bark. A load-carrying forwarder *keeps the biomass cleaner.*
8. Forwarders can be used to *collect logging slash* from a cut-over area. Slash can be reduced to chips at the road side or at a terminal and used as a clean local biofuel to replace oil.

The contrast in harvesting systems between North America and the Nordic countries has spurred considerable interest. Before the 1980s, commercial confrontation was limited. Both methods dominated their home region but enjoyed little success overseas. However, harvesting technology is globalizing, and the commercial separation of these two logging styles seems to be about to end (Laestadius 1990).

3.3 The organization of timber procurement

The Finnish forest industry derives its wood raw material from a large number of sources. Depending on the markets, the situation varies from year to year. In 1993, stumpage and delivery sales from private forests accounted for 64 % of the industry's roundwood consumption. About 11 % was purchased from state forests delivered to the mill by the FFPS, 11 % was cut from the companies' own forests, and 15 % was imported from other countries, mainly by rail from Russia.

The six largest companies together are responsible for 80 % of the industrial wood consumption in Finland (Table 4). Their role in the national wood procurement business is even more dominating, since they also deliver timber to some independent sawmills.

Enso-Gutzeit Oy and Veitsiluoto Oy, the two state-owned companies, are to be merged in a near future. The company will then operate throughout the whole country. Metsäliitto-Yhtymä is a forest owners' cooperative also present in the whole country. The other big companies, although they do not operate nationwide, are active in large areas of the country. Each company divides its operating area into *purchasing regions and them into procurement districts and sub-districts*, all of which are given an annual procurement obligation by timber assortments. The sub-districts purchase the timber from forest owners and organize the harvesting and secondary transport.

Table 4. The major industrial consumers of roundwood and residue from the mechanical forest industries in Finland in 1994. Preliminary data of the Finnish Forest Industries Federation.

Company	Round wood	Mill residue	
	Million m^3 in 1994		
Enso-Gutzeit Oy	12.7	2.8	} To be merged in 1996
Veitsiluoto Oy	4.8	0.6	
Metsäliitto-Yhtymä	10.1	1.7	
Kymmene Oy	9.9	2.2	
United Paper Mills Ltd	6.6	2.1	
Myllykoski Oy	1.4	0.3	
Others	10.9	0.3	
Total	56.4	10.0	

Wood procurement to a large integrated company possessing mills in many locations is a demanding logistic task in the complex operating environment. Timber has to be purchased from a large number of sellers and delivered to the mills according to narrow schedules either by road, rail or water. The organization has to deal with both delivery sales and stumpage sales, and production of different timber assortments must be kept in balance with the demand. Full employment of chainsaw operators and machine and truck entrepreneurs should be ensured. At the same time, timber inventories are kept at a minimum level to maintain the freshness of wood and to reduce capital costs.

The forest industry companies perform their wood procurement through forestry department or a specific procurement consortium. In mechanized operations, the procurement organization contracts out the implementation to *independent entrepreneurs*. When cutting and off-road haulage are combined into one *logging contract* (Fig. 13) and the measurement of timber produced is made by the one-grip harvester, a number of significant benefits are gained. The cost of overheads is reduced, the operational availability of the two machines is improved, and the flow of timber from stump to mill is speeded up. Replacing two traditional sub-operation contracts, cutting and off-road transport, with one broad logging contract has thus reduced the cost of procurement. It does not seem necessary to further combine logging and trucking into an even more comprehensive contract, since the forwarders and cold decking of timber in high road side piles help to keep harvesting and trucking schedules independent of each other.

Mechanization makes it possible to shift work site planning and scaling of timber from the organization's staff to entrepreneurs, and ease the organization correspondingly. In motor-manual logging, one foreman is needed to supervise 8 chainsaw operators and a forwarder, whereas in mechanized logging the same foreman is able to supervise two complete teams each composed of a harvester and a forwarder (Imponen et al. 1992).

The procurement organizations have found it appropriate to employ versatile machines which are able to work in almost any conditions, for example both in thinning cuttings and regeneration cuttings. Special equipment is avoided as it creates organizational and employment problems. Nevertheless, there is an obvious need for special equipment for logging in peatlands, for early thinnings and for salvaging residual wood for energy.

The development of *forest information systems* is an essential part of the on-going organizational rationalization. Harvesters are equipped with telephones and microcomputers for receiving instructions concerning the required log lengths and dimensions as a response to customer-oriented lumber sales, and for reporting on the daily output by assortments. Trucks are being equipped with a computer-based satellite-assisted navigation system with stored data about road maps and the location and volume of roadside inventories of timber. Trucks are given instructions on the inventories to be hauled and their destinations via a data transfer network. These information systems facilitate control over the timber flow, shorten travel time of wood from stump to mill, improve the value utilization of raw material, and help to avoid unnecessary criss-cross transport.

3.4 Delivery sales by private forest owners

In a country where every fifth family is a forest owner, social values such as rural jobs and traditional landscapes must be taken into account in forest management and timber harvesting. Many forest owners want to personally carry out the logging under their own control. In *delivery sales* the forest owner is responsible for cutting and off-road transport of timber to the road side. On the average, 10.9 million m^3 per year or 26 % of all domestic timber used by the forest industry during 1984-1993 was delivered to the road side from private woodlots. The proportion was 21 % for sawlogs and 28 % for pulpwood (Yearbook... 1994).

The delivery sales from private woodlots are restricted to farm owners. *Farmers are motivated to perform the harvesting* because (Mäkelä 1990):

- the forest owner can maintain complete control in tree selection, strip road planning, timing of the operation, etc.
- the farm tractor is needed for agricultural operations primarily during the summer season and stands more or less idle throughout the winter
- the logging accessories of the farm tractor can often be used also for agricultural work
- in self-employed operations, savings occur in the costs of social security and overheads
- the state supports delivery sales through a tax release for the logging wage up to a limit of 125 m^3 per year

Delivery sales give farmers opportunities to employ themselves and family members in the midwinter season. Over 100 000 farms are somehow involved in logging, but the volume of an individual sale is generally small, typically consisting of 50-200 m^3.

Local *Forest Management Associations provide expert assistance* to forest owners in conjunction with delivery sales and other forestry activities. They assist in selecting the cutting site, in marking trees for removal and in the measurement of timber. They carry out timber sales on behalf of the forest owner, and promote cooperation for joint sales activities and higher prices.

Figure 13. Mechanized cutting and off-road transport are combined into one logging contract and performed with a single-grip harvester and forwarder. Timberjack 1270 harvester and Timberjack 1010 forwarder (Photo Timberjack Europe).

Figure 14. Farm tractor equipped with a hydraulic crane and trailer is a common solution for off-road transport of timber in delivery sales from private forests. Valmet 6300 farm tractor, Kronos 5000 crane and Hakki-Souvari trailer (Photo Hannu Kalaja).

Self-employed forest owners use normally *a chainsaw for cutting and a farm tractor for haulage*. Out of over 200 000 farm tractors in Finland some 80 000 are estimated to participate in the harvesting of timber (Mäkelä 1987). In some cases, the forest owner may hire a forest machine entrepreneur to carry out the haulage or even cut the timber which he has agreed to deliver to the road side.

New farm tractors are commonly equipped with a turbocharged engine, a power shift transmission, large wheels, four-wheel-drive, a power-take-off, and a safety cabin. Substantial improvements in the base carrier and auxiliary equipment have made farm tractor based logging systems much more efficient and reliable compared with the situation in the 1960s, when special forest tractors started to replace farm tractors in timber harvesting. The leading make of farm tractor is Valmet with a 40 % market share.

When used for off-road haulage, a farm tractor is usually equipped with a *bogie trailer* (Fig. 14). Loading is carried out with *a mechanical or hydraulic crane*. The crane can be attached to the three-point linkage of the tractor, it can be fixed directly to the tractor, or it can be mounted on the cabin top or trailer bar. The power for the crane is supplied by the tractor's hydraulics, and the control levers are installed in the cabin. Hydraulically operated support legs give extra stability to the unit. Farm tractor-mounted hydraulic loaders usually have a reach of 5-6 m, but the most expensive cranes may have a reach of up to 9 m.

The productivity of the seasonal operations of self-employed farmers is reduced by poorer equipment and lower skill of the drivers. For example, if the tractor is equipped with a trailer and a combination of winch and mechanical boom loader, the productivity is 2-5 m^3 per operating hour over a haulage distance of 200 m, but the purchase of a hydraulic crane is not recommended unless the annual transport output exceeds 600-800 m^3 (Mäkelä 1987).

Farm tractors can also be equipped with *a skidding grapple* or *a skidding winch* coupled to the three-point linkage mechanism. Winches are used either for hauling timber over a short distance to the strip road, or alternatively for cable-skidding the timber with the tractor to the road side. With a remote controller the winch operator does not need an assistant. The productivity of skidding over a distance of 200 m is 1.5-3.0 m^3 per operating hour (Ryynänen 1986, Mäkelä 1987).

From the forest industry's point of view, *certain problems are involved in delivery sales*, and consequently the industry does not allow the proportion of timber cut by the self-employed forest owners grow too high. To this end, it tends to keep the difference between the stumpage price and delivery price of timber narrower than the industry's own logging costs should presuppose. The

Figure 15. A typical delivery sale from a private holding is composed of small piles of several assortments (Photo Erkki Oksanen).

Figure 16. Valmet 6600 farm tractor equipped with Keto 51 one-grip harvester head (Photo Erkki Oksanen).

following drawbacks are involved:

- The average volume of a single delivery sale is low and may still consist of several assortments, which are spread out in small piles (Fig. 15). This causes extra costs in measurement and trucking.
- Forest owners usually carry out the harvesting in mid winter. Consequently, large amounts of timber are handed over to the industry at the end of the winter logging season causing transport, storage and quality problems.
- The quality requirements, especially those of sawlogs, are not always met.

However, these problems should not be exaggerated. Delivery sales are *an integral part of the Finnish family forestry*, and they are of great social importance for the vitality of rural areas. They are also seen as an effective means to overcome the increasing task of early thinnings.

The technical performance and reliability of four wheel-drive farm tractors are sufficient not only for the temporary operations of self-employed farmers but also for contracting work. In the early 1980s, when equipped with a powered trailer and hydraulic loader for *permanent contracting work*, the productivity was for smaller tractors 4-5 m^3 and for larger tractors 6-7 m^3 per operating hour (Mikkonen 1984). With more efficient equipment the productivity has probably improved since then.

In addition to off-road haulage, modern farm tractors also make a suitable base carrier for processors, harvesters, debarkers, chippers, fuelwood splitters, etc. Some contractors use farm tractor *as a base carrier for a processor or harvester*. With a seat rotation of 180° the working position becomes more ergonomically acceptable. The minimum engine power requirement is about 60-65 kW. Profitability presupposes operation on a permanent basis during 8-11 months of the year (Fig. 16).

3.5 The harvesting operations of the forest industries

Three quarters of timber harvesting in Finland is carried out by the forest industries. All companies, and the FFPS which sells the timber from the state forests delivered to the mill, basically use similar technology. The extent of the operations during 1984-1993 is seen from the following annual averages (Yearbook... 1994):

	Million m^3/year
Harvesting operations of the industry:	
- From private woodlots	22.5
- From the industry's own forests	3.6
Harvesting operations of the FFPS:	
- From state forests	4.5
Industrial harvesting operations, total	30.6
Delivery sales from private forests	10.9
Industrial use of domestic wood, total	41.5

In motor-manual cutting operations the tree is felled directionally, delimbed and bucked into final lengths with a chainsaw at the stump in accordance with the quality requirements of timber (Fig. 17). The chainsaw worker bunches

Figure 17. Motor-manual cutting in a mixed stand of spruce and birch (Photo Hannu Kalaja).

Figure 18. A one-grip harvester clear-cutting a spruce stand for regeneration. Valmet 911 (Photo Sisu Logging Oy).

Figure 19. A one-grip harvester processing and simultaneously volume scaling a spruce stem. Ponsse HS 15 Ergo (Photo Ponsse Oy).

light pulpwood logs to speed up the subsequent haulage, but heavier logs are not moved manually. The length of pulpwood varies between 3-5 m and that of sawlogs between 3.1-6.1 m. The productivity of a chainsaw worker is strongly affected by the size of the tree (cf. Kahala 1980):

Stem volume m^3	Product	Pine	Spruce
		Productivity of motor-manual cutting, m^3/man-day	
0.05	Pulpwood	11.0	8.2
0.10	Pulpwood	15.0	11.5
0.20	Sawlogs + pulpwood	19.3	15.1
0.30	Sawlogs + pulpwood	22.1	17.4
0.50	Sawlogs + pulpwood	26.2	20.6

The cost of motor-manual cutting is high. In 1993, the average earnings of a chainsaw operator was 464 FIM/day including the saw costs (Yearbook... 1994) but excluding the social security and other indirect expenses. Since mechanization reduces the costs, an epochal mechanization program was started in the late 1980s, resulting in a radical reduction in the number of chainsaw operators.

In mechanized cutting operations chainsaw workers are replaced by contractor-owned harvesters which are capable of both felling and processing. *The two-grip harvesters* first sever the tree from the stump with a boom-mounted felling head and then transfer it for further processing to a separate mechanism mounted on the base carrier. *The one-grip harvesters* use a relatively light, boom-mounted head for both felling, delimbing and bucking. The two-grip harvesters have their primary application in larger trees and clear-cuttings because of their robust structure. However, since the one-grip harvesters have been developed to be able to handle larger and larger trees, all new multi-function machines presently sold in Finland, some light farm tractor mounted equipment excluded, are one-grip harvesters (Figs. 18 and 19). The average number of harvesters working in the Finnish forests year around was 720 in 1993 (Yearbook... 1994). About 220 new harvesters were sold in 1994.

The productivity of harvesters is sensitive to tree size (Fig. 20). A large national study in 1990-1992 on the productivity of mechanized harvesting per gross effective time (including interruptions shorter than 15 min) showed the following average results in softwood-dominated stands. In northern Finland the productivity is reduced by the smaller stem volume (Kuitto et al. 1994):

	Southern Finland	Northern Finland	Whole Country
	Productivity of harvesters, m^3/h		
Thinning cuttings	10.0	7.8	9.6
Regeneration cuttings	17.2	11.2	14.6
All cuttings	15.8	10.9	13.9

The cost competitiveness of harvesters is the result of many factors. In addition to direct cost reductions in cutting, the following *indirect advantages* at the system level are of great importance:

- Planning and overhead costs of the logging organization are reduced
- Timber scaling becomes an automatic low-cost operation. Accurate and detailed measurement results are received in real time
- Productivity of forwarding is improved, since loading becomes more rapid and loads larger after cutting and bunching with a harvester (Fig. 22)
- The flow of timber from stump to mill is speeded up. This is especially important during the summer, as the sawlogs and spruce pulpwood must be fresh to guarantee high quality of mechanical pulp
- Harvesters can protect stumps against harmful *Heterobasidion annosum* fungus with an automatic spraying device
- The harvester operator can grade the sawlogs with colour marks

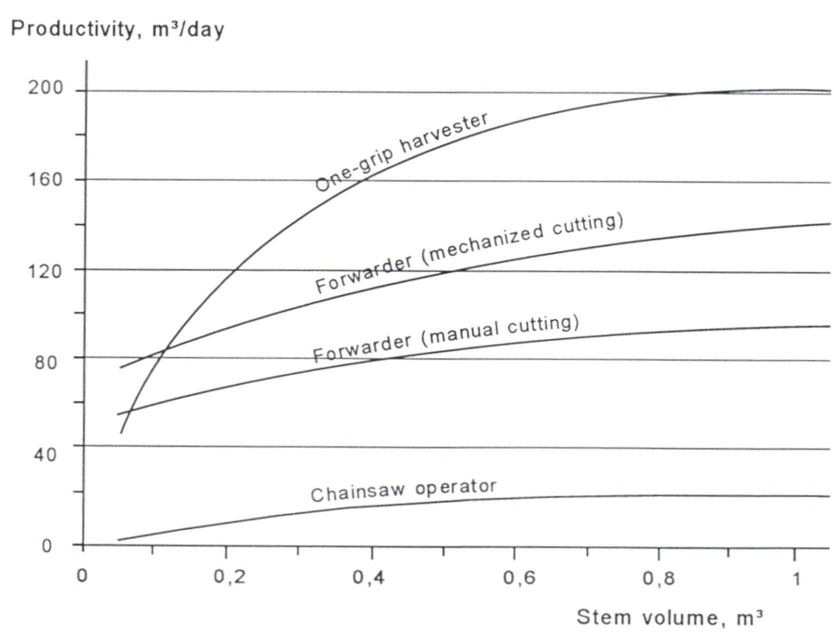


Figure 20. The average productivity of a chainsaw operator, one-grip harvester and forwarder as a function of stem volume.

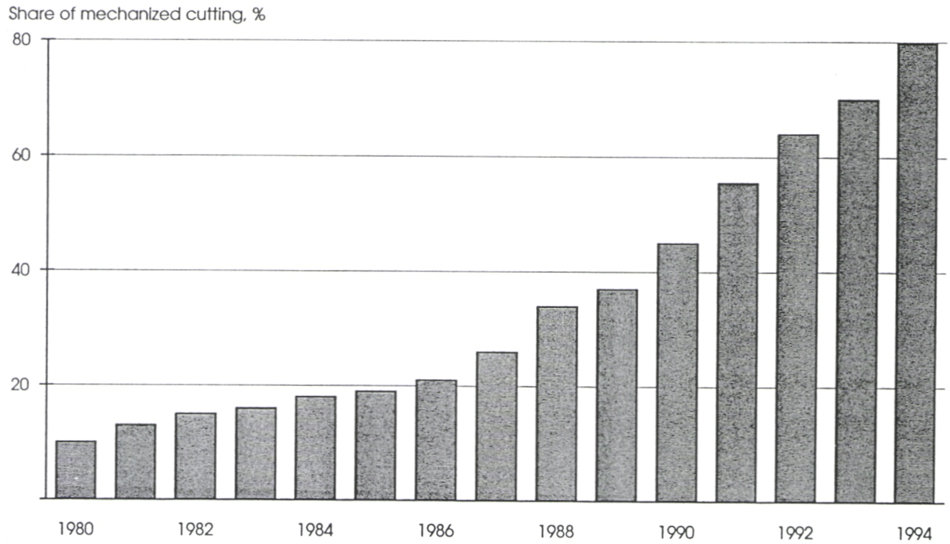


Figure 21. The average share of mechanized cutting in the operations of the forest industries and the Finnish Forest and Park Service (unpublished data from Metsäteho).

Due to the direct and indirect advantages of mechanized cutting, the use of harvesters has increased rapidly in the 1990s. In FFPS's operations the degree of mechanization is below the average because of the state's employment policy. On the average, in the operations carried out by the forest industry companies and the FFPS, 80 % of all timber was cut by harvesters in 1994 (Fig. 21). The proportion is expected to rise to 90 % in a few years. It follows that the forest management goals at the stand level have to be achieved through decisions and selections made by the harvester operator in his cabin.

Haulage to the road side is performed with a 6- or 8-wheel forwarder, equipped with a 10 m hydraulic crane (Fig. 23). In 1993, some 1150 forwarders worked in the Finnish forests (Yearbook... 1994). The average volume of a forwarder load is 11.9 m^3 for sawlogs, 10.2 m^3 for 5-m pulpwood and 8.2 m^3 for 3-m pulpwood (Kuitto et al. 1994). Depending on the hauling distance, terrain, site conditions, type of equipment, the skill of the driver, and not least on the method of the preceding cutting, the productivity varies widely. In 1990-1992 the average productivity of forwarding was as follows (Kuitto et al. 1994):

	Manual cutting	Mechanized cutting	Overall average
	Productivity of forwarders, m^3/h		
Thinning cuttings	10.6	12.5	11.0
Regeneration cuttings	12.1	17.2	15.8

Figure 22. Harvesters bunch the timber in conjunction with processing in a way that facilitates the subsequent loading of forwarders (Photo Hannu Kalaja).

Figure 23. A forwarder hauling sawlogs. Six-wheeled Valmet 840 (Photo Sisu Logging Oy).

3.6 The secondary transport of timber

The timber is transported to the industry *by road, rail or water*. In 1994, the total cost of long-distance or secondary transport of industrial timber from the road side to the mill was 1.7 billion FIM, making up 40.0 % of the cost of procurement and 15.6 % of the overall cost of timber at the mill (Metsäteollisuuden... 1994). The secondary transport is thus of great significance for the cost control of timber.

At the dawn of the Finnish forest industries in the 19th Century natural waterways were necessary for the transport of timber and as a source of energy. The mills were located accordingly. Although transport and energy conditions have changed thoroughly since then, *water transport continues to be technically possible* to most major mills. Finland is the last country in Europe where floating is still practised on a large scale. Loose floating was ended in 1991, but bundle floating remains competitive over long distances. However, the tendency to reduce timber inventories, the need for steady and rapid year-round flow of timber from forest and the stringent quality requirements of wood, all favour other ways of secondary transport. During the last few years, barges have replaced a part of the floating.

Road transport is preferred at distances less than 150 km. When distances grow, road transport is often supplemented by cheaper rail or water transport (Figs. 24 and 25). In 1993, as much as 77 % of all timber was delivered to the mill by road, but due to shorter distances only 55 % of *the total transport performance*, i.e. timber volume multiplied by distance, was carried out by truck-only regimes (Table 5).

Table 5. The performance and cost of different ways of secondary transport of domestic timber in 1993 (Oijala 1994).

Means of transport	Volume mill. m^3	Distance km	Proportion, % of volume	Proportion, % of performance	Cost FIM/m^3/km	Cost FIM/m^3
Truck only	32.2	94	76.9	55.1	0.32	29.8
Truck + train	7.3	261	17.5	34.7	0.18	45.8
Truck + barge	0.5	257	1.1	2.3	0.18 (barge and floating combined)	42.6 (barge and floating combined)
Truck + floating	1.8	242	4.4	7.9		

Figure 24. A seven-axle timber truck unit loading spruce pulpwood. Sisu SM 312 truck (Photo Erkki Oksanen).

Figure 25. At long distances, road transport is often supplemented with bundle floating (Photo Hannu Kalaja).

The Finnish highway system, and a large part of the forestry road network of over 100 000 km, have been built for *trucks with a gross mass of 60 t*. The maximum vehicle length is 22.0 m, width 2.6 m and height 4.0 m.

The maximum allowable 60 t mass can be reached with a seven-axle truck+trailer unit. About 60 % of the units have 3-axle trucks and 4-axle trailers, whereas 30 % have 4-axle trucks and 3-axle trailers. Most of the remaining 10 % have 4-axle trucks and 4-axle trailers. Adoption of the 42 t maximum limit of the EC directives would cause unreasonable extra costs for truck entrepreneurs and the forest industries.

Since flexible mobility from site to site and from pile to pile is necessary due to the fragmental ownership of forest land and small size of timber sales, *the trucks are always self-loading* (Fig. 26). Separate loaders are not economical at small landing areas. However, to increase the truck's load capacity, the crane can be detached and left at the landing site after completing the loading. The average load capacity of a truck+trailer unit is 42 t (about 50 m^3) without the crane and 39.5 t (about 47 m^3) with the crane.

Timber trucks operate evenly throughout the year. On average, 1280 timber trucks were employed in 1993 on annual basis. The leading timber truck makes are Volvo, Sisu, Scania, and Mercedes Benz. The leading timber trailer make is Jyki (Fig. 27).

With few exceptions, timber *trucks are owned by private entrepreneurs*. In 1990, an average entrepreneur owned 1.5 trucks and his annual turnover was 900 000 FIM. Salaries consisted of 26 %, capital costs 23 %, fuel and lubricants 20 %, service and repair 9 % and tires 3 % of the transport enterprise's turnover (Mäkinen 1993).

3.7 The productivity of timber harvesting

The productivity of harvesting concerns the labor input required to cut and transport timber from stump to road side. The unit of productivity is here m^3/man-day or m^3/man-year.

No covering information is available on the labor input into the delivery sales of the self-employed forest owners. Therefore, this chapter is restricted to the operations performed by the forest industry companies and the FFPS. On average, they represent 74 % of the annual performance of timber harvesting during the last ten years.

Figure 26. To reduce landing area requirements and for flexible mobility from site to site, timber trucks are self-loading. Loglift 95 timber crane (Photo Loglift Oy Ab).

Figure 27. Timber trailers can accommodate two bundles of 6-m logs in tandem. Three-axle Jyki trailer with an extendible frame (Photo Jyki Oy).

In the early 1950s, timber was cut by handsaw and axe and hauled by horse and sledge. Saw logs and pulpwood were debarked for floating, and fuelwood was split for drying. The distance of haulage to the road side or floating route was often several kilometres. According to Vanhanen & Heikinheimo (1983), in the 1950s the productivity of harvesting was 1,2 m^3/man-day or about 300 m^3 per man-year.

Productivity has increased enormously during the past 40 years, particularly during the ten last years (Fig. 28). This has been made possible by machine development and mechanization, but it is also a result of general system rationalization which does not always require high investments. The following *rationalization measures* have played an important role in the development:

- Distances of off-road transport were shortened by building over 100 000 km of permanent forest roads. The cutters' daily journey to the work site was shortened correspondingly.
- Debarking was moved from the forest to the mill, and the bark used for energy.
- The handsaw and axe were replaced by chainsaw. The cutters were made permanent and their work techniques and safety were improved through vocational training and auxiliary equipment.
- The length of a pulpwood log was increased gradually from 1 or 2 m to 3 m and further up to 5 m, resulting in faster cutting and loading, and in larger load sizes. The length tolerance of pulpwood logs was simultaneously eased and bucking without length measurement became acceptable. Reflecting this change in log lengths, the shortwood system is now referred to as log-length system.
- The horse was replaced by the farm tractor, and the farm tractor was replaced later by the forwarder-type forest tractor. The reach of the hydraulic loader in forwarders was extended gradually to 10 m, which considerably eased the bunching requirement in cutting and reduced strain on the cutter.
- Cutting mechanization was started with processors which still relied on motor-manual felling. Processors were replaced by harvesters, and fully mechanized logging became possible. Initially the harvester operations were restricted to regeneration cuttings, until the development of single-grip harvesters solved the problem of the mechanization of thinning cuttings. The measurement of timber became an automatic operation of the harvesters.
- Independent forest machine entrepreneurs were made responsible for the implementation of cutting and off-road haulage.
- Planning and organization of work were improved both at the system level and at the work site level. In 1990-1992, *the technical availability* of harvesters was 81 % and that of forwarders 90 %. *The operational*

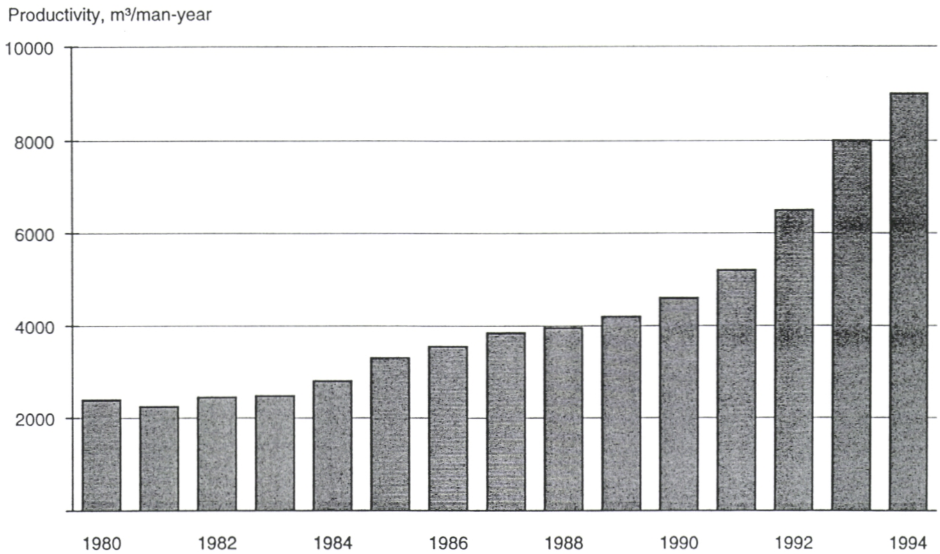


Figure 28. The development of the productivity of timber harvesting from stump to roadside since 1980 (unpublished data from Metsäteho).

availability, or machine utilization, was correspondingly 74 % and 82 % of the total work site time (Kuitto et al. 1994). Technical availability shows the technical reliability of the machine, whereas operational availability is also affected by interruptions caused by organizational delays and moving of machines from site to site.

- *The annual employment* of forest machines was improved through better planning. In 1994 the average working time of a harvester was 2400 h and that of a forwarder 1820 h. The *capacity utilization* on an annual basis was 89 % and 75 % respectively (Jaakkola 1994b).

The appearance, growth and decline of different cutting and off-road transport solutions are seen in Fig. 29. Fully mechanized logging based on the use of single-grip harvesters and 8-12 tonne forwarders has become the standard solution. By the year 2000, the share of this machine combination is expected to grow to 90 % of the total performance in the forest company and FFPS operations, delivery sales by private forest owners excluded.

The following table shows the size and total performance of the Finnish pool of harvesters, forwarders and timber trucks in 1993 (Yearbook...1994). The statistics under consideration do not indicate whether a machine worked in one or more shifts during the year. Due to a considerable increase in the consumption of domestic timber, the employment and average annual productivity of all equipment improved further in 1994.

Harvesters:	
Output of cutting, million m^3	23.1
Input, harvester-years	720
Productivity, m^3/harvester-year	32 100
Forwarders:	
Output of haulage, million m^3	31.7
Input, forwarder-years	1 150
Productivity, m^3/forwarder-year	27 600
Timber trucks:	
Output of haulage, million m^3	38.4
Input, truck-years	1 280
Productivity, m^3/truck-year	30 000

The *overall productivity of timber procurement* in 1994 is shown in the following table. Again, the delivery sales and the work input by the supervisory staff of the organization are excluded (unpublished data from Metsäteho):

	Productivity m^3/man-year in 1994
Cutting	12 100
Off-road transport	34 200
Harvesting, total	8 970
Long-distance transport	21 000
Procurement, total	6 300

Mechanization successfully helped to control the cost of timber in the 1990s (Section 4). On the other hand, the rapid increase in productivity resulted in *an abrupt reduction in the job opportunities* in forestry, as is shown by the following table. Supervisory staff and the operations of self-employed forest owners are not included (Yearbook... 1994):

	1988	1993
	Man-years	
Cutting	9 800	4 000
Off-road transport	1 800	1 300
Harvesting, total	11 600	5 300
Long-distance transport	2 400	1 900
Timber procurement, total	14 000	7 200
Silvicultural work	5 500	4 800
Other forest work	1 400	600
Forestry, total	20 900	12 600

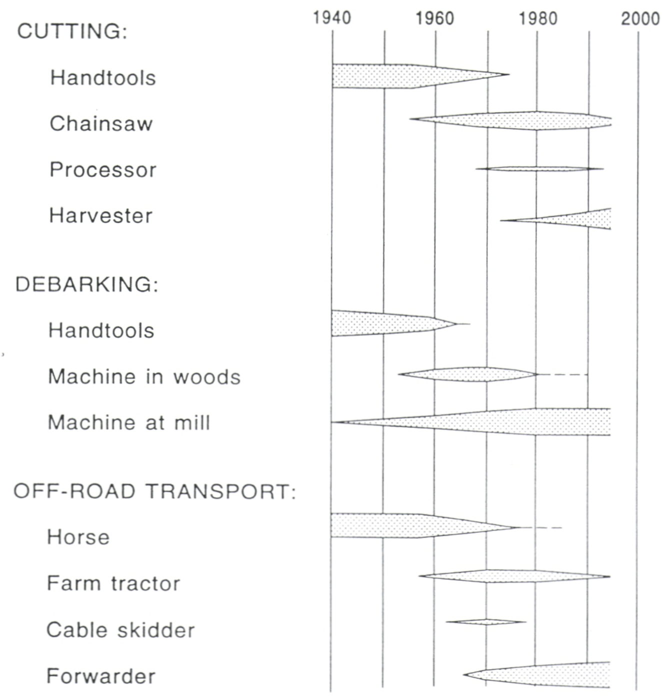


Figure 29. The development of timber harvesting technology in the forest industry companies since the 1940s.

Cutting has traditionally provided a large number of jobs for chainsaw workers, but these operations have now been taken over by independent forest machine and truck entrepreneurs. In fact, more people is needed presently for silvicultural work, such as planting and precommercial thinning, than for the commercial cutting of timber.

As the degree of cutting mechanization approaches 90 %, the rapid increase in the productivity will level out. The present technology is reaching a mature stage, and its productivity cannot be significantly increased by technical improvements. Instead, the emphasis in development work is shifting to environmental quality.

4. The cost of timber

During the last three decades Finnish forestry was characterized by the reforestation of degraded stands, repeated thinnings, adoption of environmentally sound harvesting systems, careful recovery and value utilization of timber, and almost complete utilization of the process residue from mechanical forest industries for fiber and energy. These practices would not have been feasible without attractive stumpage prices. In conditions of slow-growth, long rotation periods and high labor costs, a high stumpage price is necessary to motivate forest owners to practise intensive management. The following table shows the level of stumpage prices in March 1995 (data from Puunhankinnat... 1995):

	Southern Finland	Northern Finland
	Stumpage price, FIM/m^3	
Pine sawlogs	250	223
Spruce sawlogs	198	181
Birch veneer logs	240	..
Pine pulpwood	98	97
Spruce pulpwood	112	98
Birch pulpwood	102	101
Aspen pulpwood	15	..

Not only the stumpage prices, but also the cost of procurement tends to be high in Finland, since technical logging conditions are complex. The individual sales are small, tree size is small, proportion of thinning cuttings is large, and only 9 % of the forest area is owned by the forest industries. These drawbacks are offset by vocational training of forest workers, mechanization, high mobility of the equipment, and efficient organization in which a key role is given to independent machine entrepreneurs. The importance of stand conditions is reflected by the following costs of harvesting in 1994:

	Cost of harvesting in mechanized operations, FIM/m^3
First commercial thinnings	75 - 80
Subsequent commercial thinnings	52 - 57
Regeneration cuttings	30 - 34

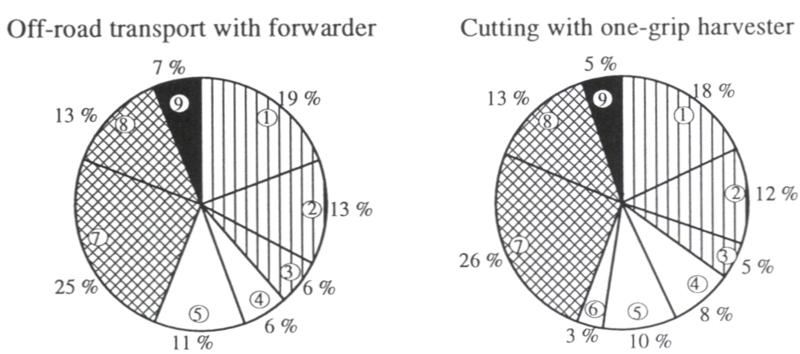
The proportions of timber assortments vary from year to year. On average, 47 % of domestic industrial timber is saw and veneer logs and 53 % pulpwood. Table 6 shows *the development of the mill cost of all timber*.

Table 6. The mill cost of all domestic timber in Finland since 1985. Data from Metsäteollisuuden vuosikirja (1994), organizational overheads added.

Cost factor	1985	1990	1994
		Cost, FIM/m^3	
Cutting	33.8	40.7	30.8
Off-road transport	21.3	23.2	16.4
Harvesting, total	55.1	63.9	47.2
Long-distance transport	36.3	38.4	32.1
Procurement, total excl. overheads	91.4	102.3	79.3
Stumpage price	132.9	174.2	147.0
Mill price, total excl. overheads	224.3	276.5	226.3
Overheads, 7 %	15.7	19.4	15.8
Mill price, total incl. overheads	240.0	295.9	242.1

The costs reached the peak in 1990. Since then the industry has been able to reduce the mill prices of timber closer to the international level and greatly improve its competitiveness. However, pressure is accumulating to adjust entrepreneurs' wages in response to rising machine costs.

Almost 40 % of the cost of mechanized logging is caused by amortization and interest. The direct and indirect wages of the operator are another important cost factor. Travelling included, they form about 35 % of the total harvester cost and 38 % of the forwarder cost (Fig. 30). In countries with lower wages the cost from the operator is less than a half of the Finnish level.



Labor costs:
1 Operator's wage
2 Indirect wage costs
3 Travelling, accommodation
Variable costs:
4 Fuel, lubricants
5 Service, repair
6 Chains, chain bars
Capital costs:
7 Amortization
8 Interest
Other costs:
9 Administration, insurance, machine moves

Figure 30. The cost structure of one-grip harvesters and forwarders in 1994 (data from Koneyrittäjien Liitto ry).

5 Forest energy - a new challenge

5.1 The present use of wood-derived energy

Since Finland has no indigenous reserves of fossil fuels, energy management was based on wood far longer than in other industrialized countries. As late as 1965, one third of the primary energy was still generated from wood. As the consumption of energy grew, Finland had to turn increasingly to foreign fossil fuels. By the second world-wide energy crisis in 1978, the role of wood-derived energy had dropped to the present level of 14 % of the primary energy consumption. Nevertheless, *wood still remains an important source of energy in Finland*; more than in any other industrialized country.

Table 7 shows the destination of the annual wood harvest in Finland, imports included, in the early 1990s. About 25 million m^3 or *46 % of wood and bark was used for the production of energy* in a solid or liquid form, corresponding to over 4 million tonnes of oil equivalent. However, it is important to realize that less than 5 million m^3 was used in the form of traditional firewood or forest chips, whereas the remaining 20 million m^3 were process residues from chemical and mechanical forest industries.

Table 7. Average annual consumption of wood in the early 1990s and its distribution into industrial end products, industrial energy from process residues, and non-industrial use for fuel and other products.

	Million m^3 equivalents/year in the early 1990s
Wood remained in end products:	
Pulp and paper	20.4
Lumber	7.4
Veneer	0.6
Particle boards, fiberboards	0.6
End products, total	29.0
Process residue used as fuel:	
Waste liquor from kraft mills (mainly lignin)	14.3
Bark	5.0
Sawdust	0.7
Other wood waste from industry	0.5
Fuel component, total	20.5
Industrial wood, total	49.5
Non-industrial wood for fuel etc.	4.5
Total consumption of wood	54.0

Practically all the wood chips, saw dust and other wood residues from the mechanical forest industries are utilized either as raw material for pulp and composite boards or for fuel. Very little industrial wood residue or even bark is left unutilized.

5.2 The energy potential of unmerchantable forest biomass

The annual increment of the Finnish forests exceeds the demand and drain by almost 20 million m^3. However, the surplus of commercially available wood is diminishing. The capacity of the forest industries is expanding, a part of the increment is being set aside for protection and multiple use, and many forest owners are giving priority to recreation instead of wood production. It follows that the available surplus is smaller than directly shown by the national forest balance statistics.

It is agreed that the use of wood for fuel must not endanger the raw material supply to the forest industries. However, large quantities of unmerchantable small-sized trees should be removed from young stands for silvicultural reasons, but there is insufficient industrial demand for this low-quality biomass reserve. Another unutilized reserve of forest biomass, although without offering notable silvicultural incentives, is the logging slash composed of crown mass and unmerchantable stem parts in clear-cutting areas of mature forests (Figs. 31 and 32).

It is difficult to estimate what proportion of this biomass reserve is actually harvestable, for the technical availability is ultimately bound to the development of energy taxation, fuel prices, labour supply, environmental factors, etc. At least 10 million solid m^3 of unmerchantable logging residue and small-sized trees, corresponding to almost 2 million tonnes of oil equivalent, can definitely be classified as *an annually harvestable energy reserve as follows*:

	Technically harvestable fuel-wood reserve, million m^3/year
Chips made of small-sized whole trees:	
From pre-commercial thinnings	1.5
From 1st commercial thinnings	2.5
From unproductive hardwood stands	2.0
Chips made of slash from clear-cuttings	4.0
Total	10.0

Figure 31. At least 6 million m^3/year of small-sized trees with branches is technically harvestable for energyproduction without endangering the raw material supply of the forest industries (Photo Hannu Kalaja).

Figure 32. Logging slash from regeneration areas is becoming a cost-competitive source of renewable bioenergy. The harvestable reserve is about 4 million m^3 per year (Photo Hannu Kalaja).

The estimate is conservative. If for some reason the availability of imported fuels becomes endangered or their costs increase steeply, an even larger biomass reserve could be mobilized, even when the ecological restrictions of intensive biomass recovery are taken into account. If the 10 million m^3 annual biomass reserve could be substituted for imported fossil fuels, the following benefits could be achieved:

- The national *energy self-sufficiency could be raised* from the present 32 % to 37 %, presupposing that the total consumption of primary energy in Finland remains at the present level.
- Procurement and use of fuel chips could *create up to 10 000 new jobs* in rural areas, the indirect jobs included.
- *Management of young forests*, i.e. precommercial thinnings and early commercial thinnings, could be intensified.
- Finland's international agreements upon the *reduction of harmful emissions* to the atmosphere could be better met. These agreements include: reduction of SO_x emissions from the 1980 level by 80 %; reduction of NO_x emissions from the 1980 level by 30 % by 1998; and stabilization of CO_2 and other greenhouse gases at the 1990 level by the end of the century.

The energy use of low-quality forest biomass is seen to be so attractive, that it is given a high priority in the government's research, development and demonstration programs. On the other hand, because of the long-term nature of investments, changes in the energy economy require time.

5.3 The reduction of carbon dioxide emissions

As a result of massive global use of fossil fuels, tropical deforestation and intensive agriculture, concentrations of carbon dioxide and other greenhouse gases in the atmosphere are growing. Compared with the pre-industrial situation the emissions are expected to double by 2030, causing a 1.5-4.5 °C rise in global mean temperatures (Hiilidioksiditoimikunta... 1994).

In Rio de Janeiro in 1992 Finland signed the legally binding Climate Convention of the UN Conference on Environment and Development, according to which carbon dioxide emissions are to be limited, and absorption of the gas by carbon sinks such as forest biomass is to be promoted. As emissions of carbon dioxide derive mainly from the fossil fuels, *substituting renewable forest biomass for oil and coal* is in Finland a natural way to contribute to the endeavour.

Carbon dioxide equivalent is a practical indicator to compare the capacities of various gases to absorb thermal radiation, and to take account of their different lifespans in the atmosphere. In Finland, the total emissions of greenhouse gases caused by human activity were in 1990 as follows (Hiilidioksiditoimikunta... 1994):

	Gas emissions' CO_2 equivalent in 1990, million tonnes
Carbon dioxide	58.6
Methane	3
Nitrous oxide	5.4
Chlorofluorocarbons (CFCs)	9
Nitrogen oxides (NO_2)	2
Carbon monoxide	0.5
Volatile organic combounds (VOCs)	2

Forestry and bioenergy could play a key role in Finland's efforts to fight the greenhouse effect. The following prospects are a new challenge to the Finnish forest sector in controlling the national carbon budget:

- The increment of the forests exceeds the drain. Accumulating biomass builds up atmospheric carbon through assimilation. In the second half of the 1980s *the annual net accrual of carbon was equivalent to 27 million tonnes of carbon dioxide*, and the balance continues to be positive.
- Small-sized trees and crown mass are left as residue at the site after silvicultural treatments and logging operations. Carbon is slowly released to the atmosphere by the decomposing residue. If 10 million m^3 of residual biomass could be salvaged annually from the forests and substituted for fossil fuels, the amount of *carbon dioxide emissions could be reduced by 7 million tonnes per year*.

5.4 The development of fuelwood harvesting technology

Since farms in Finland always own forest land, wood is a natural and economical fuel for them. It is primary or partial fuel for space heating on two thirds of the farms, usually in the form of split billets.

Rural 1 to 15 MW heating plants form another user group of fuelwood. In this category come district heating centres, hospitals, educational institutions and small industrial plants using chips as a substitute for fossil fuels. There were 113 such plants in operation in 1982, but since then many have started to use peat or oil. The cost of chips tends to be too high, and in many cases peat, where locally available, is a more economical alternative.

To increase the consumption of forest biomass for the production of energy, additional consumption must be found amongst large-scale users. If environmental taxes change the price relations in favour of bioenergy, *the forest industries* could use forest residue for generating electricity and heat for industrial processes and district heating. The forest industries' timber harvesting organizations could be used in the future to provide chips to independent co-generation or alcohol fuel plants.

Since the forest industries can use small-sized trees not only as fuel but also as raw material for pulp, the development aim *is an integrated procurement system* and sorting the biomass into two fractions, i.e. fuel chips and fiber chips. Sorting could be carried out either prior to the reduction of biomass to chips, or alternatively after the reduction through chip upgrading. The following techniques are examples of the ongoing development objectives for integrated harvesting and utilization of small-tree biomass in Finland:

- Accumulating feller-buncher and feller-forwarder for small trees
- One-grip harvester capable for multi-stem processing of small trees
- Adoption of American flail delimbing-debarking-chipping techniques to the Finnish operating environment
- Processing terminal for small whole trees based on combined use of flail delimbing-debarking and drum debarking techniques
- Mobile whole-tree chipper (Fig. 33)
- Upgrading plant for whole-tree chips

The most economical source of forest biomass for large-scale energy production is presently the logging slash from clear-cutting areas. In a typical regeneration area where the removal of stemwood is 200 m^3/ha, the amount of logging slash from stem tops and crown mass is 110 m^3 in a spruce stand and 50 m^3 in a pine stand. This corresponds to 22 and 9 tonnes of oil equivalent per hectare respectively, of which 50-75 % can be salvaged (Hakkila 1992). The most promising technology, already in common use in Sweden, is based on the collection of slash into heaps in conjunction with processing with one-grip harvesters and haulage to the roadside with conventional forwarders equipped with enlarged load space.

The present level of costs is 75 FIM/MWh for whole-tree chips and 55 FIM/MWh for chips reduced from slash. The ambitious goal of the ongoing National Bioenergy Research Program is to reduce the cost at the plant to 45 FIM/MWh which would make large-scale use possible. For whole-tree chips, the price gap is too wide to be closed by technological means only, but changes in energy taxation are expected to narrow the gap and improve the competitiveness of renewable bioenergy.

6 The Finnish logging machine industry

6.1 Farm tractor based forest equipment

The development of the Finnish forest machine industry began in the 1950s, when the farm tractor was adapted for forest use. Rural machine shops, smiths, and farmers were in close contact with forestry. When both practical knowledge of forestry and machine making skills were combined in one person, new ideas for the rationalization of logging were born and realized. One invented equipment for his own personal use, another manufactured for sale, and yet another simply fulfilled creative drive and to satisfy the need for experimentation. The successful became small entrepreneurs.

Important products were sledges, trailers, half tracks, winches and mechanical boom loaders for farm tractors. With the help of these accessories, the rapid decline in horse-drawn off-road transport capacity could be offset by farm tractors.

Figure 33. A new mobile whole-tree chipper for thinning conditions. Feeding from both sides and front of the unit. Chipset chipper (Photo Pentti Hakkila).

Simultaneously, the farm tractor proved to be a suitable base carrier for *transportable debarking machines*. A variety of farm tractor-driven machines came onto the market in the 1950s. Valon Kone became a leading manufacturer, and its product development advanced to the VK-ring debarkers. With these transportable and stationary products Valon Kone was among the first to make the Finnish logging machine industry known beyond national borders. Gradually, debarking was moved from the woods to the mill, and the VK production concentrated on stationary debarkers.

Farm tractor-driven fuelwood chippers also were developed in the 1950s. Machine manufacturers suffered when cheap oil replaced wood in the 1960s, but recovered again after the two global oil crisis in the 1970s. The markets of chippers and other fuelwood processing machinery have been remarkably unstable depending on variations in prices and the availability of fossil fuels. The major manufacturers of farm tractor driven chippers are:

Manufacturer	Make of chipper
Junkkari Oy	Junkkari disc chippers
Orion Yhtymä Oy Normet	Hakki disc chippers
Savomet Energy Oy	Sasmo spiral screw chippers
Ahlström Sahakoneet Oy	TT disc and drum chippers for entrepreneurs and industrial use

As mentioned in Section 3.4, about one fourth of the commercial timber from private forests is sold delivered to the road side by self-employed forest owners. They usually perform the cutting with a chainsaw and haulage with a farm tractor. The most common accessories in these operations are 6 to 12 t *timber trailers and hydraulic cranes*. The reach of the crane is typically 5-6 m and the lift moment 20-40 kNm. The following list shows the major manufacturers of farm tractor mounted timber cranes and trailers:

Manufacturer	Make of trailer and crane
Evimet-Group	Evi
Kesla Oy	Patu, Foresteri
Kronos	Kronos
Nokka-Tume	Hakki-Souvari
Orion Oy Normet	Farmi
Pellonpaja Oy	Patruuna

Skidding grapples and winches are other popular accessories for farm tractor-based timber haulage. Farmi winches of the Orion Yhtymä Oy Normet are among the best known export products of the Finnish forest machine industry in both developed and developing countries.

A large number of small engineering workshops make *processors and crane-mounted harvester heads for farm tractors*. They are meant mainly for professional contracting work, since the price, 100 000-150 000 FIM, is too high for seasonal use. An efficient harvester head has a mass of 280-380 kg and can delimb stems of up to 30-40 cm in diameter. Feeding takes place either in cycles or continuously with rolls, bogie rolls or tracks, and cross-cutting is carried out with a chainsaw. An automatic measurement device is available for all equipment. The leading manufacturers and products are:

Manufacturer	Make of product	Processor	Harvester
Kesla Oy	Patu	x	x
Kone-Ketonen Ky	Keto		x
Nokka-Tume/Tume Oy	Nokka	x	
Orion-Yhtymä Oy Normet	Farmi		x
Pellonpaja Oy	Patruuna	x	x
S. Pinomäki Ky	Pika	x	x

6.2 Forest tractor based equipment

<u>The products</u>

Because timber harvesting in Finland is based on the log-length system, the forest machine industry is similarly oriented. Since the 1970s the forwarder has been the base product. During the 30-year-long history of the forwarder the emphasis in the machine development has changed as follows:

- During the first decade, starting from the mid 1960s, the manufacturers' primary concern was the improvement of performance, productivity and reliability.
- When the performance approached the target level in the late 1970s, the emphasis was shifted to ergonomic considerations such as vibration, seats, visibility, noise, control levers and pedals, cabins, etc. This phase resulted in the high-standard tractor cabin which is now characteristic of all Nordic forest machines. When forwarders are exported to countries of less strict ergonomic standards, compromising the cabin specifications is not uncommon.
- Since the mid 1980s, development efforts have been focused on environmentally sound technology. Considerable improvements in reduced soil compaction and rutting have been brought about through improved power transmission, balanced mass distribution, a larger number of driving wheels, wider tires, new track designs, long-reach cranes, light materials such as aluminium, etc.

The success and wide acceptance of forwarders over the past 25 years was partly due to the development of hydraulics. In respect of system efficiency and machine design, the *long-reach hydraulic timber crane* is of utmost importance. Several manufacturers make cranes for farm tractors, forest tractors, multi-function machines and trucks. In fact, a large proportion of the world production capacity in vehicle-mounted timber cranes is in the hands of the Finnish logging machine industry.

The mechanization of cutting began in the Nordic countries in the mid-1960s. In Finland, the pioneer was Sakari Pinomäki, who was earlier known as a builder of transportable debarking machines. His pioneering work resulted in the first Finnish multi-function machine, PIKA 50 processor in 1968, and the first Nordic harvester, the PIKA 75 in 1973.

Many manufacturers in both Sweden and Finland began to develop multi-function machines in the 1970s. Initially, the focus was on processor-type equipment, for which timber had to be felled separately with a chainsaw or feller-buncher. In the 1980s, *development of multi-function machines turned towards harvesters*, i.e. fully mechanized cutting with a single machine. The early harvesters relied on the two-grip techniques (see page 37). The first machine designers to apply the single-grip principle in Finland in the late 1970s were Sakari Mononen with his continuous roll-feed Finko I processor and Tapio Saarenketo with his cycle-feed Tapio harvester. The *single-grip harvester* concept, due to its flexibility and versatility, has determined the direction of development. In fact, since 1994 all harvesters manufactured by the Finnish companies apply the single-grip techniques.

The first generation of multi-function machines were heavy and clumsy, tended to cause damage to the timber with hydraulic shears and spiked feeding rolls, caused excessive compaction and rutting of forest soil, and damaged standing trees during thinning. Today, modern single-grip harvesters produce high-quality timber, carry out volume scaling with sufficient accuracy, and can be used for thinnings. They have replaced the forwarder as the main product of the forest machine industry.

When, in 1994, the Finnish forest industries recovered from their deepest recession ever, the consumption of wood and sales of forest machines increased considerably. The total *value of the annual domestic forest machine sales* was about 864 million FIM. Chainsaws and brushsaws excluded, almost all machinery was produced by Finnish-owned companies in Finland or Sweden. Presently the most important product group is harvesters, followed by forwarders. The sales of chainsaws have been declining since the mid 1980's, and most chainsaws are presently purchased for non-professional occasional use (Table 8).

Table 8. The sales of forest machines in Finland in 1992-1994 (the sales of forwarders and harvesters in 1993 and 1994 are the author's estimates, other data from MTT/VAKOLA 1995).

Product group	1992	1993	1994
	Domestic sales, million FIM		
Chainsaws, brushsaws	110	113	146
Farm tractor-mounted forest equipment	47	64	84
Forwarders	89	115	167
Harvesters, harvester heads	205	249	414
Truck-mounted timber cranes	35	29	53
Forest machines, total	486	570	864

The manufacturers

The Finnish forest machine entrepreneur thus relies on Nordic machinery. However, because the domestic forest machine markets are limited and dispersed, additional customers must be found beyond the national borders. Fortunately, demanding Nordic customers have created a strong base for the export to other parts of the world. During the last ten years Finland together with Sweden has become recognized as a manufacturer and exporter of the world's most sophisticated forest machinery.

The bulk of forest machine manufacturing has gradually been moved, partly through mergers in Finland and abroad, from a large number of small machine shops to fewer large international companies, who due to the scale of operation are in a better position to export. Rather than single machines, many of them offer complete mechanized logging systems from stump to road side, and in the case of the Sisu Group from stump to mill. However, a number of small manufacturers remain in the Finnish market, and they are of great importance in terms of machine development, production of special equipment, and competition. The major manufacturers are listed below. *The data on annual turnover and production refer to the year 1994.*

The Timberjack Group is the largest forest machine manufacturer in the world. The major manufacturing units are *Timberjack Oy* in Finland which makes forwarders, *Timberjack AB* in Sweden which makes one-grip harvesters and harvester heads, *Timberjack Inc.* in Canada which makes skidders, feller-bunchers, log loaders and low-cost forwarders, and *Peerless Corp.* in USA makes on-road equipment such as truck trailers and chip bins for the needs of the North American forest industry. The total production for the whole-tree, tree-length and log-length systems was in 1994 over 2000 units. The turnover was 2.4 billion FIM altogether, and 300 million FIM in Finland alone. Timberjack's share of the global forest machine markets was one third, and 46

% of the machines made for the log-length system, light farm tractor mounted equipment and chainsaws excluded. Of the equipment for the log-length system, i.e. forwarders and harvesters, 22 % were sold in Finland, 21 % in other Nordic countries, 20 % in German Europe and 22 % in North America.

The Sisu Group is specialized in the manufacturing of wheeled vehicles: Valmet farm tractors in Finland, Brazil and Portugal; Valmet forest machines in Sweden, USA and Brazil; Sisu trucks in Finland; as well as terminal tractors, armoured vehicles, diesel engines, etc. *Sisu Logging AB* is responsible for the forest machine production with a turnover of 682 million FIM. The headquarters is located in Sweden, where most of the production takes place. The product range includes forwarders, single-grip harvesters, harvester heads and timber measurement systems, all carrying trademark Valmet, and Sisu Cranab timber cranes. Sisu's share of the log-length system's world markets was about 26 %. The expected production in 1995 is 235 forwarders, 175 single-grip harvesters and 110 separate harvester heads. The main markets are in the Nordic countries, central and eastern Europe, North America and Australia. *Sisu Trucks Group* is specialized in over 16 t heavy-duty trucks for timber and gravel transport. Oy Sisu Auto AB in Finland is the manufacturing unit. About 60 % of the truck production is exported, mainly to Russia, the Baltic countries, Sweden and Norway. The turnover was 569 FIM.

Ponsse Oy is a manufacturer of forwarders, single-grip harvesters, cranes and harvester heads with the trademark Ponsse. Its share of the global markets is about 8 %. A subsidiary, Kajaani Automatiikka Oy makes measurement and control systems for forest machines, and truck scales. Ponsse's production was 150 units and the turnover 236 million FIM. The share of export was 25 %, mainly to Sweden, Chile, Central Europe, Norway and Russia.

Nokka-Tume/Tume Oy had a turnover of 97 million FIM, one half of which consisted of farm machinery and the other half Nokka forest machines. The value of forest machine production is evenly distributed between timber trailers and cranes for farm tractors and, on the other hand, light wheeled and tracked harvesters (Fig. 34) and forwarders. About 55 % of the forest machine production is exported, the main markets being in Germany.

S. Pinomäki Ky's main products are PIKA forwarders, single-grip harvesters, harvester cranes and harvester heads (Fig. 35). The turnover was 25 million FIM. Exports accounted for 40 % of sales, mainly to Germany, United Kindom, France and North America.

Oy Logset Ab's production is composed of light Logset forwarders, harvesters and harvester heads, and Chipset chip harvesters. The total value of the sales was 32 million FIM. Almost 70 % of the production was exported to Germany, Ireland, United Kindom, Switzerland, Sweden and the Netherlands.

Figure 34. A light tracked one-grip harvester for thinning cuttings. Nokka 16WD equipped with Keto 51 harvester head (Photo Tume Oy).

Figure 35. A four-wheeled one-grip harvester. PIKA 4500 (Photo S. Pinomäki Ky).

Loglift Oy Ab manufactures Loglift timber cranes for forwarders, harvesters and trucks, as well as stationary cranes for mill yards. The turnover was 250 million FIM. The share of exports is 90 %. Sweden, Germany, France and Russia are the most important export countries.

Kesla Oy had a turnover of 80 million FIM in 1994. The production includes forest accessories such as trailers, cranes, processor heads and harvester heads for farm tractors, as well as cranes for forwarders, harvesters and timber trucks. The trademarks of the products are Patu and Foresteri. The exports accounted for 47 % of trade. The exports were mainly to other Nordic countries, Central Europe and North America.

Kone-Ketonen Oy is the leading manufacturer of track-fed one-grip harvester heads for farm tractors, excavators and special harvesters. The largest harvester head is able to cross-cut and delimb stems with a maximum diameter of 80 cm. In 1994, the production of Keto harvester heads was over 200 units. Another internationally known manufacturer of one-grip harvester heads is *Lako Forest Oy Ltd.*

Jyki Perävaunuteollisuus Oy's production consists of Jyki truck trailers for the transport of roundwood, chips and lumber. The annual production is 250-300 trailers. Jyki's share of the domestic markets of timber trailers is 50 %. One fourth of the production is exported, mainly to Russia and the Baltic countries.

About one fourth of the world's industrial timber is harvested using the log-length system, and three quarters using the whole-tree and tree-length systems. This difference in the basic concept tends to be a barrier of forest machine trade between regions. It is not always enough that a potential foreign customer is convinced of the technical and environmental advantages of the log-length system. Before the Nordic technology can be transferred successfully, it may sometimes be necessary to adjust the trucks to cope with new assortments, rearrange the millyard handling and debarking of timber, or adopt a totally new logistic system and way of thinking. However, as increasing weight is given to environmental and ergonomic considerations and improved utilization of wood, and as the emphasis of global wood production is shifting more and more from natural forests to managed plantations, Nordic forest machinery and harvesting systems are gaining acceptance in new regions of the world. According to unpublished statistics of Timberjack Europe, the global sales of forwarders was 894 and those of harvesters 580 units in 1994.

7 Forest operations research

Although forest research is presently dominated by biological and ecological issues, technological and economic considerations also play an important role in the holistic development of modern forestry and the forest sector as a whole. Professor Ulf Sundberg (1988) from the Swedish University of Agricultural Sciences defines the discipline of Forest Operations and Techniques as follows:

> *The discipline Forest Operations and Techniques* is the study of the interaction of labour and machines with the forest. It involves an understanding of the relationships between labour, technology, the forest resource, forest industries, people and the environment. It becomes an approach to other, traditional subjects and disciplines rather than a subject itself. Yet, it is an academic discipline and a subject in forest science conducted with scientific rigour, and the approach has important practical applications.

Forest operations research is closely associated to most of the traditional subjects in forest science, e.g. forest management, silviculture and forest economics, and these relationships are in particular apparent in the planning of forest activities (Sundberg 1988). The recent development toward mechanized cutting has made these linkages more obvious and closer than ever before, as the machine entrepreneurs and harvester operators have become responsible for both realizing the forest management goals, cutting and processing the stems into timber assortments in accordance with changing requirements of the users.

In all Nordic countries *forest operations research is recognized as an integral part of the development of forest sector*. The primary goal of forest operations research is to improve the operational efficiency of work; i.e. to increase the productivity of forest work, decrease the costs of wood production and timber procurement, develop work methods and machines ergonomically, improve utilization of wood, intensify the recovery of forest biomass, decrease the damage to standing trees and soil, and develop ecologically sound operation methods in order to protect the sustainability of the ecosystem and maintain its biological diversity.

In Finland, forest operations research has *close connections to machine development*, and it is therefore often performed as a concerted effort in cooperation with machine manufacturers and the forest industries. The researchers are also involved in the introduction and application of the results in practical forestry. The *emphasis is thus on applied research*.

The boundaries of the discipline have blurred as research has been organized in larger problem-oriented projects. This integration has made it difficult to specify the human and financial resources used for forest operations research, but this development has not reduced the importance of the work. It is estimated that the annual *expenditure for forest operations research* in Finland is c. 20 million FIM; that is 6-7 % of the total funding of forest research and 0.7 % of the total cost of timber procurement of the forest industries and FFPS (Pölkki 1995).

The responsibility for higher education in the field of forest operations belongs to the Department of Forest Resource Management at the Faculty of Agriculture and Forestry at the University of Helsinki, and the Faculty of Forestry at the University of Joensuu. Forest operations research is carried out by several government and private institutions. *Acta Forestalia Fennica* (in English), *Silva Fennica* (in English) and *Folia Forestalia* (in Finnish) are the primary national forums for publishing results of scientific studies on forestry.

The Finnish Forest Research Institute, FFRI, (Metsäntutkimuslaitos, METLA) is the leading forest research organization in Finland. The Institute, subordinated to the Ministry of Agriculture and Forestry, employs 220 researchers and altogether 800 permanent persons. The staff for forest operations research consists of 11 researchers and 12 assisting persons. The technological research is carried out in the Vantaa Research Center 20 km north of Helsinki, and at the Kannus and Suonenjoki Research Stations. In addition to the national series of forest science, results are published in Metsäntutkimuslaitoksen Tiedonantoja (Research Papers of the Finnish Forest Research Institute).

Forest operations research at the FFRI is closely integrated into general forest management and wood utilization research. Since the early 1980s, the program has placed special emphasis on environmentally sound technology and on the environmental consequences of timber harvesting. In the mid-1990s, the most important topics are: mechanization of thinnings and regeneration, harvesting and utilization of small trees and residual biomass for energy, forest machine and timber truck enterprises and entrepreneurs, logging on drained peatlands, soil and tree damage in logging, and timber quality.

The Department of Forest Resource Management at the University of Helsinki has two professorships to cover both logging and utilization, one lecturing in Finnish and another in Swedish. In addition, a post of an associate professor is assigned to cover wood technology, and three other researchers work permanently in the field of forest operations. Presently, work studies are carried out in the following fields: modelling and expert systems of wood procurement, operational planning, and raw material problems related to the forest industries. Besides the national series, research results are published in Helsingin yliopiston metsävarojen käytön laitoksen julkaisuja series (University of Helsinki, Department of Forest Resource Management, Publications).

The Faculty of Forestry at the University of Joensuu has placed higher education in forest technology since 1990. The professorship of forest technology covers wood harvesting and forest work studies. The main areas of research are timber procurement planning, modelling of mechanized wood harvesting and the ergonomics of the forest machine operator. The University of Joensuu publishes Silva Carelia and Research Notes of the Faculty of Forestry.

The Work Efficiency Institute or TTS Institute (Työtehoseura) is a private-sector organization enjoying state support. It aims at the rationalization in agriculture, forestry, home economics, and related fields. The Institute's Department of Forestry has activities in Helsinki and Rajamäki. The department has a total staff of 15-20 researchers and assisting workers. The Institute's Forest Experiment Station is engaged in the development and manufacturing of TTS scarifiers.

The main interest of the Institute focuses on the rationalization in small-scale private forestry. The primary problem areas are forest work methods and appropriate equipment for self-employed forest owners, use of farm tractors in forestry, and harvesting and use of fuelwood. The results are published in Työtehoseuran Metsätiedote and Työtehoseuran Julkaisuja series.

Metsäteho, the Research and Development Department for Wood Procurement and Production at the Finnish Forest Industries Federation, is a private research unit located in Helsinki. Two thirds of the budget is financed through annual fees by the forest industry enterprises and contract customers, the FFPS and the Finnish Private Forestry Employers' Association. The remaining third is financed through project-specific funding by clients and through sales activities. The total number of staff is 32, including 21 university graduates. Metsäteho is thus the largest research organisation on forest operations and techniques in Finland.

Metsäteho's activities are focused on three research and development areas. Of the resources 20 % are given to wood production, 25 % to wood procurement techniques and 55 % to control of the wood flow. A notable trend during the last few years has been the integration of the program with other R&D work within the forest industries. Metsäteho also takes part in large customer oriented research projects, in which wood production and procurement are seen as integral parts of the production line from stump to the end use. Environmental items are given increasing emphasis. The results are published in Metsäteho Review and Metsäteho Report series, and in client-specific reports. Research results are transferred to practitioners through training, consultations and seminars.

Topics touching on forest operations are studied on a minor scale in other research organizations as well. *The Institute of Agricultural Engineering* at the Agricultural Research Center of Finland (*MTT-VAKOLA*) at Vihti carries out research, development and inspection of machinery used in agriculture, forestry and horticulture. The Institute is a certified organisation for testing roll-over protective structures, falling object protective structures, firewood machinery and chainsaws in accordance with the EU machinery safety directive. It also studies wood as a construction material and as a fuel. *The Kuopio Regional Institute of Occupational Health* in Kuopio carries out research on the strain and health of workers, machine drivers and entrepreneurs in agriculture and forestry. *VTT Energy* in Jyväskylä carries out research on the harvesting and use of wood for energy. Special emphasis is given to upgrading whole-tree chips. It is responsible for the coordination of the National Bioenergy Research Program

Differing needs of the forest owners, forest workers, machine entrepreneurs, forest industries, nature conservation and society as a whole often require different approaches and solutions to the problems which arise. This justifies the existence of several research organizations in the discipline of forest operations and techniques. To avoid unnecessary overlapping and splitting of limited resources, representatives of the major organizations meet regularly under the umbrella of the *Cooperation Committee for Forest Technology Research*, set up by *the Finnish Society of Forest Science*. The Committee discusses problems of common interest and coordination of the research programmes in order to concentrate the resources on the key topics.

At the regional Nordic level, *the Nordic Research Council on Forest Operations* (NSR) is responsible for program coordination with equivalent organizations in Sweden, Norway, Denmark and Iceland. On the European and global forum the Division of Forest Operations of IUFRO, the Joint FAO/ECE/ILO Committee on Technology, Management and Training, and the Task XII of the IEA Bioenergy Agreement are the key organizations for information exchange and joint studies in the field of forest operations.

Literature

Andersson, S. & Laestadius, L. 1987. Efficiency in highly mechanized wood harvesting systems. In: Harvesting, Transport, Ergonomics and Safety in Plantation Forestry. Proceedings from IUFRO Division 3 meeting in Brazil.

Annual ring 1992-93. Forests, forestry and forest industries in Finland. 1993. Finnish Forestry Association, Helsinki. 8 p. 1993.

Dykstra, D. & Heinrich, R. 1995. FAO model code of forest harvesting practice. FAO. Rome. 115 p.

Finland no bashutugizutu. 1991. (Japanese translation of: Hakkila, P. 1989. Logging in Finland.) Forest Engineering Research Institute, Ioyoma, Japan. 55 p.

Finnish Forestry Association. 1992. The presentation of the revised forest 2000 program. Finnish forest policy in the 1990s. 26 p.

Haarlaa, R. 1995. Environmentally sound forest harvesting in the Finnish context. Paper for FAO/IUFRO satellite meeting in Tampere, Finland, August 4, 1995. 5 p.

Hakkila, P. 1966. Investigations on the basic density of Finnish pine, spruce and birch wood. Communicationes Instituti Forestalis Fenniae 61:5. 98 p.

Hakkila, P. 1989. Logging in Finland. Acta Forestalia Fennica 207. 39 p.

Hakkila, P. (toim.) 1992. Metsäenergia. Metsäntutkimuslaitoksen tiedonantoja 422. 51 p.

Heiskanen, V. & Rikkonen, P. 1976. Havusahatukkien kuoren määrä ja siihen vaikuttavat tekijät. Summary: Bark amount in coniferous sawlogs and factors affecting it. Folia Forestalia 250. 67 p.

Hiilidioksiditoimikunta II:n mietintö. 1994. Summary: Report of the Carbon Dioxide Committee II. Komiteamietintö 2/1994. 145 p.

Imponen, V., Hämäläinen, J. & Örn, J. 1992. Hakkuun koneellistamisen taloudelliset ja organisatoriset vaikutukset. Summary: The economic and organizational effects of mechanization of cutting. Metsäteho Report 407. 21 p.

Jaakkola, S. 1994a. Puunkorjuujälki parani viime vuodesta. Koneyritttäjä 7: 12-13.

Jaakkola, S. 1994b. Optimismi leviää konetyöaloille. Koneyrittäjä 8: 12-13.

Kahala, M. 1980. Puutavaran valmistus moottorisahalla. Summary: Preparation of powersaw. Metsäteho Report 364. 19 p.

Kuitto, P-J., Koskinen, S., Lindroos, J., Oijala, T., Rajamäki, J., Räsänen, T. & Terävä, J. 1994. Puutavaran koneellinen hakkuu ja metsäkuljetus. Summary: Mechanized cutting and forest haulage. Metsäteho Report 410. 38 p.

Laestadius, L. 1990. A comparative analysis of wood-supply systems from a cross-cultural perspective. Dissertation. Virginia Polytechnic Institute and State University. 149 p.

Lammi, M. 1995. The Finnish forest clusters - the success story of paper, machines and know how. Paper and Timber 77(3): 84-87.

Maintenance of forest biodiversity in Finland. 1994. Ministry of the Environment. Official report. Helsinki. 82 p.

Marjomaa, J. 1992. Puutavaralajien tuoretiheyden vaihtelu. Summary: Variations in the weight of timber assortments. Metsätehon katsaus 4/1992. 8 p.

Metsäteollisuuden vuosikirja 1994. 1994. Metsäteolllisuus ry. 68 p.

Mikkonen, E. 1984. Puutavaran metsäkuljetus maataloustraktorilla. Summary: Forest haulage with an agricultural tractor. Metsäteho Report 391. 23 p.

MTT/VAKOLA. 1995. Maatalous- ja metsäkoneiden myynti vuosina 1992-1994. Metsäkoneet. 1 p.

Mäkelä, J. 1987. Maataloustraktorin käyttöön perustuva puunkorjuu. Summary: Logging in small-scale operations based on the use of the farm tractor. Työtehoseuran Metsätiedote 14. 4 p.

Mäkelä, J. 1990. Delivery sales in the harvesting of timber in the private forests of Finland. XIX IUFRO World Congress, Montreal. Voluntary paper. 12 p.

Mäkinen, P. 1988. Metsäkoneurakoitsija yrittäjänä. Summary: Forest machine contractor as an entrepreneur. Folia Forestalia 717. 37 p.

Mäkinen, P. 1993. Puutavaran kuljetusyritysten menestymisen strategiat. Summary: Strategies used by timber truck transport companies to ensure business success. Acta Forestalia Fennica 238. 83 p.

New Environmental Programme for Forestry in Finland. 1994. The Ministry of Agriculture and Forestry and the Ministry of the Environment. 63 p.

Oijala, T. 1994. Puutavaran kaukokuljetusten kehitys vuosina 1985-1993. Työtehoseuran Metsätiedote. 4 p.

Paavilainen, E. & Tiihonen, P. 1988. Suomen suometsät vuosina 1951-1984. Summary: Peatland forests in Finland in 1951-1984. Folia Forestalia 714. 29 p.

Parviainen, J. 1994. Finnish silviculture. Managing for timber production and conservation. Journal of Forestry 92(9): 33-36.

Parviainen, J. & Seppänen, P. 1994. Metsien ekologinen kestävyys ja metsänkasvatusvaihtoehdot. Metsäntutkimuslaitoksen tiedonantoja 511. 110 s.

Puunhankinnat kohoavat 10-15 prosenttia. 1995. Metsälehti 5: 8.

Pölkki, V. 1995. Tutkimus puuhuollon näkökulmasta. Metsätehon juhlaseminaari. 3 p.

Rikkonen, P. 1987. Havutukkien kuorelliseen latvaläpimittaan perustuva tilavuuden määrittäminen. Summary: Volume of coniferous saw logs based on top diameter over bark. Folia Forestalia 684. 47 p.

Ryynänen, S. 1986. Farm tractors in timber harvesting. In: Forestry needs technology:7. Finnish Foreign Trade Association, Helsinki.

Saikku, O. & Heiskanen, V. 1976. Kuitupuun kuoren määrä ja siihen vaikuttavat tekijät. Summary: Bark amount of pulpwood and factors affecting it. Folia Forestalia 262. 22 p.

Silversides, C. R. & Sundberg, U. 1989. Operational efficiency in forestry. Volume 2. Practice. Kluwer Academic Publishers. 169 p.

Sirén, M. 1987. Damage in thinning with different harvesting methods in Finland. In: Development of thinning systems to reduce stand damages. Swedish University of Agricultural Sciences, Department of Operational Efficiency. Research Notes 98:12-28.

Sundberg, U. 1988. The emergence and establishment of forest operations and techniques as a discipline in forest science. Meddelelser fra Norsk Institutt for Skogforskning 41.8: 107-137.

Sundberg, U. & Silversides, C. R. 1988. Operational efficiency in forestry. Volume 1. Analysis. Kluver Academic Publishers. 219 p.

The Finnish forest industries in brief. 1995. Paper and Timber 77(3):72-73.

Vanhanen, H. & Heikinheimo, L. 1983. Productivity in forestry and socio-economic change 1950-1981. TIM/EFC/WP.2/R58.

Verkasalo, E. 1995. Metsänhoito ja puun laatu - Miten tunnistat hyvän ja huonon laadun? Mimeograph. 19 p.

Wästerlund, I. 1992. Extent and causes of site damage due to forestry traffic. Scandinavian Journal of Forest Research. Vol. 7(1): 135-142.

Yearbook of Forest Statistics 1993-94. 1994. The Finnish Forest Research Inst. 348 p.

METRIC CONVERSION FACTORS

From metric to English units		From English to metric units	
Length			
1 mm	=0.03937 in	1 in	=25.400 mm
1 cm	=0.3937 in	1 in	=2.5400 cm
1 m	=3.2808 ft	1 ft	=0.3048 m
1 m	=1.0936 yd	1 yd	=0.9144 m
1 km	=0.6214 mi	1 mi	=1.6093 km
Area			
1 mm^2	=0.001550 in^2	1 in^2	=645.16 mm^2
1 cm^2	=0.1550 in^2	1 in^2	=6.4516 cm^2
1 m^2	=10.7639 ft^2	1 ft^2	=0.09290 m^2
1 m^2	=1.1960 yd^2	1 yd^2	=0.8361 m^2
1 ha	=2.4711 acres	1 acre	=0.4047 ha
1 km^2	=0.3861 mi^2	1 mi^2	=2.5900 km^2
Volume			
1 cm^3	=0.0610 in^3	1 in^3	=16.387 cm^3
1 dm^3	=0.2641 gal (US)	1 gal (US)	=3.7854 dm^3
1 m^3	=35.3147 ft^3	1 ft^3	=0.02832 m^3
1 m^3	=423.776 bd ft	1 bd ft	=0.0023597 m^3
1 m^3	=1.3080 yd^3	1 yd^3	=0.76456 m^3
1 m^3	=0.3531 cunit	1 cunit	=2.8317 m^3
1 m^3 (st)*	=0.27590 cord (st)	1 cord (st)	=3.6246 m^3 (st)* ≈ 2.5 m^3 (s)**
Mass			
1 g	=0.035274 oz	1 oz	=28.3495 g
1 kg	=2.2046 lb	1 lb	=0.4536 kg
1 t (tonne)	=1.1023 sh ton (US)	1 sh ton (US)	=0.9072 t (tonne)
1 t (tonne)	=0.9841 long ton (UK)	1 long ton (UK)	=1.0161 t (tonne)
Miscellaneous forestry units			
1 t/ha	=0.4461 sh ton/acre	1 sh ton/acre	=2.0242 t/ha
1 m^2/ha	=4.3560 ft^2/acre	1 ft^2/acre	=0.22957 m^2/ha
1 m^3/ha	=14.291 ft^3/acre	1 ft^3/acre	=0.06997 m^3/ha
1 m^3/ha	=0.1429 cunit/acre	1 cunit/acre	=6.9973 m^3/ha
1 m^3 (st)*/ha	=0.1117 cord (st)	1 cord/acre	=8.9565 m^3 (st)/ha ≈ 6.2 m^3 (s)**/ha

All timber volumes in the text refer to unbarked wood, and m^3 refers to solid measure.

* m^3 (st) = m^3 stacked
** m^3 (s) = m^3 solid

Exchange rates as of May 24, 1995:

1 FIM =	0.24 US $	1 US $ =	4,24 FIM
1 FIM =	1.69 SEK	1 SEK =	0.59 FIM

VOCABULARY OF TIMBER HARVESTING

The terminology used in this review (ISO/TC 23/SC 15 N 266, 1994-11-28) is in accordance with ISO 6814 identification vocabulary for mobile and self-propelled forest machinery (currently under revision).

Timber harvesting functions

Bucking (slashing, crosscutting): Cutting felled trees or parts of trees into logs.
Bunching: Gathering and arranging trees or parts of trees in bunches or heaps.
Cable yarding: Transporting trees or parts of trees by means of a cable system.
Chipping: Slicing trees into small pieces of specified dimensions.
Crushing: Reduction of trees or parts of trees by compression or impacting.
Cutting: Felling combined with other processing functions, such as delimbing and bucking.
Debarking: Removing bark from trees or parts of trees.
Delimbing: Removing branches from trees or parts of trees.
Felling: Cutting down or uprooting trees.
Forwarding: Off-the-ground transportation of trees or parts of trees.
Loading: Lifting trees or parts of trees from the ground, or from a vehicle, and placing them on another vehicle.
Piling: The orderly depositing of trees or parts of trees.
Processing: A combination of functions other than felling that change the form of the material.
Skidding: The transportation of trees or parts of trees by trailing or dragging.
Sorting: Separating trees or parts of trees into groups based on particular attributes.
Splitting: Longitudinally severing trees or parts of trees into pieces.
Topping: Cutting off the top of trees at a predetermined point.

Timber harvesting machinery

Single function machines:

Cable yarder: A mobile machine designed to transport trees or parts of trees by means of a cable system. A tower is used which may be integral to the machine or a separate structure.
Chipper: A mobile machine designed to chip whole trees or parts of trees.
Crusher: A mobile machine designed to reduce trees or parts of trees by compression or impaction.
Debarker: A mobile machine designed to remove the bark from trees.
Delimber: A mobile machine designed to remove limbs from trees.
Feller: A self-propelled machine designed to fell standing trees.

Forwarder: A self-propelled machine designed to carry trees or parts of trees.

Log loader: A machine designed to lift trees or parts of trees during piling or loading.

Skidder: A self-propelled machine designed to transport trees or parts of trees by trailing or dragging.

Slasher(bucker): A mobile machine designed to cut felled trees into lengths.

Multi-function machines:

Delimber-buncher: A machine designed to delimb trees and arrange stems in bunches.

Feller-buncher: a self-propelled machine designed to fell standing trees and arrange them in bunches.

Feller-forwarder: A self-propelled self-loading machine designed to fell standing trees and transport them by carrying.

Feller-skidder: A self-propelled, self-loading machine designed to fell standing trees and transport them by skidding.

Slasher(bucker)-buncher: A machine designed to cut stems to predetermined lengths and arrange the logs in bunches.

Processor: A multi-function machine which does not fell trees but performs two or more subsequent functions which change the form of the raw-material.

Delimber-debarker: A machine designed to delimb and debark trees.

Delimber-debarker-chipper: A machine designed to delimb, debark, and chip trees.

Delimber-slasher(bucker): A machine designed to delimb and slash trees.

Delimber-slasher(bucker)-buncher: A machine designed to delimb and slash trees and arrange logs in bunches.

Harvester: A self-propelled multi-function machine which combines felling with other processing functions. Harvesters are generally divided into two types depending on the basic concept used to perform the function of handling the tree for felling and bunching. These are: single- grip (or one-grip) harvester and two-grip harvester.

Feller-chipper: A self-propelled machine designed to fell and chip whole trees.

Feller-delimber: A self-propelled machine designed to fell and delimb trees.

Feller-delimber-buncher: A self-propelled machine designed to fell and delimb trees and arrange stems in bunches.

Feller-delimber-slasher(bucker)-buncher: A self-propelled machine designed to fell, delimb, and slash trees and arrange logs in bunches.

Feller-delimber-slasher(bucker)-forwarder: A self-propelled machine designed to fell, delimb, and slash trees and carry logs to a landing.

Metsäntutkimuslaitoksen tiedonantoja 557
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