ACTA FORESTALIA FENNICA

207

PENTTI HAKKILA

LOGGING IN FINLAND

PUUNKORJUU SUOMESSA

THE SOCIETY OF FORESTRY IN FINLAND
THE FINNISH FOREST RESEARCH INSTITUTE

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LOGGING IN FINLAND

Puunkorjuu Suomessa

Pentti Hakkila

The Society of Forestry in Finland — The Finnish Forest Research Institute

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Due to the high level of salaries and cost of social security, strict ergonomic standards, specific logging conditions, predominance of private ownership, and strong influence of environmental and conservation aspects, the Nordic countries have been forced to develop completely new logging technology to meet their own specific requirements. Demanding domestic markets have created a strong base for the production and export of forest machines. In the 1980s Finland has become the leading manufacturer of logging machinery in Europe.

The Finnish logging technology rests typically on the log-length method and the use of load-carrying forwarders. This constrains the export of logging machinery in many countries, but as increasing emphasis is placed on thinnings, improved timber recovery, productivity, ergonomy, and protection of environment, increasing interest is shown in this techology.

The paper presents a synthesis of logging in Finland. The technical logging conditions, development of mechanization, present technology, productivity of work, and forest machine industry are explained and reviewed from the viewpoint of a foreign reader.

Puuston ja olosuhteitten erityispiirteitten, korkean palkka- ja sosiaalikustannustason, ankarien ergonomisten vaatimusten, pienmetsälövaltaisen omistusmuodon sekä ympäristönäkökohtien suuren merkityksen vuoksi Pohjoismaitten on ollut pakko kehittää oma puunkorjuutekniikkansa. Vaativat kotimarkkinat ovat luoneet vankan perustan myös metsäkoneitten viennille. Suomesta on 1980-luvulla tullut Euroopan johtava metsäkoneitten tuottaja.

Suomalainen puunkorjuuteknologia pohjautuu perinteisesti tavaralajimenetelmään ja kuormaakantavien traktoreitten käyttöön. Tämä rajoittaa koneitten vientimahdollisuuksia monissa maissa, mutta suurissa metsätalousmaissa kiinnostus suomalaiseen korjuuteknologiaan kasvaa sitä mukaa kuin harvennushakkuut yleistyvät, tarve puun käytön ja työn tuottavuuden parantamiseen kasvavat sekä ergonomiset ja ekologiset vaatimukset kiristyvät.

Katsaus on ulkomaiselle lukijalle laadittu synteesi suomalaisesta puunkorjuusta. Siinä selostetaan vallitsevia korjuuteknisiä olosuhteita, korjuun koneellistumista, nykyistä teknologiaa, työn tuottavuutta sekä suomalaista metsäkoneteollisuutta.

Keywords: Logging, mechanization, log-length method, machine manufacturing, Finland.
ODC 31+(480)

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PREFACE

Logging, i.e. cutting and off-road transport of timber, is an integral part of forestry and forest industries. After the second world war, technical development has been faster in logging than in any other field of forestry. However, mechanization has not progressed similarly in all countries. The methods and machinery have diversified depending on technical logging conditions, cost and availability of labor and capital, infrastructure of the country, timber demand and structure of forest industries, and the public's concern over the forests and environment.

Due to the vital importance of forestry and forest industries in their national economies, specific logging conditions, high level of salaries and cost of social security, fast rural depopulation, strict ergonomic standards set by legislation, predominance of private ownership, and strong influence of environmental and conservation aspects, the Nordic countries have been forced to pioneer and develop completely new logging technology to meet their own requirements.

Modern Nordic technology offers a wide range of alternatives for thinnings and clearcuts for small-scale farm-owner operations as well as for large-scale industrial operations. Independently of the degree of mechanization and scale of operation, the Finnish solutions with only few exceptions are typically based on the *log-length method,* in which the trees are delimbed and bucked to timber assortments at the stump prior to subsequent transport to the road side in load-carrying tractors.

The Finnish logging technology and forest machine industry presently enjoy a worldwide reputation. Applicability and feasibility of this technology is expected to increase in foreign countries with:

1. Intensification of silvicultural management of forests, particularly with the introduction of thinnings.
2. Increasing emphasis of ergonomic improvement of logging work.
3. Increasing pressure for environmental improvements in forest management.
4. Changes in public attitudes towards forestry and increasing need for better utilization of conventional timber and presently unmerchantable residual forest biomass.

Foresters, engineers, researchers, and machine manufacturers visiting Finland are often interested, in addition to seeing technical solutions in the forest, also in the background of the past development and in gaining a more comprehensive understanding of logging systems as an inherent part of forest management. The purpose of this review is to present a synthesis of logging in Finland. The author wishes that the review will help the foreign reader appreciate the problems and solutions of timber harvesting, forest machine manufacturing, and forest operations research encountered in the country.

The manuscript was typed by Miss Maija Tuuri and Miss Susanna Järvinen. The line drawings were made by Mrs. Ritva Parviainen. Mrs. Kaija Kanninen assisted in all phases of the study. Mr. Hannu Kalaja, Mr. Erkki Oksanen, FMG Lokomo Forest, and Valon Kone contributed photographs. The English language was checked and improved by Mrs. Elva R. Nurmi and Miss Robin Richardson. The manuscript was reviewed by Dr. Pertti Harstela, Finnish Forest Research Insitute, and Professor Esko Mikkonen, University of Helsinki.

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Padasjoki, August 1989

Pentti Hakkila

1. OPERATING ENVIRONMENT

11. Role of wood in the Finnish economy

Finland, like Alaska, is located between the 60th and 70th degrees of northern latitude. A large part of the country lies north of the Arctic Circle at the limit of human habitation (Figure 1).

In general, the climate is rather harsh for agriculture and the soil poor in natural resources. A narrow zone in the northernmost part of the country is treeless tundra. There are *no fossil fuels,* and the known ore resources are becoming exhausted.

However, 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 high-quality coniferous timber. In fact, Finland is *the most forested country in Europe.* The forest area amounts to 4.5 ha per capita. Boreal forests cover 20.1 million ha or 66 % of the total land area of 305 000 square kilometers. Inland lakes and rivers cover another 32 000 square kilometers thus forming *an excellent network of floatways* for timber transport to the mills.

The annual increment of timber is 72.1 million m^3 including bark. The allowable drain is 67.1 million m^3 or 13 m^3 per capita per annum. The actual annual drain varies from 50 to 55 million m^3 (Yearbook... 1989).

The forest balance is thus clearly positive. Finland's forest resources have increased gradually since the 1920s, when they were inventoried for the first time. The total volume of the growing stock is presently 1750 million m^3, or the highest in this century (Yearbook... 1989). However, new pulp and paper mills are under planning and construction, and the *demand of pulpwood is expected to increase* at least 10 million m^3/a by 1995.

Roughly 80 % of the total annual drain is used by the forest industries, 10 % for other purposes such as fuel, farm use, timber exports etc, and another 10 % is left as natural loss or logging residue in the forest. More than half of the industrial roundwood is processed by the pulp and paper industries. This proportion will increase further in the future since pulp production is expanding whereas the capacity of the sawmill industry is being reduced.

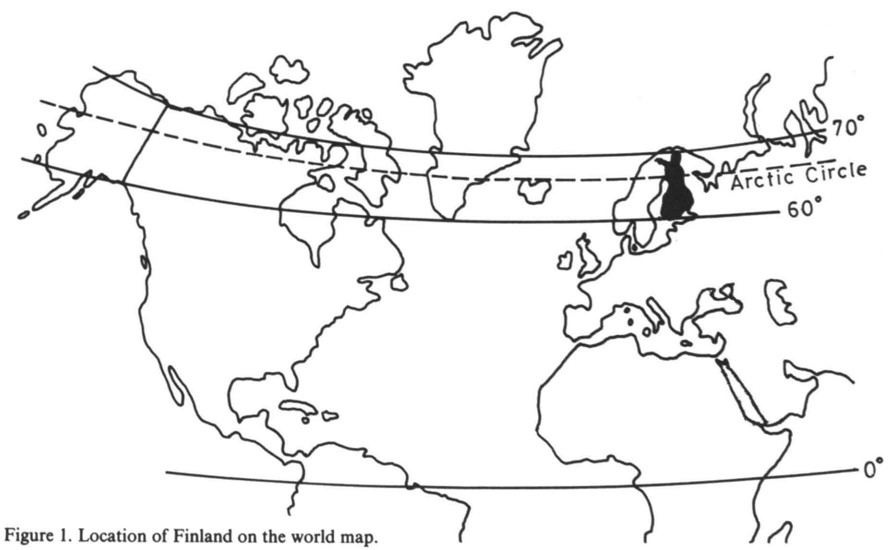

Figure 1. Location of Finland on the world map.

Finland's national economy and its relatively high standard of living are to a large extent dependent on sustained management of the renewable forest resources. Forest products account for *almost 40 % of the total export earnings.* Furthermore, since the forest industry in Finland is supplied by domestical raw material inputs to a greater extent than the other branches of the export industries, its share of net export earnings of the country is well over 50 %. Consequently, the society gives a high priority to the development of forestry and forest industries. Furthermore, machines for the chemical and mechanical forest industries and for forestry play *an important role in the metal industries* which is another major export branch in Finland.

Stumpage *prices of timber are higher* than in most other forest industry countries. Although only 10—15 % of the stumpage price is derived from actual silvicultural expenses, under northern climatic conditions high stumpage price is a precondition for intensive silviculture, since the growth of trees is slow and the annual yield of timber per hectare relatively low. In the late 1980s, stumpage price comprised 15 % of the average export price of pulp and paper products and 45 % of that of coniferous lumber (Pellervon... 1989). Since the average stem volume and sale size are relatively small, the cost of logging is also high, resulting in high mill prices of timber. Therefore, requirements are strict regarding the effectiveness of stemwood recovery. Moreover, maintenance of good timber quality in all phases of logging and storage is of great importance.

According to preliminary estimates, *the volume of roundwood consumed* by the wood-processing industry totalled 48.1 million m^3 in 1988. The industry uses primarily indigenous timber. However, 10.0 % of its roundwood consumption was imported, mainly from the Soviet Union. In addition, the wood-processing industry used 9.2 million m^3 solid of industrial secondary residue such as sawmill chips and sawdust, and practically all bark residue was used for energy production (Yearbook... 1989). The flow of wood raw material to various end uses in 1987 is illustrated in Figure 2.

12. Principles of forest management

Private citizens own 63 % of the forest area and produce three quarters of the timber. There are 277 000 private forest holdings of 5 ha or more of forested land, about half of which are owned by farmers. In Finland, *forestry is thus closely bound with agriculture.* The state owns 24 %, forest industry companies 9 %, and municipalities, parishes, and foundations the remaining 4 % of the forest land (Yearbook... 1989).

The *predominance of small-scale private ownership* strongly influences the way and intensity in which the Finnish forests are managed and utilized. The average woodland area of a private forest holding is 35 ha, and the average sale consists of only 340 m^3 of timber. These facts constrain mechanization and increase the cost of timber procurement.

The *selection of tree species* is exceptionally small: roughly 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, both pine, spruce, and birch produce excellent raw material for the forest industries. From the management, logging, transport, and processing points of view the scarcity of tree species is an obvious advantage.

The target *rotation period* is usually 70—90 years in southern Finland and 100—120 years in northern Finland. Management systems are characterized by *repeated selective thinnings from below* (Figure 3). The purpose of thinning operations is to salvage suppressed and dying trees which would be otherwise lost through natural mortality, to provide earlier incomes to the forest owner, to regulate the spacing and composition of tree species for faster diameter growth and quality improvement of the subsequent timber production during the later development of the stand, and to maintain the vitality of the stand. The present thinning practice was adopted several decades ago as soon as the development of the pulp and paper industries guaranteed markets for small-sized timber. Presently, the minimum top diameter of pulpwood is usually 6 cm.

Nearly all stands in southern Finland are thinned selectively twice or three times during the rotation period. In thinning oper-

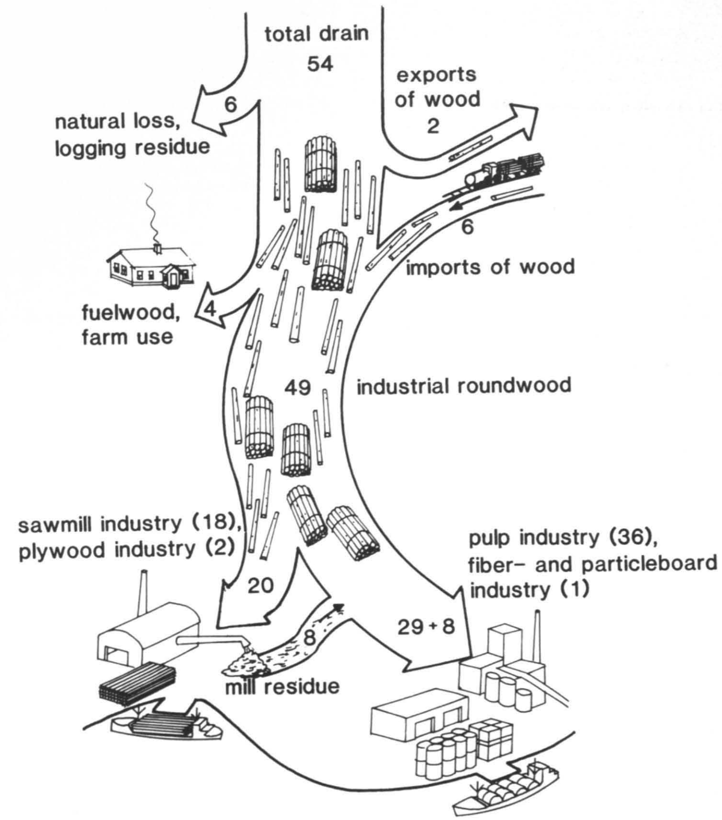

Figure 2. The flow of wood to various end uses in million cubic metres in 1988
(Sources: Annual ring... 1988, Yearbook of... 1989)

ations, the productivity of work is lower and mechanization much more complicated than in clearcuts. Consequently, the logging costs are higher and the stumpage prices lower, as shown by the following indicative schedule for southern Finnish conditions. The cost figures refer to motor-manual methods.

Treatment	Approximate age, years	Relative cost of logging
Precommercial thinning	10—15	
1st commercial thinning	25—35	300
2nd commercial thinning	40—50	200
3rd commercial thinning	55—65	150
Final cutting	70—90	100

Unfortunately, due to the higher cost of logging, *the thinning targets of some 300 000–400 000 ha/a are not reached* presently in the full scale. Less than 30 % of all timber is harvested from thinnings. Because of the age class distribution of the Finnish forests, the need for early thinnings of young stands will increase considerably from the present level during the 1990s. This development will create a real challenge to the logging organizations and machine manufacturers.

The results from the practice of the repeated thinnings since the second world war can be seen everywhere in Finland. Successive national forest inventories which have been carried out by the Finnish Forest Research Institute 7—8 times since 1921, indicate a favorable development in the

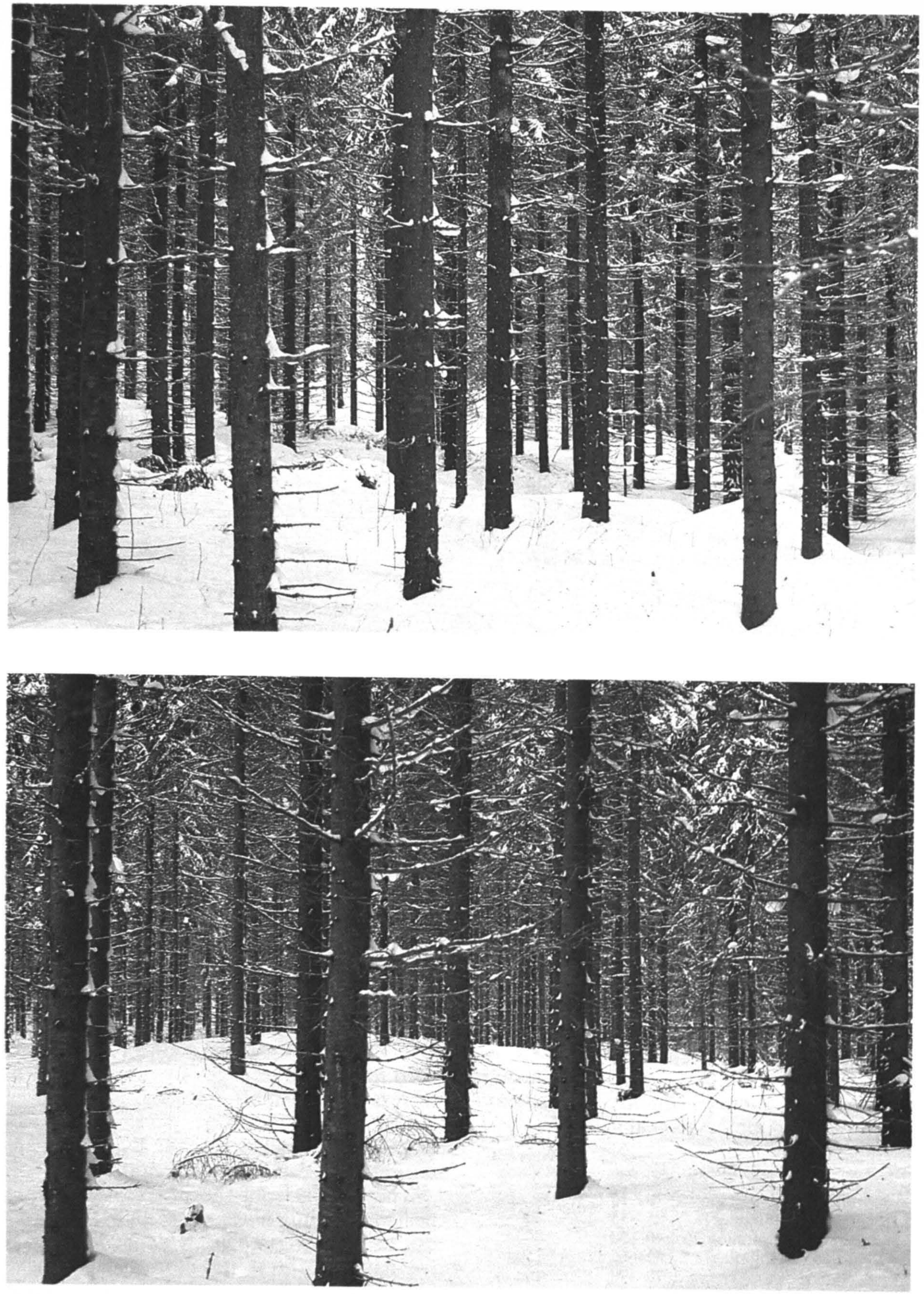

Figure 3. A 52-year-old spruce plantation at Multatöyry in central Finland prior to (above) and right after (below) the second thinning (Photos P. Hakkila).

structure of the forests; decreased natural loss, decreased proportion of decay-defective timber, decreased amount of logging residue, improved species composition, and increased average tree size. If the thinning programs can not be materialized in the future, this favorable development will be threatened.

A major part of the timber from the final cuttings is derived from stands which were naturally regenerated at the turn of the century. If the current rate of artificial forest regeneration is maintained, 130 000 ha/a out of the total regeneration area of 200 000 ha/a, man-made forests will account for 30 % of the total area of productive forests by the year 2000. However, since the *man-made forests* are composed of native species, they *differ only slightly from managed, naturally regenerated stands.*

In Finland, the forest and its intangible values are part of the way of life. The multiple use of forests and general environmental and ecological considerations put increasing pressure on forest management and logging operations. Avoidance of damage to standing trees and forest soil, careful planning and timing of logging, use of seed and shelter trees for natural regeneration where possible, and *recreation and environmental aspects are gaining importance.* Consequently, this rapid change in the operation environment must be acknowledged in the development and application of forest technology. These factors influence more and more in the operational planning and equipment selection, and therefore they have an increasingly important role in the forest machine design as well.

13. Technical logging conditions

In Finland the forests generally lie below the altitude of 200 m. The terrain configuration is of *low relative relief* and characterized by small hills. The slopes, seldom steeper than 20—30 %, are traficable with forest tractors. Consequently, unlike in many other forestry countries, cable logging systems are not used.

The prevailing forest *soil type is moraine,* typically featured by an abundance of boulders. *The snow cover levels the ground surface* during the winter months easing timber haulage in uneven terrain, but at a depth of 80—120 cm it can seriously reduce the productivity of preparation and transport of timber. In the winter, the *ground generally freezes,* thus facilitating timber haulage from soft sites. However, this does not happen each year.

Excessive stagnant water is a common problem in flat terrain, resulting in *peat formation and bogs.* Peatlands account for as much as one third of Finland's land area. Approximately 5.8 million ha of wet forest lands have been drained for improved timber production by ditching. Drainage of peatlands has increased the annual increment of timber by about 7 million m^3 (Paavilainen and Tiihonen 1988). Since large areas of drained peatlands are now reaching the phase of the first commercial thinning, harvesting small-sized timber from peatlands will be one of the most difficult tasks for the Finnish logging organizations in the 1990s. Machine manufacturers therefore have put great efforts into the development of machines and methods for operations on soft soils (Figure 4).

A major factor affecting the productivity and cost of both motor-manual and mechanized logging is the size of the trees removed. Due to the cold climate and slow growth *the trees remain relatively small* in Finland. Since the target is to recover all trees with a minimum breast height diameter of 7—8 cm, the average stem volume of harvestable trees in southern Finland in the 1990s will be 0.05—0.06 m^3 in the first commercial thinnings and 0.11—0.12 m^3 in later thinnings (Lilleberg and Raitanen 1989). In the final fellings the average stem volume varies usually between 0.2—0.7 m^3. Trees larger than 1.5—2 m^3 in volume are uncommon. The small tree size reduces the productivity of work and constrains the use of expensive logging machines.

The state supports *forest road construction* on private lands with low-interest loans and free planning. 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 timber removed. The annual work result in the whole country is about 4 000 km of new permanent forest roads (Figures 5 and 6). Altogether, more than 90 000 km of forest roads have been built since 1950 in private, company-owned, and state-owned forest lands. The program has decreased the average off-road haulage distance in southern Finland to approximately 300 m.

Figure 4. Harvesting small-sized timber from drained peatlands requires special equipment. Forwarding with light rubber-tracked Farmi-Trac crawler (Photo H. Kalaja).

Figure 5. Permanent forest roads serve timber harvesting, silvicultural operations, and multiple use of forests (Photo H. Kalaja).

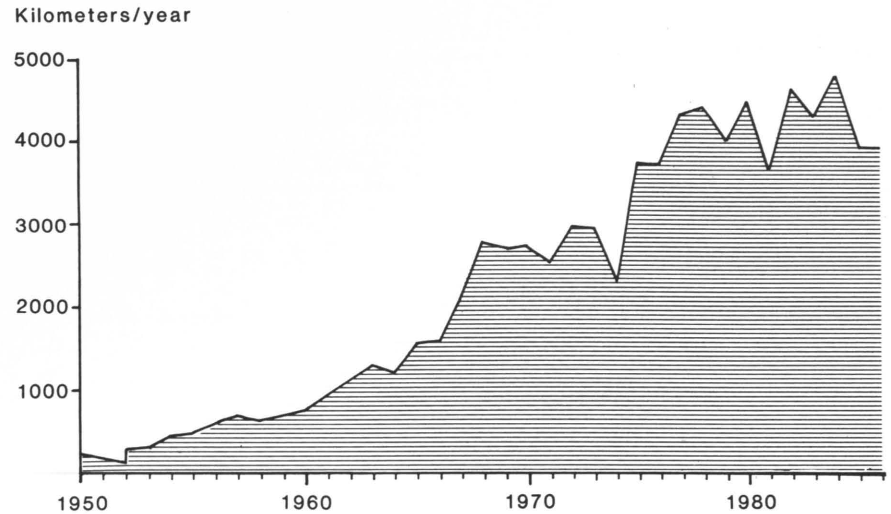

Figure 6. Construction of permanent forest roads, 1950—1986 (Yearbook of... 1989).

2. DEVELOPMENT OF MECHANIZATION

21. Mechanization of cutting

Trees were felled, bucked, delimbed, split and hewn with an ax for thousands of years. The hand saw replaced the ax as a felling and cutting tool in the last half of the 19th century. As late as in the mid-1950s all timber was prepared with *hand saw and ax.*

The first experiments with powersaws in Finland were conducted during World War I, but they were too heavy and awkward to be used in the woods. Although more practical powersaws were gradually developed, operation required two men for a long time to come (Putkisto 1970).

In Finland, the *powersaw became competitive* in the 1950s, when it had been trimmed down to a 15-kilogram chainsaw, suitable for one man to use alone. It was first used in felling and bucking large trees, then in the felling and bucking of pulpwood-size trees and soon, with the weight further decreased, in delimbing as well. A half century after its invention, the powersaw was finally ready to replace the traditional handtools.

In the 1962/1963 procurement season, one half of the Finnish cutters used the chainsaw in felling and bucking. The same usage level in delimbing was reached five years later, and by the mid-1970s the handsaw and ax disappeared from Finnish logging sites (Figure 7). The process to replace manual cutting by motor-manual methods was over in two decades. Ergonomic aspects and safety, however, were neglected in the early development of the chainsaw and its work methods, resulting in new occupational illnesses and hazards.

As late as in the early 1950s, all pulpwood and a large part of saw timber logs were debarked manually in the woods. Manual debarking doubled the labor demand of cutting. The work was extremely strenuous, especially when it had to be done in below freezing temperatures. In the mid-1950s, farm tractor-driven *transportable debarking machines came into use.* These machines were initially fed manually, and later on by hydraulic cranes. Truck-mounted mobile debarking units were also developed.

In-woods debarking of timber was mech-

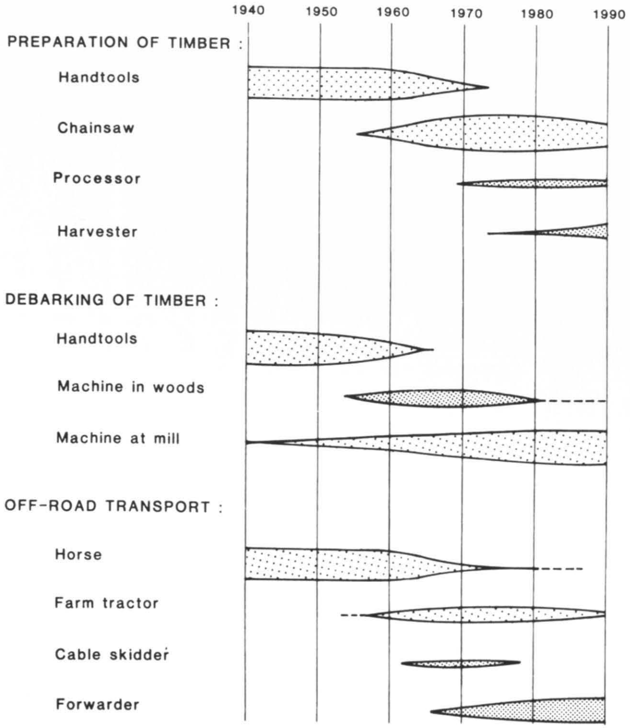

Figure 7. Development of timber harvesting methods since the 1940s. Contractor operations are represented by dense dots.

anized completely in the 1960s on the principle of the ring debarker. Thus, the heaviest phase of the cutter's work was eliminated and the demand for forest labor was reduced substantially. The debarking work was correspondingly shifted to independent machine contractors. Forest machine contracting, which is presently the backbone of Finnish logging systems, was thereby created.

The phase of development during which timber was debarked by a mobile unit at a landing site was brief, however. The development of mill-operated, stationary, multi-log debarking units, the increase in the energy value of bark, changes in trucking and floating systems as well as the decrease in transport time from stump to mill all contributed to the decline of debarking at landing site. *Debarking was gradually centralized to the mill yard* and the bark residue recovered for energy production.

In recent decades, logging has been rationalized not only through mechanization but in a variety of other ways as well. *The standard length of the pulpwood log has been increased,* the accuracy requirement of nominal lengths have been modified, and delimbing requirements relaxed. These factors have substantially reduced the labor consumption and cost of cutting. The gradual lengthening of the pulpwood log from 1 or 2 m to 3 or 5 m was necessary for both improving the cutter's productivity and for the rationalization of the subsequent off-road and on-road transport and mill yard handling of pulpwood. Compared with 2 m pulpwood, the total cost of harvesting and trucking is 8 % lower for 3 m pulpwood and 12 % lower for 5 m pulpwood (Imponen and Pennanen 1989).

In thinnings, the mechanization of off-road transport brought along with it the practice of *bunching pulpwood manually* to

the strip road. The work became more strenuous and serious ergonomical problems developed, particularly because the log length and thus weight were gradually increased. The problem was substantially eased in the early 1980s when forwarders were equipped with a *long-reach, 9–10 m crane.*

The first machines for felling, delimbing, and bucking were introduced in Finland in the late 1960s. Due to their multi-function characteristics, these machines are called *multi-function machines.* During two decades of development the output, reliability, work quality, and ergonomic properties of multi-function machines have improved greatly, and work done with machines has become economically competitive in a variety of stand types. The machines and mechanized work methods have also become more environmentally considerate regarding soil compaction and damage to standing trees. In many cases, the use of multi-function machines provides considerable savings in work site planning, timber scaling, cost of social security, and cost of subsequent off-road transport. Also, because they can be used more than one shift per day and are not overly affected by weather, they cope well to accomplish the peak levels of harvesting expected during the winter months. However, many factors still constrain the use of multi-function machines in Finland:

1. Due to the high standard of vocational training of cutters and the piece rate system of forest work wages, the productivity and competitiveness of motor-manual methods are still good under several types of logging conditions.
2. Job opportunities of permanently employed cutters must be taken into consideration in the development of mechanization.
3. Both the uncertainty of the multi-function machine's employment and the technical obsolescence accompanying rapid machine development threaten the contractors' investments.
4. There is a shortage of experienced multi-function machine operators.
5. Attitutes towards multi-function machines are still prejudiced. There are especially problems in the mechanization of thinning operations, and forest owners are concerned with tree and soil damage.
6. Since many silvicultural operations are still performed by labor-intensive methods, it is important to maintain a significant share of logging as motor-manual work to ensure the availability of a manual labor force for seasonal operations such as planting and pre-commercial thinnings.

In 1988, the share of timber prepared with multi-function machines was 30 % in the operations of the forest industries and the State Board of Forestry, and 20 % of all market timber in Finland including the delivery sales of private forest owners. Although this percentage is substantially smaller than in Sweden, it is nevertheless larger than in the USA or Central Europe, for example.

The use of pulpwood is expected to increase in Finland in the 1990's by more than 10 million m^3 annually while simultaneously the number of cutters is expected to decrease. Consequently, the rate of mechanization of logging must be increased. Figure 8, based on studies by Metsäteho, shows that the use of multi-function machines is economically competitive on a far larger scale than present application indicates. The most competitive methods are based on *harvesters,* which also fell trees, thus representing fully mechanized timber preparation with one machine.

22. Mechanization of off-road transport

During the first half of this century there were 350 000—400 000 horses in Finland. Off-road transport of timber was traditionally based on use of the *horse and sledge* in winter (Figure 9). It was not unusual at the turn of the century for horses to haul loads over a 10-kilometer distance to the floating route. Because transport distances were so

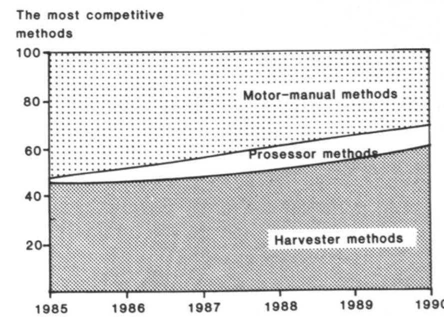

Figure 8. Development of economic competitiveness of motor-manual and mechanized harvesting methods in the late 1980s (Imponen et al. 1985).

Figure 9. Off-road transport of timber was based on use of the horse and sledge in winter untill the 1960s (Photo P. Hakkila).

Figure 10. Valmet 903 farm tractor equipped with a self-powered trailer and the RKP 2600 crane for forwarding timber (Photo H. Kalaja).

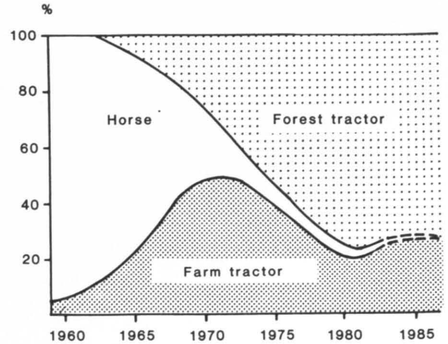

Figure 11. Development of off-road transport of timber, 1958—1987 (Mäkelä 1987).

long, loads were made as large as possible. As a result, temporary winter roads demanded a lot of up-keep. Even though sledges and road maintenance techniques improved and transport distances shortened, the methods inherited from past generations remained basically intact up to the early 1950s. From 45 000—85 000 horses were employed in timber hauling during the winter season at that time. The number of horses started to drop drastically in the early 1950s, and in 1987, there were only 1170 work horses in agriculture and forestry in Finland (Heiskanen et al. 1989).

When the mechanization of farming began in the early 1950s, *farm tractors* were tried in off-road transport of timber. By the mid-1950s, over 2000 farm tractors were used in forwarding operations. The farm tractor, however, required the opening and levelling of a strip road. In horse transport, the sledge was taken right up to the stump, whereas in tractor transport, it became necessary to carry pulpwood manually or winch sawlogs by tractor to the strip road.

The farm tractor needed accessory equipment to perform off-road transport (Figure 10). In the 1960s, the most important were half-tracks, dual rear wheels, load-carrying semi-sledges, powered semi-trailers, winches, and winch-driven boom loaders. Although the performance of equipment used in the 1960s remained far short of today's forest-equipped farm tractors, it nevertheless filled the gap in off-road transport capacity created by the drop in the number of horses and horse drivers. The peak use of farm tractors occurred in Finland in the early 1970s when approximately one half of all off-road transport of timber, including delivery sales, was carried out with farm tractors. At present, the share of farm tractor transport is only 5 % in the logging operations of the forest industry but as high as 80 % in the delivery sales of self-employed forest owners. On average, 25—30 % of all market timber (Figure 11) is hauled to the road side with farm tractors.

The four-wheel-drive *cable skidders* were imported from North America first to Sweden and then to Finland in the early 1960s. As their performance proved to be far superior to the farm tractor, they gave real incentive to the Nordic forest machine industry, and soon both Sweden and Finland began to manufacture cable skidders. In the late 1960s, the share of cable skidders in the off-road transport operations of the forest industry and the State Board of Forestry rose to 10 %. However, skidders were designed for the tree-length system, whereas logging in Sweden and Finland was traditionally based on the short-wood or log-length system. Tree-length skidding required large landing areas and proved to be an inefficient method of transporting small-sized stems and bucked timber. It was not suitable in predominantly small-owner based forestry, where the goal of an undamaged remaining stand cannot be compromised.

In Sweden, and soon also in Finland, work began to develop a tractor better suited to Nordic forest management systems and thinning operations. By the mid-1960s, a large-wheeled, *load-carrying forwarder,* typically equipped with a hydraulic knuckle-boom loader, was created. Skidders disappeared from Finnish logging sites in the 1970s. In contrast Canada, the United States, Eastern Europe, the Soviet Union, and China, for example, use wheeled or tracked skidders extensively for off-road transport in their tree-length and whole-tree haulage operations.

The forwarder solved the problem of mechanization of off-road transport in Finland. During the last two decades, it has undergone radical changes resulting in improved productivity and reliability. Today most timber is brought to the road side by medium-sized 10—12 t forwarders. In the late 1980s, lighter forwarders and light rubber-tracked, load-carrying crawlers were developed primarily for peatland logging and for early commercial thinnings. The percentage of off-road transport covered by these new light machines is still small, however.

The forwarder has become an internationally recognized trademark of the Nordic forest machine industry and forest technology. It is characterized by high productivity, flexible mobility from site to site, advancéd ergonomics, and is environmentally considerate.

3. LOGGING TECHNOLOGY AT THE END OF THE 1980s

31. Organization and infrastructure for logging

Forest industry companies purchase two thirds of their timber standing. The purchasing forest industry company is responsible for the planning and organization of the logging operations. The manual labor, forest machine contractors, and truckers are hired separately. One third of the wood raw material is delivered as timber assortments at the road side by self-employed forest owners.

No matter what sale type is used, the forest industry companies buy the raw material *through their own woodland divisions.* In order to rationalize wood procurement, to improve the operational availability of machines, to avoid criss cross transport of timber, and to reduce overheads some companies have merged their forest departments and formed *timber procurement consortiums.*

Traditionally and still today, sub-operations of a logging system are kept independent of each other by using buffer storage at the stump or road side. This *cold decking* makes the system less vulnerable to disturbances and helps to increase the operational availability and over-all system productivity. In Finland, hot logging schedules are avoided.

The tree-length method today represents less than 1 % of the off-road transport of timber. The log-length method and load-carrying tractors have proved their superiority in the Nordic conditions. *Factors favoring the log-length methods* in Finland are listed in the following:

1. A large proportion of timber is harvested from *thinning operations.* Inventories on thinnings reveal that presently less than 2 % of remaining trees are damaged. About 60 % of these damages are located on the stems and 40 % on the roots (Sirén 1987). Research results from other countries indicate that tree-length skidding tends to cause more serious damage to the stems and roots of the standing trees.
2. Skidders are an economic solution when the trees are large. Because *the stem volume* in Finland is rather small, the productivity of skidders tends to remain low. The productivity of load-carrying tractors, on the other hand, is less sensitive to stem size.
3. Boulders and stumps cause swinging of the tractor, resulting in whole-body vibration and health problems for the driver. The skidders drive faster, have simpler cabins and fewer wheels, and their load is seldom as well balanced as in load-carrying forwarders. Therefore, *vibration problems* are more serious with skidders.
4. Due to the small size of the forest holdings there is generally *a shortage of landing areas.* Forwarders are capable of storing the timber with the crane in up to 4 m high piles thus reducing the landing area requirement radically.
5. In the log-length method the *load-carrying tractors sort the timber* and pile it in conjunction with unloading at the landing site according to assortment (Figures 12 and 13). This cold decking makes it easy for the trucks to deliver different assortments to different mills. Hot schedule is avoided, loading time is decreased, criss cross transport is reduced, and handling of timber at the mill yard becomes easier.

Figure 12. In the log-length method, a load-carrying tractor sorts the timber according to assortment at the landing site. Lokomo 909 forwarder (Photo FMG Lokomo Forest Oy).

Figure 13. Forwarders are capable of storing timber in high piles thus reducing the landing area requirement (Photo P. Hakkila).

Up to the 1960s, cutting and off-road transport of timber were carried out primarily by small-farm owners as a part-time job in the winter. Timber was prepared with handsaw and ax, and hauled to the road side with horse and sledge. As rural depopulation occurred and mechanization had to be increased correspondingly, the forest industry companies were forced to gradually base their timber procurement organization on *trained, professional forest workers.* A majority of Finland's 24 000 forest workers are now employed by the companies on a permanent basis. About 400 students complete a two-year forest workers' vocational programme annually (Figure 14).

Forest workers are paid by piece rate. The average daily earnings of a worker using his own chainsaw is roughly 300 Fmk or US $ 70. In addition, the employer has to pay almost 50 % more for social security, occupational safety, health services, vacations, insurance, travel expenses, etc. The total cost of a chainsaw operator at the end of the 1980s was about US $ 100 a day.

The logging machines and timber trucks are owned by private contractors (Mäkinen 1988, Hakkila et al. 1989). Most of them have a permanent contract with a timber company guaranteeing a certain minimum amount of work per year or a certain minimum annual earning. *Forest machine contracting* in Finland is *usually limited to one work phase* only, such as off-road transport or timber preparation. However, comprehensive contract systems from stump to road side, combining fully mechanized cutting and off-road transport, offer organizational and economic advantages and are becoming more common. A *comprehensive contract,* based on fully mechanized logging, is performed with a combination of a harvester and a forwarder or, less frequently, with a single machine capable of cutting and hauling.

At the end of 1988, *the logging machine fleet* contained more than 2000 forwarders and 600 multi-function machines in active use (Figure 15). On the average, a private forest machine contractor owns 1.8 tractors. In addition, a large number of farm tractors is available for logging operations of self-employed farmers.

Modern logging machines apply advanced technology and require high operator skills and careful maintenance. The operators must be able to carry out emergency repairs. Although almost 300 *forest machine operators* complete a two-year training program annually, a shortage of experienced operators constrains the mechanization of cutting.

The employment of forwarders suffers for existing over-capacity. The basis of calculations in the annual wage negotiations is 2000 work hours per annum per forwarder, but the actual number of hours of usage tends to remain smaller (Figure 16). A high demand of pulp and paper products contributed to a considerable improvement in the employment situation at the end of the 1980s. Average use time of forwarders was 1800 work hours and that of multi-function machines 2300 work hours per machine in 1988 (Kilkki 1987 and 1988).

The long-distance transport always starts with a truck, generally equipped with a full trailer. In February 1987, the number of employed *timber trucks* was 1450. As much as 97 % of the trucks were owned by private contractors. When the hauling distance is long, the truck transport often continues by rail or floating. Natural waterways formed by inland lakes and rivers have been improved for bundle floating. In fact, in 1981—1985 approximately 33 % of the total performance, i.e., timber volume multiplied by transport distance, in the long-distance transport of round wood took place by floating. The corresponding figures were 49 % for truck transport and 18 % for rail transport. The average transport distance was 145 km (Hakkarainen 1986).

Due to the high stumpage prices, frequency of timber sales from small private forest lots, and piece rate system of forest work wages, it is necessary to *measure the timber* in the woods. The measuring unit for round wood is always solid cubic meter including bark. Important metric conversion factors are given on page 39.

A considerable share of timber is measured standing by timber cruises before logging. Measurement of timber in piles at the landing and by piece in the forest or at the landing are common alternatives as well. With the increasing application of modern

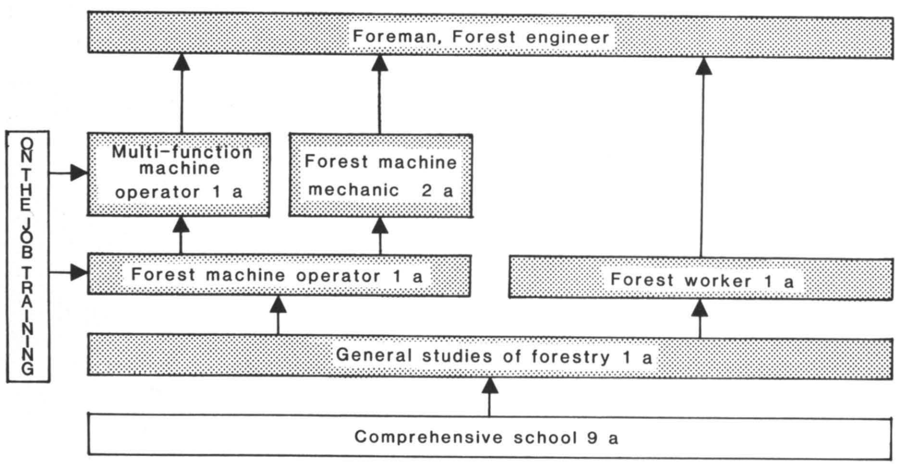

Figure 14. The basic study lines for forest workers' and forest machine operators' training.

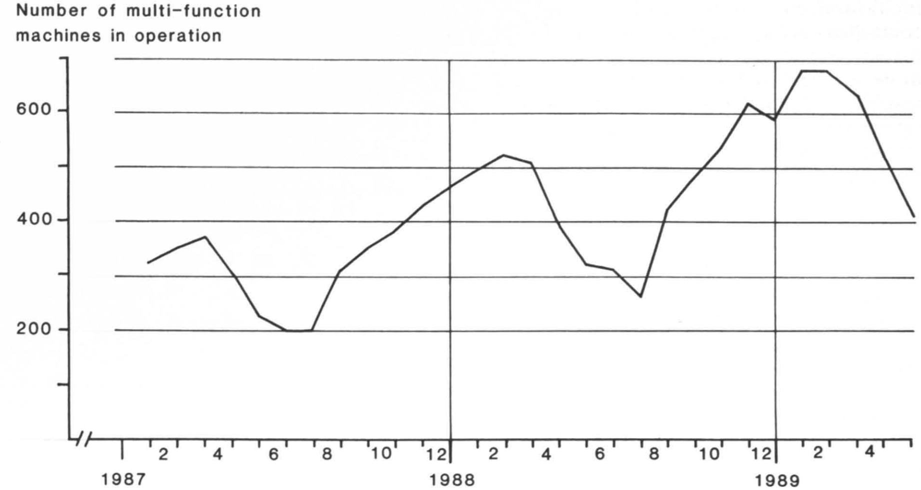

Figure 15. The number of multi-function machines in operation from January 1987 to May 1989 (Yearbooks of... 1988, 1989).

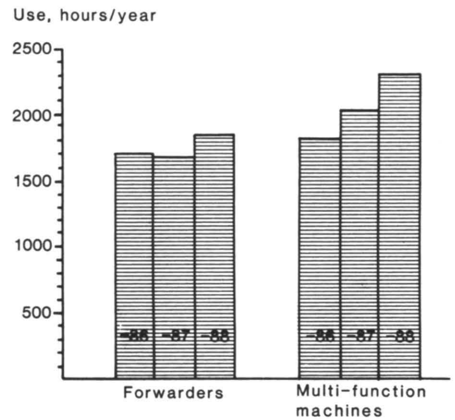

Figure 16. The average number of hours of annual usage for forwarders and multi-function machines in 1986—1988 (Kilkki 1987 and 1988).

multi-function machines, micro-computer controlled bucking decision-making and automatic measurement of timber are becoming more accurate and cost-competitive. This is resulting in reduced cost of scaling, improved utilization of saw timber, and immediate inventory data by dimension on timber produced.

32. Technology based on the use of forest tractors

Finnish harvesting technology is strongly affected by the structure of forest ownership, technical logging conditions, forestry principles, existing infrastructure, general organization for logging, and traditions. Compared to countries such as the United States, Canada, and the Soviet Union, economic and technical logging conditions are different and the ecological and environmental requirements generally stricter.

In *motor-manual methods* the tree is felled, delimbed and bucked into final lengths with a chainsaw at the site in accordance with the quality requirements applied, and small-sized pulpwood logs are bunched (Figure 17). The length of pulpwood varies usually between 3—5 m and that of sawlogs between 4—7 m. The average annual output of a chainsaw worker is 2500—3000 m3, including bark. However, the output is strongly affected by the size of the tree, as shown by the following table (cf. Kahala 1980):

Stem volume, m^3	Product	Scots pine	Norway spruce
		Productivity of motor-manual timber preparation 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

In mechanized methods chainsaw operators are replaced by contractor-owned multi-function machines which are classified in three main groups: feller-bunchers, processors, and harvesters. The *feller-bunchers*, performing only felling and bunching, are used very little in Finland. *Processors* carry out delimbing and bucking, thus chainsaw operators or feller-bunchers are required for felling. *Harvesters* are also capable of felling the trees.

A large majority of multi-function machines sold in Finland in the late 1980s was harvesters. The first generation of these machines were *double-grip harvesters*, which first sever the tree from the stump with a crane-mounted felling head and then transfer it for further processing to a separate mechanism mounted on the base carrier. A more common option is presently the *single-grip harvester*, which uses a relatively light, crane-mounted head for both felling and subsequent delimbing and bucking (Figure 18). The majority of the new machines are crane-mounted single-grip harvesters. Double-grip harvesters have their primary application in larger trees because of their robust structure and higher productivity.

Compared to motor-manual methods, multi-function machines are economically competitive particularly in final fellings, in large-scale operations, for large trees, and especially for trees with a long live crown such as spruce. However, light multi-function machines, designed for smaller trees and thinning conditions, are also becoming more competitive.

Nevertheless, the productivity and cost-competitiveness of multi-function machines are typically very sensitive to tree size. The productivity of forest tractor-mounted harvesters in late thinnings and clear cuttings varies between 15—50 m^3 per operating hour depending on tree size and the type of machine. The smallest harvesters mounted on light rubber-tracked vehicles may produce 4—5 m^3 timber per operating hour under difficult conditions of early thinnings with an average stem size of 0.04 m^3 (Sirén 1989).

Haulage to the road side is performed with a load-carrying forwarder, equipped with a long-reach hydraulic crane (Figure 19). Except in early thinnings, typical logging operations produce pine sawlogs, spruce sawlogs, birch veneer logs, and pulpwood from each of the three tree species. The forwarder sorts different timber assortments to their own piles at the landing site. Depending on the hauling distance, terrain, site conditions, type of equipment, and the skill of the driver, the output varies generally from 8 to 15 m^3 per operating hour. For small rubber-tracked vehicles the transport output remains significantly lower. A conventional forwarder, working 2000 hours annually,

Figure 17. In motor-manual methods, the cutter fells, delimbs and bucks the trees. Small-sized pulpwood logs are also bunched (Photo H. Kalaja).

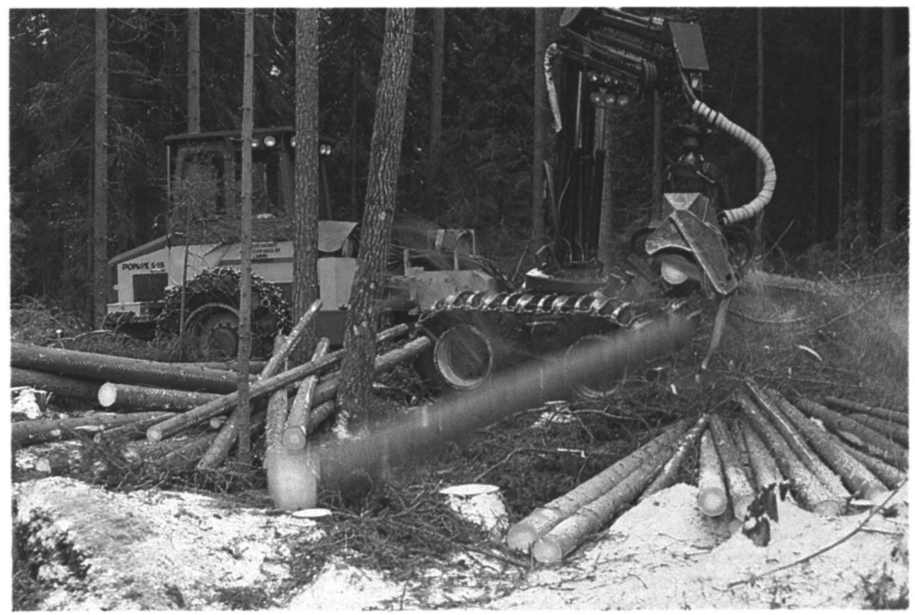

Figure 18. A medium-sized single-grip harvester is presently the most common option for fully mechanized timber preparation. Ponsse S 15 / 600 H harvester (Photo H. Kalaja).

has an annual output of 15 000—25 000 m^3.

The most common type of off-road transport machine is a six-wheel 10—12 t forwarder. Due to their better ergonomic and environmental properties, the number of eight-wheel forwarders is increasing. In the present forwarder pool, the average machine mass is 11.2 t and the crane reach 8.1 m. The newest forwarders are somewhat lighter and have a longer crane reach. A rule of thumb regarding a typical medium-sized forwarder purchased during the late 1980s is as follows: machine mass 10 t ; load capacity 10 t; and crane reach 10 m.

Long-distance transport is done, or at least started, with a self-loading truck-trailer unit. The maximum allowable weight of a unit is presently 48 t and from 1990 on 56 t. To increase the load capacity, the truck's own crane is usually detached and left at the landing site after completing the loading (Figure 20).

The most common timber haulage combination is composed of a three-axle truck, equipped with a three-axle full-trailer and a detachable grapple loader with an average reach of 7.6 m. This type of equipment constitutes 84 % of all truck-trailer units. The average engine power is 285 kW and load capacity without the crane 30.9 t and with the crane 28.2 t. The leading timber truck makes are Volvo, Finnish-made Sisu, Scania, and Mercedes Benz in the order of importance. The leading timber trailer make is Finnish-made Jyki (Säteri 1987).

33. Technology based on the use of farm tractors

One third of the total annual cut of timber is delivered to the road side by self-employed forest owners working usually with chainsaw and farm tractor. The delivery sale system gives many farmers an opportunity to employ themselves in the midwinter. The difference between stumpage prices of standing timber and delivery prices at the truck road side in southern Finland in the cutting season 1987/1988 indicates the additional income from timber preparation and off-road transport (Yearbook of... 1989):

Timber assortment	Stumpage price Marks*/m^3 solid with bark	Delivery price
Pine sawlogs	219	246
Spruce sawlogs	164	201
Birch veneer logs	222	250
Pine pulpwood	93	164
Spruce pulpwood	108	185
Hardwood pulpwood	69	139

*1 U.S. $ is approximately 4.5 Finnish marks, summer 1989.

Local Forest Management Associations provide expert assistance to forest owners in conjunction with delivery sales and other forestry activities. For example, they assist in selecting and marking trees for sale and in measurement of timber, carry out timber sales, and promote cooperation among forest owners for joint sales activities.

There are over 200 000 farm tractors in Finland. Some 80 000 of them are estimated to participate temporarily in harvesting of timber from delivery sales annually (Mäkelä 1987). About 9000 new farm tractors were sold in 1988. The leading make is Valmet.

New 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. The engine output is 50 kW on average. Substantial improvements in the base machine and auxiliary equipment have made farm tractor-based logging systems much more effective than before. Their forestry use is not necessarily restricted to off-road haulage of timber, as modern farm tractors also make a suitable prime mover for processors, harvesters, debarkers, chippers, fuelwood splitters, etc.

When *used for off-road haulage*, a farm tractor is usually equipped with a bogie trailer or sledge. Loading is carried out with a simple cable-operated boom loader or, increasingly, with a hydraulic crane. In case of small-diameter pulpwood, manual loading is not uncommon.

According to Mäkelä (1987), purchase of *a hydraulic crane* cannot be recommended unless the annual transport output exceeds 600—800 m^3. 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 to the crane is supplied by the tractor hydraulics, and the control levers are installed in the tractor cabin. Hydraulically operated support legs give extra stability to the unit. Farm tractor-mounted hydraulic

Figure 19. A medium-sized forwarder, equipped with a long-reach crane, is the principal solution for off-road transport of timber. Valmet 832 forwarder (Photo H. Kalaja).

Figure 20. A three-axle truck, equipped with a three-axle full-trailer and a detachable grapple crane, is the most common combination for long-distance transport of timber. Sisu SM 320 timber truck, Fiskars MZ crane, and Jyki trailer (Photo H. Kalaja).

loaders usually have a reach of 4.0—5.5 m, but the most expensive cranes may have a reach of 7—9 m. Approximately 2000—4000 hydraulic cranes are sold annually for farm tractors.

The technical performance and reliability of modern four wheel-drive farm tractors are presently sufficient not only for the temporary transport operations of self-employed farmers but also for permanent contracting work when equipped with a powered trailer and hydraulic loader. The technical availability of the unit under consideration is 90 %. In permanent contracting work *the productivity* is 6—7 m^3 per operating hour for larger farm tractors but considerably less, about 4—5 m^3 per operating hour, for smaller farm tractors (Mikkonen 1984). In the temporary operations of self-employed farmers, the productivity is lower due to the poorer equipment and less skill of the operators. 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 (Mäkelä 1987).

Farm tractors are frequently equipped with *a skidding winch* coupled to the three-point linkage mechanism. The use of a winch allows wide spacing of strip roads in thinnings, say 50 m. Winches are used either for skidding timber over a short distance to the strip road only, or alternatively for cable-skidding the timber with the tractor to the road side. The productivity of skidding stems or logs over a distance of 200 m is 1.5—3.0 m^3 per operating hour. The winch is always remote-controlled either by radio or by a rope coil carried by the operator in a backpack. With the remote control the operator no longer needs an assistant. A farm tractor can also be equipped for tree-length logging by attaching a skidding grapple to the three-point linkage (Ryynänen 1986, Mäkelä 1987).

Farm tractors are used increasingly *as a prime mover of a multi-function machine* for mechanized cutting (Figure 21). The minimum engine power requirement is about 60—65 kW. However, from the economic point of view, purchase of auxiliary equipment such as a boom-mounted single-grip harvester head is feasible only if it can be employed during 8—11 months of the year. This presupposes a contracting-type operation and puts new requirements on the farm tractor.

One of the main problems in professional cutting with farm tractors is *the ergonomy which is poorer* with farm tractors than with special forest tractors. In cutting, controlling the hydraulic crane requires sitting backwards, but this cannot be done fully satisfactorily in conventional farm tractors. Some recently designed farm tractors allow seat rotation of 180°. Consequently, the working position becomes more ergonomically acceptable. However, the ergonomical standards of forest tractor cabins are still not yet achieved.

34. Special technology for harvesting small trees

Mechanization of thinnings is always difficult on account of the risk of damage to the growing trees and forest soil, and due to the small size of the trees. The problems are aggravated in early thinnings.

The average volume of trees removed in the first commercial thinning is typically only 0.04—0.06 m^3, which inevitably results in a great proportion of residual biomass and low productivity of work. Although the productivity of off-road transport can be kept at an acceptable level due to the relative insensibility of forwarders to tree size, the preparation of small-sized trees to timber assortments is always costly.

A proven alternative for raising productivity and improving biomass recovery in early thinnings is based on *whole-tree logging*. The most laborious work phase of manual cutting, delimbing, is abandoned and the above-ground biomass of small-sized trees is recovered almost totally. The chainsaw operator only fells the trees, bucks them into 5—8 meter sections and, when possible, manually bunches the lightest sections to ease the subsequent loading of a forwarder. Alternatively, bucking can be done in conjunction with forwarding by attaching a hydraulic saw to the grapple of the crane. To prevent excessive loss of nutrients from the forest soil, trees may be topped simultaneously and the tops left on the site.

Forwarders with standard equipment, essentially including a long-reach crane, are suitable for hauling unlimbed tree-sections to the road side. However, the presence of

Figure 21. Farm tractors are used increasingly as prime movers for multi-function machines. Valmet 815 farm tractor equipped with Joutsa 46 TX crane and PIKA 36 double-grip harvester (Photo H. Kalaja).

Figure 22. Farm tractors are well suited as prime movers of light and medium-sized chippers for producing fuel chips from small-sized trees. Valmet 903 farm tractor and TT 1000 TU disc chipper (Photo H. Kalaja).

Figure 23. In the tree-section method pulpwood is delivered to the mill with branches intact, whereupon it is delimbed and debarked simultaneously in drums (Photo Erkki Oksanen).

crown mass lowers the bulk density of the load. The cost of off-road hauling is therefore higher, but the cost savings in cutting more than compensate this.

Whole-tree material can be reduced to chips at the landing site. The chipping is performed in small-scale operations with farm tractor-driven and in larger operations with truck-mounted chippers. In gentle terrain, comminution on the strip road with mobile farm or forest tractor-mounted chippers may be a competitive alternative.

It is technically possible to produce high-quality pulp and board products from *whole-tree chips*. However, costly process disturbances make this uneconomic. Therefore, the chips should be upgraded prior to pulping. Because upgrading systems for dirty chips are not yet satisfactory, whole-tree chips from small trees and logging residue are used in Finland mainly as an oil-substituting, indigenous fuel (Figure 22). About 800 000 m^3 solid of forest-made chips were produced in 1982 (Hakkila 1984), but reductions in the prices of oil and other fossil fuels have reduced the use of fuel chips since then.

In *the tree-section method*, the unlimbed raw material is hauled to the pulp mill by truck instead of being chipped at the landing site. Since lowered bulk density of unlimbed timber results in higher trucking costs, the method is competitive only within a rather limited radius around the point of utilization. At the mill, the raw material is simultaneously delimbed and debarked in long drums, specially adapted for unlimbed tree sections. The main product from the process, bark-free stem and branch wood, is ultimately reduced to clean chips for sulfate pulping. The residue from the bark and crown mass is recovered as a by-product and burned to produce process energy for the mill. At least three sulfate pulp mills received a part of their raw material in the form of tree sections in 1988 (Figure 23).

Harvesting and utilization of forest residue, including residual tree parts and whole unmerchantable small-sized trees, has been intensively investigated and developed during the last two decades in the Nordic countries, especially in Sweden and Finland. The potential and state of the art of forest residue utilization was reviewed in detail in a holistical monograph by Hakkila (1989).

4. PRODUCTIVITY OF LOGGING WORK

Productivity is shown by the labour input required to complete a task. In the harvesting of timber it is given as cubic meters per work hour, day, or other time unit. Productivity is calculated separately for work phases such as cutting or off-road transport, or it is calculated for a complete harvesting system from stump to road side. Productivity can also be calculated for forestry as a whole, in which case all forestry work, including stand establishment and other silvicultural operations, is taken into consideration.

A study by Vanhanen and Heikinheimo (1983) compares the development of the productivity of logging work in Bulgaria, British Columbia, Finland, and the state forests of Baden-Württemberg in the Federal Republic of Germany during a period of almost 30 years. The annual *increase in the productivity* can be seen in the following table:

	Bulgaria	British Columbia	Baden—Württemberg	Finland
	Annual increase in productivity, %			
1953—60	..	..	6.0	4.3
1960—64	4.8	7.8	5.7	6.7
1966—70	0.6	3.8	8.5	9.4
1970—74	3.0	-0.9	3.9	12.2
1974—80	2.6	1.7	7.1	7.6

The fast increase in the productivity in Finland is a result of many factors. In addition to mechanization, the following *rationalization measures* have been of great significance:

1. The forest workers were made permanent, their chainsaws and work methods were improved, and their vocational training was intensified.
2. All debarking was moved from the forest to the mill.
3. The length of a pulpwood bolt was increased from 1 or 2 m gradually to 3 m and further up to 5 m . Consequently, the traditional shortwood system is now referred to preferably as log-length system. Bucking pulpwood by eye became acceptable.
4. The quality requirements of delimbing were eased. As mentioned earlier, some companies even have trucking and mill handling facilities for small-diameter, unlimbed tree sections.
5. The planning and organization of forest work was improved.
6. The distances of off-road transport were shortened by building new forest roads.

The motor-manual harvesting method, based on use of the chainsaw and forwarder, has obviously now reached the stage where the productivity can not be significantly increased with technical changes or organizational improvements. Because the labor force of forestry is continuously decreasing and the timber demand of the pulp and paper industries increasing, it is necessary to improve the productivity also in the future. This creates increasing pressure to *replace chainsaw work with multi-function machines.* Consequently, the proportion of mechanized preparation methods is expected to double by the late 1990s.

If productivity and the labor situation are examined with the whole of forestry in mind, both long-distance transport and silvicultural operations must be considered as well. Because there has been little success in mechanizing planting, direct seeding, and precommercial thinnings, the labor demand required to perform these tasks grew as forest management activities increased in intensity in the 1950s and 1960s. As a result, although the productivity of timber harvesting grew 4—5 fold over 20 years, only a 3—4 fold increase took place in *productivity within forestry as a whole.* In the future, an increasing proportion of the forest labor force will therefore do work of purely silvicultural nature rather than logging.

In 1988, productivity of forest work for the forest industry enterprises and State Board of Forestry was approximately as shown in the following table. The productivity of all work in forestry is equal to the volume of wood harvested annually divided by the total number of mandays, including long-distance transport and all silvicultural operations such as stand establishment and precommercial thinnings.

	Productivity of forest work in Finland, m^3/manday
Cutting	11
Off-road transport	55
Cutting and off-road transport	9
All work in forestry	6

Overall productivity is still considerably below that in North America, but when the small stem volume and small timber yield per unit area and work site are taken into consideration, it is actually rather high according to international standards. Mechanization in Finland, however, lags behind Sweden by several years.

Because the total consumption of indigenous roundwood has changed very little in postwar years (Figure 24), and productivity of work has simultaneously multiplied, *the labor demand of harvesting has sharply decreased* (Figure 25). Although there has been an increase in labor-intensive silvicultural operations, the total labor input of forestry has dropped from 200 000 man years in the early 1950s to not more than 40 000 man years in the late 1980s.

5. LOGGING MACHINE INDUSTRY IN FINLAND

When forestry began its process of mechanization in the postwar years, it was not possible for the Nordic countries to fully rely on the technical advances made abroad. Development of machines and technology more appropriate to the prevailing conditions and to better comply with the strict requirements of forestry and forest owners was considered necessary.

In the beginning, Sweden was in a more favorable position than Finland, since war had not battered Sweden's wealth, industry, and national economy. Also, technical development lagged behind in Finland because new ideas and materials from North America and Central Europe entered via Sweden after some delay. Sweden therefore initially attained an indisputable lead in Nordic forest technology and forest machine industry. Furthermore, a higher wage level created better conditions for the mechanization of forestry there.

51. Farm tractor-based machinery

The first steps of the Finnish forest machine industries were taken in the 1950s. The farm tractor was adapted to forest use with the aid of *accessory equipment*. In those days, rural machine shops, smiths, and naturally farmers were still in close contact with forestry. When both practical knowledge of forestry and machine making skills were combined in one person, many new ideas for the rationalization of logging were born and realized. One invented equipment for his own personal use, another made to sell, and yet another simply to fulfill creative drive and satisfy the need for experimentation. The more 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, off-road transport of timber could be handled adequately by farm tractors compensating for the quick drop in horse transport capacity. Presently, among the best known of these products are the Farmi winches of Orion Yhtymä Oy Normet.

Simultaneously, the farm tractor proved to be a suitable prime mover for *transportable debarking machines*. A variety of farm tractor-driven disc, cutter and ring debarking machines came onto the market in the 1950s. Initially logs were fed into the debarking machines manually, but later on with a hydraulic crane. Valon Kone became a leading manufacturer, and its product development advanced via Valo and Veikko machines to the VK-ring debarkers, which came onto the market in 1960. With these transportable and stationary products Valon

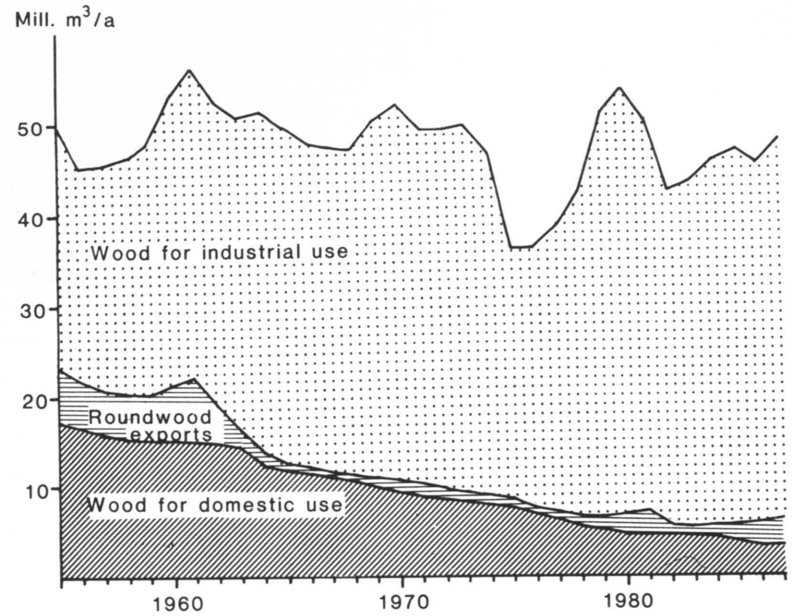

Figure 24. The total consumption of indigenous roundwood, 1955—1987 (Yearbook of... 1989).

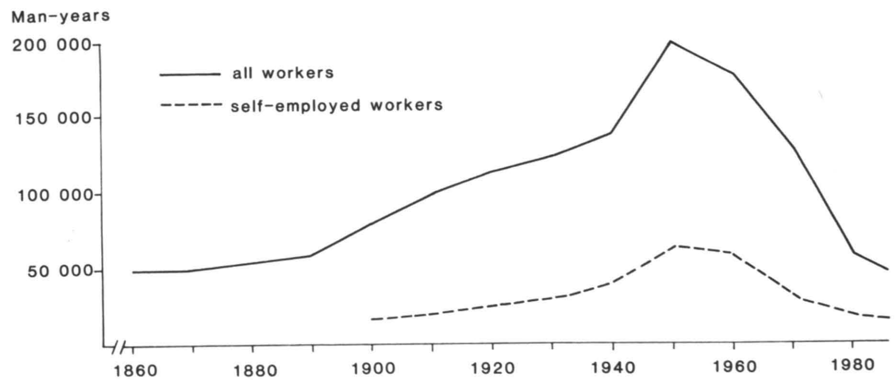

Figure 25. Development of the labor demand in forestry (Elovirta 1988).

Figure 26. In Finland debarking of timber is carried out with stationary machines at the mill, but transportable debarkers are still exported to all parts of the world. Debarking eucalyptus logs with farm tractor-driven VK 16 STE ring debarker in Africa (Photo Valon Kone).

Kone was among the first to make the Finnish logging machine industry known beyond national borders around the world. Although in-woods debarking of timber has since been replaced by centralized systems in Finland and the domestic demand is presently limited to stationary machines, transportable debarkers are still exported to all parts of both the developed and developing world (Figure 26).

In the 1950s, the farm tractor came into use as a prime mover for hand-fed *transportable chippers*. Chips made from small-sized wood seemed momentarily to have attained a permanent status as an indigenous fuel source, and many disc and drum chipper manufacturers appeared on the field. When cheap oil, however, made the use of fuel chips unprofitable in the 1960s, the demand for transportable chippers was seriously reduced.

In the 1970s, the world-wide energy crisis made the fuel chip competitive again. When the forest industry simultaneously began to show interest in whole-tree chips as a raw material for pulp and composite boards, the production of transportable chippers revived rapidly in the late 1970s. In addition to the light disc, drum and conescrew chippers designed mainly for farm use, also larger chippers suitable for contractors' use appeared on the market. Several chipper types were developed, mounted either on their own chassis or on farm tractors, forwarders, or trucks. In particular, TT disc and drum chippers became well known internationally.

When the unexpected reduction in oil prices again checked the demand for chippers in the mid-1980s, structural rationalization in the field became necessary. The number of manufacturers dropped once again. The production of the TT chippers was transferred from Perusyhtymä Oy to Bioneer Oy, which was subsequently taken over by A. Ahlström Oy. Major producers of smaller farm tractor-mounted disc chippers are presently Junkkari Oy and Orion Yhtymä Oy Normet. Conescrew or spiral-head chippers, mainly aimed at production of 50—100 mm chunks, are manufactured by Savomet Oy.

52. Forest tractor-based machinery

The first articulated cable skidder came from North America to Sweden in 1961. Encouraged by Swedish experiences, skidders were imported also to Finland. The manufacture of cable skidders was soon commenced in Nordic countries. The first Finnish cable skidder, 4-tonne Valmet Terra, came onto the market in 1963.

In Scandinavia, however, timber is traditionally bucked at the stump. As has been explained in Chapter 31, skidding of whole trees or stems is not easily applicable to the Nordic forest management system which is characterized by small-ownership, high standard of silviculture, and repeated 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 in the fall of 1962 from a farm tractor which had had its front wheels removed. Valmet Oy built the first Finnish forwarder in 1965.

Development of the forwarder over the past 25 years is largely due to the development of hydraulics. The improvements made on the operation and reach of the hydraulic crane are of great significance. Nordic timber cranes have attained a strong foothold nearly everywhere that the log-length method is used. A large proportion of the world manufacturing capacity of cranes designed for farm tractors, forwarders and trucks is presently in the hands of the Finnish logging machine industry. The leading European manufacturer of forest machine cranes is Partek Oy Ab, which owns Loglift Oy Ab in Finland and Hiab-Foco Ab in Sweden. Kesla Oy, L. Marttiini Ky Konepaja and Rovaniemen Konepaja Ky are also significant Finnish crane manufacturers.

The Nordic forwarder has passed through many phases over the past quarter of a century. In the late 1960s and early 1970s the development of forwarders was characterized by a need of higher *performance, reliability and productivity*. However, somewhat narrow goal resulted first in ergonomic and ecological problems as the operator's needs were ignored and, on the other hand, the machines became too heavy.

When operators began to complain of back problems and other illnesses caused by oscillation and inconvenient working positions, more attention was paid to *ergonomic aspects* in the late 1970s. Consequently, the ergonomic characteristics of forwarders improved significantly in the 1970s and 1980s, partly forced by strict Nordic labor legislation. These ergonomic characteristics are tested by the Research Institute of Engineering in Agriculture and Forestry, VAKOLA, which pays attention to properties such as the cabin's spaciousness, comfort and safety, the positions and motive power of control levers and pedals, the characteristics and adjustibility of the seat, visibility in various directions, and vibration of the steering wheel. The work surfaces on the tractor and their nonslip pads are also examples of the machine properties of concern.

The test reports issued by VAKOLA on the ergonomic characteristics of new tractors are nowadays usually quite positive. The oscillation caused by rough forest terrain and resulting whole-body vibration may still jeopardize the operator's health, however. Although seats have improved greatly since the 1960s, they still succeed primarily in decreasing only vertical oscillation. Horizontal oscillation, which is the most hazardous to health, remains a problem.

Since the early 1980s, development has focussed particularly on making the forwarder *more environmentally considerate.* Although Finnish methods and equipment certainly hold their own when compared with foreign counterparts, forest owners demand that stem and root damage and soil compaction be reduced even further. Significant improvements regarding rutting were brought about by developing power transmissions, adjusting the mass distribution, increasing the number of driving wheels, widening the tires, using new materials such as aluminum, etc. Figure 27 from a joint study of the Finnish Forest Research Institute and the State Board of Forestry, illustrates rutting on unfrozen soft peatland. It is substantially less with the newest wheeled forwarders and light rubber-tracked crawlers than with somewhat older tractors, even though the latter were equipped with modern 600 mm tires for the field tests.

Compared to the forwarders produced in the mid-1970s, present equipment has a 40—

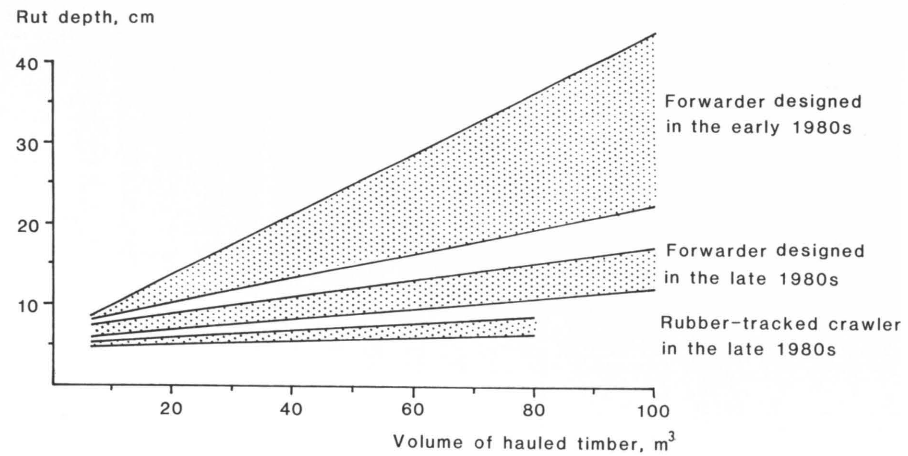

Figure 27. Rutting as a function of hauled timber volume and carrier type in an experiment in soft agricultural peat land (Sirén et al. 1987).

50 % greater power/mass ratio (kW/t) and a 30—50 % larger carrying capacity/tractor mass ratio. Furthermore, crane reach is 50—60 % longer and ground pressure 30—50 % smaller (Rysä 1985).

Mechanization of timber preparation began in the Nordic countries in the mid-1960s. A feller-buncher and a harvester were first imported to Sweden from Canada, and soon Nordic machine manufacturers began to develop their own processor-type logging machines. In Finland the way was cleared by Sakari Pinomäki, who was earlier known as a builder of debarking machines. His lengthy pioneer work was rewarded in 1968 with the creation of the first Finnish multi-function machine, PIKA 50 processor for combined felling, bucking, and bunching. By the end of 1972, some 15 of these machines were already in operation. In 1973, Ky Sakari Pinomäki became the first Nordic manufacturer of a harvester-type logging machine, the PIKA 75.

Many manufacturers in both Sweden and Finland began to develop multi-function machines. At first the focus was on processor-type equipment, for which timber first had to be felled with a chainsaw or feller-buncher. In the 1980s, *development turned definitely towards harvesters*, which also fell trees, thus representing fully mechanized cutting with a single machine.

The first generation of multi-function machines often caused damage to the timber with hydraulic shears and spiked feeding rollers, and the accuracy of bucking selection was unsatisfactory. They were also clumsy and heavy, weighing up to 15—30 t which caused excessive compaction and rutting of forest soil. Today, modern harvesters produce better quality timber, usually fit into the 10 t size class, and are frequently applicable not only in clearcuts but also in late thinnings.

Effective multi-function machine combinations can also be built from lighter carriers: small forwarders, farm tractors and light rubber-tracked crawlers. The placement of a relatively light felling-processing head onto the tractor's crane creates a competitive alternative to heavier *double-grip harvesters*. This *single-grip harvester* concept has had a definite effect on the recent direction of development. The first machine designers to apply this principle in Finland were Tapio Saarenketo with his cycle-feed Tapio harvester and Sakari Mononen with his continuous roll-feed Finko I processor. According to the sales statistics of multi-function machines compiled by VAKOLA, crane-mounted one-grip harvesters accounted for 85 % of all domestic multi-function machine marketing in the late 1980s. The remainder were processors and double-grip harvesters. In addition to ordinary forest machines, an excavator can also be used as the prime

Figure 28. Light harvesters are capable of operating in young thinning stands. Nokka Joker double-grip harvester, equipped with Nokka felling head and Hakki processor (Photo Erkki Oksanen).

Figure 29. The basic solution for fully mechanized logging is a combination of a single-grip harvester and a forwarder equipped with a long-reach crane. Lokomo 990 single-grip harvester and Lokomo 910 forwarder (Photo FMG Lokomo Forest Oy).

mover for a crane-mounted harvester head.

In 1988, 274 new multi-function machines came into use in Finland. By the year's end over 600 multi-function machines in all were in continuous use (Figures 28 and 29). Transferring strenuous motor-manual work from chainsaw operators to the machine operators has thus truly begun.

Adaptation of fully mechanized timber preparation methods is expected to speed up even more, as soon as a totally satisfactory accuracy of log measurement, bucking selection, and scaling automation are found. In a study carried out in August 1988, every fourth multi-function machine was able to meet the suggested bucking-accuracy target: at least 70 % of the timber within ± 3 cm and 90 % within ± 5 cm of the nominal length. The differences in accuracy between machines were due primarily to the equipment, but also to equipment calibration and to operator skill (Halinen 1989).

The manufacture of forwarders and multi-function machines has increasingly moved from small machine shops to fewer large international companies, who *make use of top technology and engineering skills.* The bulk of Nordic production of forwarders and multi-function machines is in the hands of two large Finnish groups. The Forest Machine Group of Rauma-Repola (FMG) controls a considerable part of global forest machine markets. FMG is made up of several units: FMG Lokomo Forest Oy in Tampere and Joensuu, Finland; FMG Cemet-Agrip S.A. in France; FMG ÖSA Ab, FMG Alfta Ab and FMG Filipstad Ab in Sweden and Timberjack Inc. in Canada, the world leader in the production of wheeled skidders. The Tractor Group of Valmet is also widely diversified and owns, for example, Velsa Oy in Kurikka, Finland; Nordtrac Oy in Rovaniemi, Finland; Umeå Mekaniska Ab and Cranab Ab in Sweden; Gafner Machine Inc. in Michigan, Implemater Equipamentos Florestais in Brazil, as well as significant farm tractor manufacturing units in Brazil, Finland and Tanzania.

Oy Norcar Ab has recently established the third large Finnish forest machine manufacturing group, especially in the lighter machine size classes. In 1988, it grew substantially as a manufacturer of forwarders, light rubber-tracked crawlers, and multi-function machines by acquiring Ponsse Oy and Finntrac Oy.

Small manufacturers produce multifunction machinery in Finland as well. Their product development and competition are of great importance to the field. Among the producers of various kinds of harvesters and processors are Oy Arctic Forest Machines Ltd, Kesla Oy, Kone-Ketonen Ky, L. Marttiini Ky Konepaja, Lännen Engineering Oy, Nokka-Forest Oy, Orion-Group Oy Normet, S. Pinomäki Ky, and Soinin Metalli Oy.

Finland has long been known internationally as a manufacturer of modern machines for the pulp and paper industries and other branches of forest industries. In recent years Finland has also become recognized as a manufacturer of forest machinery. This specifically regards timber harvesting with the log-length method, whose central elements are the forwarder, long-reach crane, and crane-mounted single-grip harvester head. In comparison with other manufacturing countries, modern Nordic technique is typically light, environmentally considerate and ergonomically advanced. A high price level, caused partly by strict ergonomic requirements, is a problem, however. The abundance of machine trademarks and types reduces the production series and raises costs further.

The Finnish machine contractor relies on domestic machinery. According to VAKOLA statistics, domestic machinery accounted for three quarters of all *forest machine sales in Finland* in 1988. The total sales value was 828 million Finnish marks. According to the sales statistics, the most important machine types were forwarders 245 million mk, multi-function machines 189 million mk, chainsaws and brush saws 177 million mk, and separately sold timber cranes for farm tractors 94 million mk (Figure 30). Chainsaws and brush saws were mainly imported from Sweden and West Germany. If they were to be excluded, the proportion of domestic machinery would actually be more than 95 %.

Because Finnish forest machine markets are limited and dispersed, customers must be found beyond national borders. Fortunately, demanding domestic markets have created a strong base for the export of forest machines. As Finnish forest machine groups have taken over several major Swedish forwarder and multi-function machine manufacturers, they have simultaneously acquired a strong foothold in Sweden's national forest machine

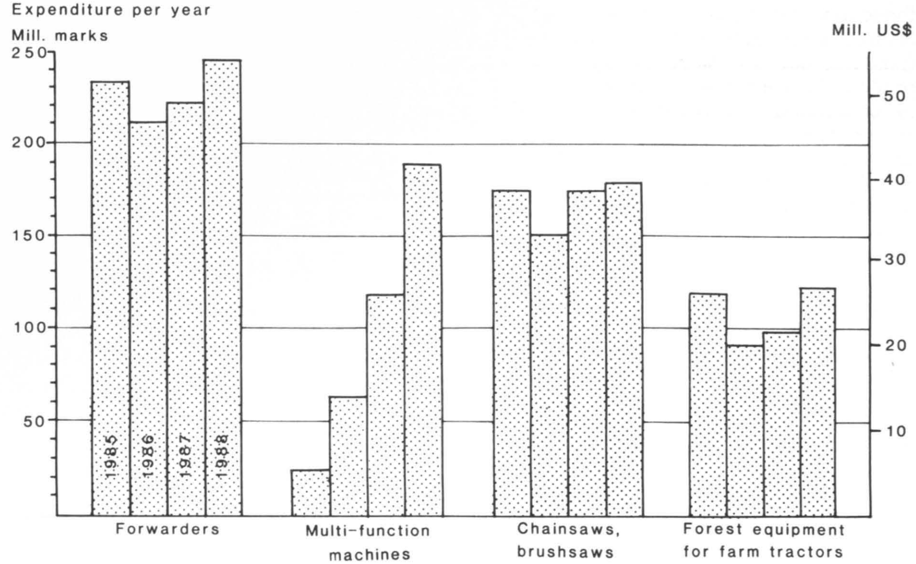

Figure 30. The sales of the major forest machine groups in Finland, 1985—1988 (data from VAKOLA 1989).

markets. From the viewpoint of the world markets of the mobile multi-function machines, Sweden is of special importance due to its high degree of mechanization. Over 40 million m^3 of timber is prepared by multi-function machines annually in Sweden, while the corresponding figure in Finland is only 10 million m^3/annum.

The Finnish forest machine industry rests typically on the log-length method, while outside Scandinavia the tree-length method is chiefly used. This difference constrains the export of forest machinery outside the Nordic countries. It is not necessarily enough that a potential foreign buyer is convinced of the possibilities and advantages of a Nordic solution. He may have to accept a completely new way of thinking and adopt a new logging and mill-yard handling system. Nevertheless, as increasing emphasis is placed on silvicultural and environmental expectations and requirements in the forest management, increasing interest is also shown in Nordic logging technology all over the world.

6. ORGANIZATIONS FOR FOREST OPERATIONS RESEARCH

The allowable and actual drain of timber, as measured in m^3/ha/a, is higher in Finland than anywhere else in corresponding climatic conditions. This is basically a result of active forest policy and intensive management of forests, but it would not have been possible without long-term holistic forest research.

Although the forest research problems are more often biological and ecological rather than economic or technical in nature, forest operations research also has long traditions in Finland. It is recognized as an integral part of the national forest research program, serving not only all parties of forestry and forest products industries but forest machine manufacturers as well. The main goals of forest operations research are to increase the productivity and operational efficiency of forest work, decrease the costs of timber procurement, develop the methods and machines ergonomically, intensify the recovery of forest biomass, decrease the damage to standing trees and soil, and develop ecologically sound operation systems.

The leading forest research organization in Finland is the *Finnish Forest Research Institute*. The actual research work is carried out in nine research departments in Helsinki and at seven research stations in different parts of the country. In 1989, the Institute employed 800 permanent persons, including 220 research officers. The research results are published in three series of journals: Acta Forestalia Fennica, Folia Forestalia, and Metsäntutkimuslaitoksen tiedonantoja.

One of the nine departments of the Finnish Forest Research Institute is the Department of Forest Technology. The Department is divided into two sections or professorships: Forest Operations and Wood Utilization. The scientific sphere of the Forest Operations Section covers three main lines: logging operations; silvicultural operations; and ergonomics of forest work. During the 1980s, harvesting and utilization of residual forest biomass, mechanization of thinnings, logging in peatlands, forest machine contractors, and ergonomics have been important research subjects. The staff for forest operations research at the Finnish Forest Research Institute consists of 25 permanent employees, 11 of which are research officers. The Department is located at the Institute headquarters in Helsinki, but some of the staff members work at the Suonenjoki and Kannus Research Stations in central Finland.

The Department of Logging and Utilization of Forest Products at the University of Helsinki is responsible for higher education in Forest Technology in Finland. It has three professorships each covering both logging and utilization; one to be held by a professor lecturing in Finnish and another lecturing in Swedish, and an associate professor. The staff has 6 research officers and 3 other permanent employees. Presently, work studies are carried out in the following fields: wood procurement in the future; operational planning; expert systems for the forest industries; forest roads, etc. The research results are published in Helsingin Yliopiston Metsäteknologian Laitoksen Tiedonantoja, Acta Forestalia Fennica, and Silva Fennica.

Metsäteho, The Forest Work Study Section of the Central Association of Finnish Forest Industries, is a private research organization located in Helsinki. It is maintained by the forest industries and the State Board of Forestry, and financed by membership fees. The total number of staff is 35—40, including some 20 university graduates. Metsäteho is thus the largest logging research organization in Finland.

The primary function of Metsäteho is to develop and rationalize forest work methods for the needs of the forest industries through investigations and machine tests and by distributing information to the member companies. The central areas of interest are the development of new work methods, mechanization, and wage scales as well as the planning and control for the effective and economic use of resources. The results are published in Metsäteho Report and Metsäteho Review series.

The Forestry Department of Työtehoseura, the Work Efficiency Institute, is a private organization enjoying state support. The Institute aims at the rationalization of agriculture, forestry and home economics. The forestry sector consists of the Forestry Department in Helsinki and the Forest Experiment Station at Rajamäki. The Forestry Department employs 13 research officers.

The main forest research interest of Työtehoseura is in rationalizing forest operations in small-scale farm forestry. Important problem areas are the logging methods and equipment of self-employed forest owners, harvesting and conversion of fuelwood, the use of farm tractors in logging work, and development of site preparation machines. The results are published in Työtehoseuran Metsätiedote and Työtehoseuran Julkaisuja series.

Machine testing is also carried out by *VAKOLA, Finnish Research Institute of Engineering in Agriculture and Forestry*. The main emphasis is on agricultural machinery. The section of forest machine testing employs one research officer. The *Faculty of Forestry at the University of Joensuu* has recently started higher education in forest technology, the emphasis being in operational planning. The *Kuopio Regional Institute of Occupational Health* carries out research on the health of forest workers, ergonomy of forest machines, and forestry working methods.

In Finland forest operations research is frequently connected in one way or another with machine development and testing. It is also involved in the introduction and application of research results in practical forestry. The emphasis is typically in applied research, but the immediate needs and approaches of various parties differ, giving thus a good reason for having several organizations for forest operations research.

The existence of several active organizations in the same scientific field naturally creates a danger of unnecessary overlapping and splitting of resources. To avoid this, representatives of the major organizations meet regularly under the umbrella of the *Cooperation Committee for Forest Technology Research*, set up by the Society of Forestry in Finland. The Committee discusses and coordinates the annual research programmes and problems of common interest in general. As a result of the cooperation, each institute is able to concentrate its resources more effectively on a few key areas. Also, information exchange and program coordination is carried out with the Scandinavian sister organizations in Sweden, Norway, and Denmark through joint research projects under the framework of the Nordic Research Council on Forest Operations (NSR).

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METRIC CONVERSION FACTORS

From metric to English units		From English to metric units	
Length			
1 mm	= 0.0393701 in	1 in	= 25.400 mm
1 cm	= 0.393701 in	1 in	= 2.5400 cm
1 m	= 3.28084 ft	1 ft	= 0.3048 m
1 m	= 1.09361 yd	1 yd	= 0.9144 m
1 km	= 0.621371 mi	1 mi	= 1.60934 km
Area			
1 mm^2	= 0.0015500 in^2	1 in^2	= 645.16 mm^2
1 cm^2	= 0.15500 in^2	1 in^2	= 6.4516 cm^2
1 m^2	= 10.763915 ft^2	1 ft^2	= 0.0929030 m^2
1 m^2	= 1.19599 yd^2	1 yd^2	= 0.836127 m^2
1 ha	= 2.47105 acres	1 acre	= 0.404686 ha
1 km^2	= 0.386102 mi^2	1 mi^2	= 2.58999 km^2
Volume			
1 cm^3	= 0.061024 in^3	1 in^3	= 16.38706 cm^3
1 dm^3 = 1 l	= 0.264172 gal (US)	1 gal (US)	= 3.785412 dm^3
1 m^3	= 35.3147 ft^3	1 ft^3	= 0.0283168 m^3
1 m^3	= 423.7759 bd ft	1 bd ft	= 0.002359738 m^3
1 m^3	= 1.30795 yd^3	1 yd^3	= 0.764555 m^3
1 m^3	= 0.353147 cunit	1 cunit	= 2.83168 m^3
1 m^3 (st)*	= 0.275896 cord (st)*	1 cord (st)*	= 3.62456 m^3 (st)* ≈ 2.5 m^3 (s)*
Mass			
1 g	= 0.0352740 oz	1 oz	= 28.3495 g
1 kg	= 2.20462 lb	1 lb	= 0.453592 kg
1 t (tonne)	= 1.10231 sh ton (US)	1 sh ton (US)	= 0.907185 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	= 2.02417 t/ha
1 m^2/ha	= 4.35600 ft^2/acre	1 ft^2/acre	= 0.229568 m^2/ha
1 m^3/ha	= 14.2913 ft^3/acre	1 ft^3/acre	= 0.069972 m^3/ha
1 m^3/ha	= 0.1429 cunit/acre	1 cunit/acre	= 6.9973 m^3/ha
1 m^3 (st)*/ha	= 0.111651 cord (st)*	1 cord/acre	= 8.95647 m^3 (st)*/ha ≈ 6.2 m^3 (s)*/ha

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

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Manuscripts should be sent to the editors of the Society of Forestry as three full, completely finished copies, including copies of all figures and tables. Original material should not be sent at this stage.

The editor-in-chief will forward the manuscript to referees for examination. The author must take into account any revision suggested by the referees or the editorial board. Revision should be made within a year from the return of the manuscript. If the author finds the suggested changes unacceptable, he can inform the editor-in-chief of his differing opinion, so that the matter may be reconsidered if necessary.

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