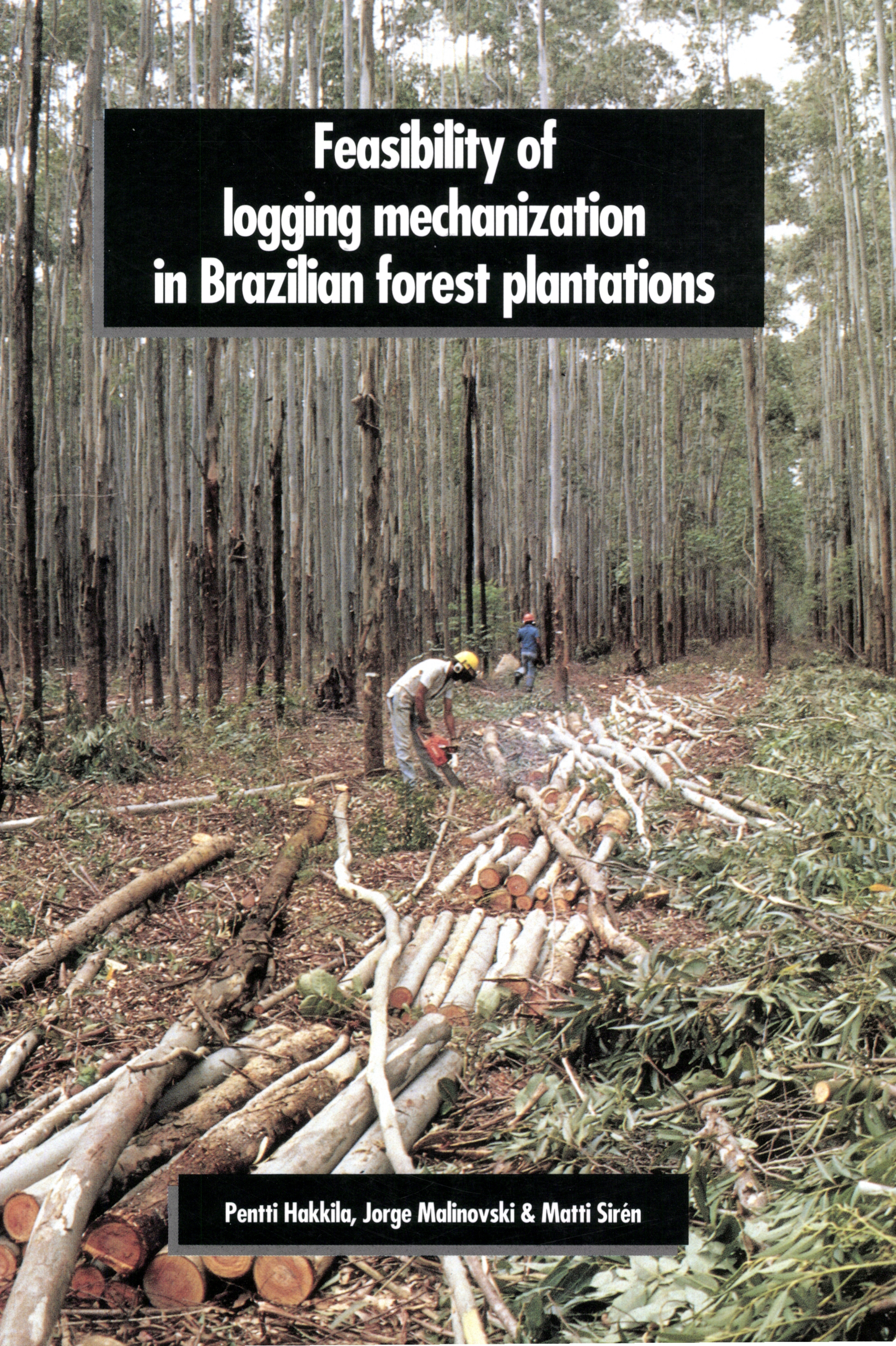
Feasibility of logging mechanization in Brazilian forest plantations



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A comparison between Brazil and Finland

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Metsäntutkimuslaitoksen tiedonantoja 404
The Finnish Forest Research Institute. Research Papers 404
Helsinki 1992

Hakkila, Pentti, Malinovski, Jorge & Sirén, Matti 1992. Feasibility of logging mechanization in Brazilian forest plantations. A comparison between Brazil and Finland. Metsäntutkimuslaitoksen tiedonantoja 404. The Finnish Forest Research Institute. Research Papers 404. 68 p. ISBN 951-40-1201-1, ISSN 0358-4283.

The prevailing timber harvesting systems of the Brazilian pulp and paper industry are characterized by low level of costs, high recovery of wood, and short passage time of timber going from stump to mill. Nevertheless, the foreseeable expansion of production will require improved efficiency and, at the same time, will create favorable conditions for introduction of new logging technology without seriously hurting the existing organizational structure, rural employment, or local communities.

Before an entirely new logging system can become operational, work method development, modifications, operator training, and restructuring the organization are needed. It is therefore recommended that, although the labor-intensive technology continues to be cost-competitive and cheap rural labor is still readily available, Brazilian forest industry companies should launch a cautious testing, development, and training program to find proper mechanization solutions for their specific conditions. The joint study of the Finnish Forest Research Institute and the Federal University of Paraná shows that the modern Finnish log-length system, based on the use of one-grip harvesters and load-carrying forwarders, offers a cost-competitive and environmentally sound alternative for the long-term development of timber harvesting from the Brazilian pine and eucalyptus plantations.

Keywords: logging, mechanization, plantation, Brazil, Finland

Publisher: The Finnish Forest Research Institute; Project: 3035-1. Accepted for publication by Professor Jari Parviainen, Research Director, in March 23, 1992.

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Distribution: The Finnish Forest Research Institute, Department of Forest Production, Unioninkatu 40 A, SF-00170 Helsinki, Finland.

ISBN 951-40-1201-1
ISSN 0358-4283

Gummerus Kirjapaino Oy
Jyväskylä 1992

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Preface

In 1985, the Federal University of Paraná (UFPR) and the Finnish Forest Research Institute (FFRI) signed an agreement on cooperation in forestry research. The goal was to promote research in subjects of mutual interest, to establish collaboration contacts, and to encourage dissemination of information about forestry and forest industries. The original program was composed of the following topics: production methods for containerized *Pinus elliottii* seedlings (Carneiro & Parviainen 1988), dendrochronology of *Araucaria angustifolia* (Kanninen & Seitz 1988); productivity and strain of workers in clear-cutting of *Eucalyptus* plantations (Harstela & Malinovski 1988), and the energy potential of thinning residue from *Pinus taeda* plantations (Soares & Hakkila 1988).

The second phase of the collaboration program was started in late 1988 with the signing of a new memorandum of understanding. In May 1989, the Ministry of Trade and Industry in Finland awarded funds for implementing two joint sub-projects under the auspices of the agreement; one dealing with the production technology of containerized seedlings and the other with the feasibility of logging mechanization in Brazilian pine and eucalyptus plantations.

The present report is a result of the sub-project on the feasibility of logging mechanization in Brazil. It is essentially based on data collected by a questionnaire, originally designed by Pentti Hakkila and Matti Sirén and later revised and sent to major wood-using companies by Jorge Malinovski in Brazil. The manuscript was first drafted by the Finnish authors and then revised and completed by the three authors jointly. In addition to the present report in English, a Portuguese version will be published by UFPR in Brazil.

The authors are grateful to the authorities who provided the framework and necessary support for the collaboration in both countries. We thank those Brazilian wood-using companies who kindly returned the laborious questionnaire and supplied the research team with invaluable, confidential information on logging issues such as operating environment, technology applied, labor situation, cost of timber procurement, and system performance.

The report was skillfully typed by Ms Maija Tuuri and Ms Essi Puranen. The figures were drawn by Ms Tuula Nurmi. The English text was revised by Mr Paul Service. Professor Rihko Haarlaa, University of Helsinki, commented on the manuscript suggesting worthwhile improvements.

The authors wish to thank all the organizations and persons who contributed to different phases of the project. Our special thanks are extended to Professor Jose Geraldo de Araujo Carneiro from the Federal University of Paraná and Professor Jari Parviainen from the Finnish Forest Research Institute for their support in the project.

We sincerely hope that the joint study, despite its shortcomings, will promote mutual understanding and further cooperation between Brazil and Finland and help decision-makers and forest machine manufacturers and dealers to holistically evaluate the feasibility of different machine and system alternatives under the socio-economic and environmental conditions prevailing in Brazilian forest plantations. Finally, we hope that the report will stimulate the development of logging towards improved operational efficiency, as understood in its broad sense, so as to benefit the forestry sector and the entire rural society in Brazil.

Curitiba and Helsinki, December 1991

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1. Introduction

Procurement of timber from stump to mill yard is a vital function of forest industry. *Logging*, i.e. cutting and off-road transport from stump to road side, is the central operation in timber procurement.

A procurement system links forest management with wood utilization. In the service of large-scale forest industries it must be reliable and cost-competitive, although it must also meet the social and environmental expectations of society. *Efficiency* is thus not only a result of the technical and economic performance of the system; it is also affected by a number of social and environmental issues (cf. Sundberg & Silversides 1988).

Up to the late 1940s, logging all over the world was based on the use of human muscle, simple hand tools, and draught animals. In many industrialized countries, mechanization of agriculture initiated rural depopulation and resulted gradually in a shortage of forest labor and workhorses in the 1950s. Consequently, it soon became necessary to mechanize forestry operations as well. The tempo of development only accelerated during the decades to come, and a revolution took place in logging technology. The introduction of tractors as forest transport vehicles made tree-length skidding a competitive alternative to the traditional short-wood transport system. While the North American forest industries chose the tree-length system, the log-length system still remained the more efficient under European conditions. *The northern European and North American harvesting technologies grew apart.*

On the other hand, the development of forest work remained slow in non-industrialized countries, where such technical and socio-economic development did not occur. *Differentiation of logging technology between the boreal forest zone and the southern tropical and subtropical regions took place.* At present, only 40 years after the mechanization of timber harvesting was introduced on a large scale, differences between the south and the north as regards the technology, labor conditions, and system performance are generally immense.

In Brazil, both traditional undeveloped and modern advanced technology are being applied simultaneously, the latter typically transferred from either northern Europe or North America. Unlike in developing countries generally, the prevailing logging systems of the Brazilian pulp and paper industry are characterized by rather high productivity of labor, low costs, high recovery of wood, and a short passage time of timber going from stump to mill. The charcoal industry, also a large consumer of timber, often uses less efficient technology. Although there may be exceptions, pressure for the development of logging technology in the industrial forest plantations does not seem to be very urgent, if the situation is viewed in cursory way.

Nevertheless, to meet the future challenges and increasing requirements of society and to maintain its international cost-competitiveness, an exporting industrial enterprise is bound to watch progress in other countries and introduce new technology when appropriate. The Brazilian forest industry is no exception. Since its demand for timber is expected to increase rapidly during the 1990s, the foreseeable *expansion of production will require improved efficiency* and, at the same time, will probably *create favorable conditions for introducing entirely new logging technology* without seriously hurting the existing organizational structure, rural employment, or local communities.

The ongoing *opening up of the Brazilian economy to foreign investors*, including the reduction in the import tax on machinery to an average level of 25–30 % plus a 5–15 % tax for industrial products in July 1991, will probably further improve the atmosphere from the viewpoint of technology transfer. Since Finland is one of the world leaders in forest machine manufacture, and since the physical operational environment in the Brazilian plantation forests in many respects resembles that of the northern European forests, modern Finnish logging technology seems to offer an attractive alternative for the long-term development of timber procurement in Brazil, even though socio-economic conditions in the two countries differ greatly.

The overall objective of the present joint study on the feasibility of logging mechanization in Brazilian pine and eucalyptus plantations is, first, to support strategic planning and decision-making concerning the long-term development of timber harvesting in the Brazilian wood-using industries. Secondly, the goal is to produce a state-of-the-art review and a holistic evaluation of Brazilian logging technology for the use of local and foreign machine manufacturers and dealers. To reach *the overall objectives, the following immediate objectives were set for the study:*

1. To chart the present operational environment of timber procurement in the Brazilian plantation forests and its expected changes during the 1990s
2. To produce a state-of-the-art review of timber harvesting technology in the Brazilian plantation forests
3. To compare the findings with Finnish logging technology and identify possible problems and bottlenecks which should be solved
4. To study the needs and possibilities for the development of logging technology through mechanization or by other means
5. To study the benefits and risks of transferring advanced Finnish logging technology to Brazil

2. Research material

The feasibility study is based on published literature, company visits and, primarily, on a *questionnaire* sent by UPFR to 48 Brazilian companies using plantation timber for fiber, lumber, or energy. The questionnaire comprised 58 questions as follows:

Theme	Number of questions
General information on the company	4
Forest management practice	6
Logging environment	4
Labor situation	11
Techniques of cutting	7
Techniques of off-road transport	10
Techniques of on-road transport	9
General data on logging mechanization	7

The questionnaire was sent out in April 1990. The companies were requested to return it by the end of July. Altogether, 17 companies, none of them a sawmill, returned the questionnaire. However, three of them were received from fledgling companies that had not started harvesting activities. Since their answers were based on theoretical calculations and expectations rather than on practical experience, data from only 14 companies was finally accepted.

The answers were divided into three groups: producers of pine fiber, producers of eucalyptus fiber, and producers of eucalyptus fuelwood for charcoaling or direct combustion. Three of the companies simultaneously produced pine pulp and eucalyptus pulp and were therefore included in both groups.

The accepted *answers represent a total annual pulpwood cut of 11.8 mill. m^3 or 40.4 %* of the pulpwood harvest from plantations. The material seems to be sufficient to give an overall view of pulpwood harvesting in Brazil, although bias toward the most efficient organizations is possible. As regards the charcoal industry, the answers cover *2.3 mill. m^3 or 9.9 % of the annual cut of plantation timber for charcoal*. Since the charcoal industry gets its wood raw material mainly from native forests, the answers cover less than 2.0 % of the total use of wood by the charcoal industry. Therefore, they must be interpreted with caution.

The majority of the answers were received from the *south and* *south-east regions of Brazil*. All timber assortments included, they represented an annual cut of 17 mill. m^3 in 1989. Many of the companies were considering expansion of the capacity resulting in an estimated total consumption of 28 mill. m^3 or an increase of 64 % by the year 2000. Although probably only a part of the plans will materialize by this time, logging organizations are being forced to prepare themselves for capacity increases and develop the logging organization accordingly. One alternative for improved efficiency is mechanization, which is the main topic of the present study.

3. Operating environment in the Brazilian forest plantations

31. Forest plantations as a source of timber

The total area of Brazil is 851 mill. ha. Before the arrival of European settlers, some 523 mill. ha of land was covered by forests (Magnanini 1959), but since then large land areas have been cleared for agriculture and cattle raising. During the first half of this century, deforestation, the inaccessibility of remote forest regions, and the unsuitability of many native hardwoods for use by forest industries resulted in aggravating timber shortages in densely populated regions of the country. Pulp and paper had to be imported, and the metallurgy industries suffered from the shortage of fuelwood and charcoal. Whilst the destruction of native forests continued and the demand for wood increased, the government deemed it necessary to ensure the future timber supply through afforestation and intensive plantation management.

In the mid 1960s, the total area of man-made forests was only half a million hectares. To make the country self-sufficient and gradually a major exporter of pulp and paper products and steel, land use and taxation policy was then aimed at promoting the establishment of forest tree plantations through fiscal incentives. Owing to the availability of large tracts of fertile land, the favorable climate, fast growth rates, the low cost of labor, and suitable terrain conditions for mechanization, the new forestry philosophy and federal subsidies led private companies to *greatly expand their afforestation efforts in the 1970s and the 1980s.*

Native tropical forests are still the main source of timber in the north and north-east, although in other regions their role as a timber supply has been reduced greatly. In the south and south-east of Brazil, the raw material of large-scale industries is based on timber produced in intensively managed plantations on a sustained yield basis. At the beginning of the 1990s the area covered by forest tree plantations was 6.7 mill. ha or 0.8 % of the total land area of the country (Siqueira 1989):

	Area	
	Mill. ha	%
Closed tropical forests	260	30.5
Savanna-type cerrado forests	146	17.1
Semi-arid caatinga shrub forests	44	5.2
Even-aged plantations	6.7	0.8
Total forest area	456	53.6
Total land area	851	100.0

Although the area of man-made forests is only 1.5 % of the total forest area, during the last two decades *the Brazilian forestry sector has largely evolved around or been a function of the plantations*. The highly successful plantation program is contributing to moving the country from an agricultural to a more industrial economy (Kengen 1987). Furthermore, it reduces the pressure to exploit native forests.

Originally, forests were often planted to take advantage of tax incentives rather than to produce timber for a specified purpose. Subsequently, plantations have been used primarily to supply wood to pulpmills, sawmills, and metallurgy industries. After the second worldwide energy crisis in the late 1970s when the forest sector was called on to contribute to the Brazilian energy balance by substituting renewable forest biomass for imported oil, for example the ceramic and cement industries also started operating plants on fire-wood (Rezende & Neves 1988).

Since the introduction of the fiscal incentives scheme, a large number of enterprises in the pulp and paper, and steel industries have specialized in afforestation and forest management, particularly through the establishment of subsidiary companies. There are also independent firms producing plantation timber for third parties that are unable to establish their own plantations. The majority of the plantations are owned by large companies, whereas little effort has been directed to encouraging plantation activities of small-farm owners.

Fiber plantations are concentrated mainly in the southern and south-eastern regions of the country, particularly in the states of São Paulo, Paraná, Espirito Santo, and Santa Catarina, where most of the pulp mills are located (Figure 1). *Charcoal plantations are largely in the state of Minas Gerais*. Although government policy and the rise in land prices in the south attract plantation expansions increasingly to less developed regions in the north-east (ANFPC 1987), only one major pulp mill, Cia Monte Dourado (Jari Project), is presently situated in the north of the country in the state of Pará. The area of forest plantations by regions is presented in Table 1.

Tree size and the technical properties of wood can be controlled in plantation forestry through tree breeding, forest management, and timber procurement arrangements. In even-aged man-made

Figure 1. The great regions of Brazil and the states with the largest concentration of forest plantations.

forests, technical logging conditions are basically rather similar to those in the managed forests of northern Europe, though generally easier from the mechanization point of view. Therefore, northern European principles and systems of logging are technically suitable for the vast majority of the plantation forests in Brazil.

Pulp production in Brazil was initially based on long-fiber raw material. Consequently, pine was the prevailing crop of the early tree plantations. The most popular species of pine, *Pinus elliottii* and *Pinus taeda*, belong to the southern yellow pine group from the United States. Other long-fiber plantation species are *Pinus caribea* in the north-east and the native *Araucaria angustifolia* in the south. Although the role of pine has gradually diminished, 29 % of all pulp is still made from pine wood.

No matter whether plantations are established for the production of fiber or energy, in both cases the primary crop is at present eucalyptus wood. In 1986, about 65 % of all pulp in Brazil was made from eucalyptus. Important species are *Eucalyptus alba*, *E. camaldulensis*, *E. dunnii*, *E. globulus*, *E. grandis*, *E. saligna*, *E.*

Table 1. The area of forest plantations in Brazil by region at the end of 1989 (Siqueira 1989).

Region	Pine	Eucalyptus	Other sp.	Total
		Plantation area, mill. ha		
South	1.00	0.13	0.13	1.25
South-east	0.56	2.62	0.00	3.18
Central-west	0.10	0.76	0.00	0.86
North and north-east	0.38	0.40	0.63	1.41
Total	2.04	3.91	0.76	6.70

Table 2. Consumption of wood by product group in Brazil in 1989 (Siqueira 1989).

Product	Wood consumption, mill. m^3/a	
	From native forests	From planted forests
Pulp and paper	7.6	29.2
Lumber, plywood, boards	23.2	9.5
Charcoal	70.6	23.5
Industrial energy	22.0	13.7
Rural energy	136.8	12.3
Total	260.1	88.2

tereticornis, *E. urophylla*, *E. viminalis* and their hybrids. For charcoal production, high-density species such as *E. citriodora*, *E. cloeziana*, *E. pilularis*, and *E. pyrocarpa* are recommended (Magalhães 1988). In addition to eucalyptus, *Gmelina arborea*, *Acacia sp.*, and sugar cane bagasse are also used as raw material of short-fiber pulp. For energy purposes, cultivation of species other than eucalyptus is exceptional.

Brazil is the world leader as a producer of tropical hardwood for lumber and furniture manufacture. The raw material is exploited primarily from natural forests in the states of Pará and Rondonia in the Amazon region, not from southern or south-eastern plantations. However, pine also is suitable for manufacturing construction lumber and plywood, whereas eucalyptus is generally an inferior raw material for them.

The role of plantations with regard to the total consumption of wood in Brazil is seen in Table 2. In 1989 the harvest of plantation timber was 88.2 mill. m^3. The primary use was for pulp, charcoal, firewood, and lumber. As regards the timber extracted from native forests, as much as 88 % was used for energy purposes, either for direct combustion or for charcoaling.

32. Forest management practice

The end use of timber has a strong influence on the forest management principles. In Brazil *the goal of plantation management is typically the production of pulpwood or fuelwood.* Management has not been well conducted by the sawmill and veneer industries, and log quality is inadequate for the production of high-grade lumber and plywood. New management practices for the pine plantations need to be implemented, and the industry should revise the roundwood specifications to promote more complete utilization of timber and better control of waste (Murakami 1987).

It is worth mentioning that in Chile, another emerging southern American forest industry country, the ultimate objective of current silvicultural practice is generally to produce large-diameter, knot-free radiata pine logs for the sawmill industry, whereas pulpwood is more or less a by-product. The allowable cut from the Chilean radiata pine plantations will reach 27 million m^3 by the year 2000 and will then be equally divided between pulpwood and sawlogs (Jélvez et al. 1990). Therefore, treatments such as pruning and thinning are applied commonly.

Since the production of high-quality saw or veneer logs is only seldom the ultimate goal in Brazil, stem characteristics such as taper, sweep, crookedness, branchiness, and even size tend to be of minor significance. It follows that systematic or selective thinning cuttings are not necessarily needed to accelerate diameter growth. In fact, eucalyptus plantations are not thinned at all. Logging damage to standing trees or timber is less harmful when wood is used for pulping and energy purposes only.

Pine stands are always established by planting. The spacing and rotation age vary depending on external conditions and the company policy. Whereas one company plants only 1600 trees per hectare and follows a 12-year rotation cycle, another company may plant 2500 trees per hectare and applies a 25-year cycle. Accordingly, in some companies thinning cuttings are not a part of the pine management regime, whereas in most cases pine stands are thinned repeatedly, commonly three or four times during the rotation cycle.

Eucalyptus stands are established initially by planting as well. After clear-cutting, most companies regenerate their eucalyptus stands at least twice by coppicing. However, some companies have temporarily abandoned the coppice treatment to be able to take immediate advantage of the improved varieties now available due to successful tree breeding. When coppicing is used, avoidance of mechanical damage to stumps requires extra care during the off-road transport of timber.

Pulpwood producers plant 1100–2000 eucalyptus trees per hectare, energywood producers more. On average, the number of eucalyptus seedlings is about 1600 per hectare in pulpwood plantations, 2100 in energywood plantations. The rotation cycle is

Figure 2. A seven-year-old eucalyptus plantation in southern Brazil. The first generation after the establishment of the stand (Photo Jorge Malinovski).

generally 6 or 7 years in the pulpwood plantations in the south and south-east (Figure 2) and a few years less or more in energywood plantations, which often occupy less productive areas.

The average annual growth of pine varies at present from 20 to 40 m^3/ha. Use of improved seedling stock is expected to result in a further 10–15 % growth increase in the future. The annual growth of eucalyptus in pulpwood plantations is at present about 30 m^3/ha. Owing to tree improvement, the average annual growth is expected to rise to 40 m^3/ha by the year 2000, some companies already exceeding it. An average growth of 50 m^3/ha/a at the turn of the century is considered realistic by a few pulpwood companies. However, owing to less suitable soil and climate, the average annual growth of charcoal plantations of eucalyptus is only 13–18 m^3/ha.

33. Technical logging conditions

Irrespective of the degree of mechanization, the performance of a harvesting system is strongly dependent on technical logging conditions such as tree size, dimensions of logs produced, yield of timber per unit area and work site, requirements set for the remaining stand, road density, terrain, and climatic conditions. Since in Brazil these conditions are greatly different in native forests and in plantations, specialized logging equipment and work schedules are needed for both of them. Appropriateness of equipment and methods, productivity, physical and mental strain on workers, safety, and even the organizational requirements are all dependent on external conditions. Therefore, the efficiency of a system and an organization cannot be evaluated disregarding the operational environment. Transfer of technology must be studied accordingly.

Land ownership affects the management of forests and timber procurement. A Brazilian industrial enterprise using plantation-grown wood for pulping or charcoaling typically cuts the timber from its own land. In the present study, 85 % of all timber came from companies' own plantations, whereas 9 % of timber was purchased from other wood-producing companies and 6 % from private landowners. Differences between pine and eucalyptus users were minor in this respect. As a result of the ownership pattern, Brazilian plantations form large solid units allowing efficient planning and implementation of timber harvesting.

Terrain conditions in the Brazilian plantations are generally easy for both motor-manual and mechanized logging. Boulders, ground vegetation, or underbrush seldom hinder vehicles. Conventional farm tractors can be used for the off-road transport of timber, and even trucks can often drive to the stump for load collection. Since taking trucks directly to the stump tends to increase vehicle breakdowns and soil compaction, the system is no longer as popular as earlier.

However, a considerable part of the plantations, especially in the south and south-east, is located in hilly terrain where steep slopes may prevent the use of tractors for hauling. According to the questionnaire material, altogether 15.4 % of the area was considered too steep for farm tractors. In additional 27.8 % of the area steep ground configuration was seen as a harassing factor.

Bearing capacity of the ground is generally sufficient. The use of machines was totally hampered in 0.2 % and greatly hampered in 2.3 % of the plantation area by ground softness.

Owing to the dense network of permanent truck roads, the average *off-road transport distance* is for most companies only 150–250 m. However, exceptions do exist. For example, there are cases where load-carrying tractors haul energywood directly to charcoal ovens from distances of several kilometers.

Stem size is of utmost importance regarding the productivity of manual and mechanized harvesting systems, and it actually deter-

Table 3. Orienting data on stand characteristics in Brazilian pine plantations under a management regime of three consecutive thinnings and the final cutting.

	Treatment			
	First thinning	Second thinning	Third thinning	Final cutting
Stand age, a	8–9	12–13	16–17	25–30
Trees removed, %	50	40	40	100
Dbh, cm	12	16	23	32
Height, m	12	16	19	25
Stem volume, m^3	0.07	0.16	0.40	0.97
No. of trees remaining per ha	1000	550–600	280–350	–

mines which type of equipment is most economical. First thinnings excluded, in the Brazilian plantations there are few undersized trees to reduce the productivity of machines. Neither are there single extra-large trees suggesting over-dimensioning of machines. Table 3 shows the size of trees harvested from a pine plantation under a typical management regime composed of three successive thinnings and the final cutting during a rotation period of 25–30 years. The first and the second treatments are partly a combination of systematic removal of complete rows of trees and individual selection of single trees between the opened corridors, whereas the third thinning is selective only. If thinnings are omitted, the situation of the final cutting is naturally different from what is proposed in Table 3, depending on the initial spacing, growth rate, and rotation period. For eucalyptus, average stem volume at the phase of final cutting was in the questionnaire material for some companies only 0.08–0.10 m^3, for several others 0.18–0.22 m^3, and in one case 0.30 m^3. Differences between companies are thus great, but within a specific logging site the stem volume is fairly constant.

The amount and size of branches must be taken into consideration when cutting is mechanized. The proportion of live crown is short in both pine and eucalyptus, typically 5–7 m in length depending on the spacing. The dead crown of pine is long and branchy, whereas in eucalyptus, due to its fast self-pruning, the zone of dead crown is only 2–5 m in length and composed of relatively thin branches. The branch-free part of the stem is very short in pine but 10–15 m in eucalyptus.

Pinus taeda tends to grow thicker branches than *Pinus elliottii*. If the spacing is wide, and especially on the edges of a plantation, its branches may be 5–6 cm or more in diameter. In eucalyptus the branches are considerably thinner. The branch angle in pine is 45–90 degrees but sharper in eucalyptus, typically 30–60 degrees. Whorls of thick and sharp-angled branches tend to cause problems to the delimbing device of a multi-function machine.

Minimum top diameter with bark is 14 cm for pine sawlogs and 6–8 cm for pine and eucalyptus pulpwood, depending on the company. These top diameters can be reached easily with multi-function machines without significant breakage of merchantable timber. When eucalyptus wood is used for energy purposes, the minimum top diameter is 3–4 cm, which may be too thin for larger harvesters.

Selection of *bolt length* is a critical rationalization issue, since the bolt length affects all phases of cutting, transport, storage, and mill-yard handling of timber. In Brazil the length of pulpwood is commonly 2.2 m or 2.4 m, the length of sawlogs 3.1–4.6 m, the length of veneer logs 1.6 m, and the length of energywood bolts typically 1.2, 2.2 or 2.4 m. These lengths are not sufficient to allow a logging organization to take full advantage of the scope for rationalization offered by modern technology.

34. Comparison with Finland

The feasibility of logging mechanization is determined by the operational environment in the forests, the infrastructure supporting economic activities, labor situation, availability and cost of capital, socio-economic conditions, and trends in timber demand. This subsection compares the operational environment of the Brazilian plantation forests and that of the southern Finnish forests (cf. Hakkila 1989). With regard to the functioning and productivity of harvesters, the following differences are of special significance:

1. In Brazil the company-owned *plantation forests form extensive continuous units*, thus offering considerable advantages to the procurement organization from the management point of view. The possibility of centralizing operations is particularly important when expensive machines are used, since operational delay time should be avoided and machine time should not be wasted on frequent moving from site to site. In large uninterrupted operations the proportion of effective time in machine utilization is increased and, consequently, time consumption and the capital input per unit volume of timber reduced. Supervision, transport of workers, machine service, scheduling of trucks, and measurement of timber are greatly facilitated. Furthermore, the organization is not burdened with timber purchasing obligations.
   In contrast, in Finland timber must be purchased mainly from private lands either standing or delivered to the road side by the forest owner. Forest holdings are small, and therefore the average size of a sale is only 340 m^3. Since several companies purchase timber from the same geographic area, the work sites of a specific company are scattered and force workers and machines to move frequently criss-

Figure 3. A 17-year-old pine plantation is being clear-cut in southern Brazil (Photo Jorge Malinovski).

cross from site to site. Only 7 % of the annual cut is harvested from company-owned lands (Hakkila 1989).

In Brazilian conditions, it should be possible to employ expensive machines for, say, 220–250 days annually, on average in 1.5 shifts, and thus reach an annual machine utilization of some 3000–3500 h. In Finland, owing partly to over-capacity, the average annual machine utilization was 1799 h for forwarders and 2175 h for multi-function machines in 1989–1990 (Jaakkola 1990a). Increase in the annual machine utilization reduces capital costs as calculated per cubic meter of timber.

2. The Brazilian plantations are monocultures of even-sized trees of one species (Figure 3). The *number of timber assortments* produced is typically 1–3 only, whereas native and man-made forests in Finland comprise a mixture of 2–4 species and produce 4–7 assortments of pulpwood, sawlogs, and veneerlogs at a time. Although forwarders and multi-function machines can be used to segregate different assortments apart, the productivity of the machines suffers. In otherwise equal conditions, the productivity of forwarders can be expected to be some 5–10 % higher if only one timber assortment is produced instead of four (Kahala & Kuitto 1986).
3. In Brazil the plantations are managed primarily for the production of fiber or bioenergy, whereas in Finland the ultimate goal is always high-quality timber for manufacturing lumber and plywood. Therefore, intermediate *thinning cuttings* are less common in Brazil but a must in Finland, where 30 % of industrial timber is harvested from thinning stands. Great care must be given in thinnings to the avoid-

ance of root and stem damage to the remaining trees. Norway spruce with its superficial root system particularly sets many restrictions on logging as regards planning, season, equipment, and operator skill. Although repeated thinnings may be a standard procedure in the pine plantations of many Brazilian companies too, and although regeneration of eucalyptus by coppicing requires protection of stumps from logging damage, restrictions concerning stand damage when selecting logging systems, equipment, and machine operators, are not as strict in Brazil as in Finland. Moreover, the emphasis being on clear-cuttings may facilitate the introduction of new technology. High annual productivity can be expected and less driver's skill is required when cutting takes place in a clear-cutting environment.

4. The Brazilian forest plantations are characterized by gentle *terrain* configuration, lack of large boulders, and good bearing capacity of ground, thus making year-round use of farm tractors possible. However, some of the plantations are in steep terrain and therefore unsuitable for conventional farm tractors.
   In Finland, although steep slopes are uncommon, the terrain conditions are more difficult for farm tractors in other ways. Stones and large boulders are frequent, the thickness of snow cover is 50–100 cm during mid-winter, and as much as 24 % of the productive forest area is soft peatland (Eeronheimo 1991), where the use of wheeled tractors is advisable only when the ground is frozen in the wintertime. Farmers' delivery sales excluded, off-road transport is therefore carried out mainly by forwarder-type forest tractors which have high performance and the ability to operate on slopes of up to 30–40 %.
   The prime movers for the Finnish multi-function machines are similar to or developed from the forwarder equipment. Accordingly, they have about the same capability to move in rough terrain. As regards farm tractors equipped with a crane-mounted one-grip harvester head, they are affected by difficult terrain less than farm tractors hauling a loaded trailer. Since the multi-function machines do not carry a heavy load of timber, they cause less soil compaction in cutting than do farm and forest tractors used as transport vehicles.
5. Among the Brazilian companies who returned the questionnaire, *the yield of timber* from final cuttings was 240–760 m^3/ha for pine and 115–320 m^3/ha for eucalyptus. In southern Finland the average yield, composed of several timber assortments, is 59 m^3/ha from later thinnings and 219 m^3/ha from final cuttings (Eskelinen 1988). Since the productivity of work increases with timber yield per unit area at least up to a certain point, this factor also favors the Brazilian operations and may give a productivity advantage of 10 % to harvesters and 5 % to forwarders as compared to Finland (Lindroos & Örn 1991).
6. In Brazil, *average size of a stem* in final cutting is according to company 0.20–0.80 m^3 for pine and 0.08–0.30 m^3 for eucalyptus, depending on the growth rate, rotation cycle, spacing, and number of preceding thinnings. In pine plantations especially, there is little underbrush to disturb the machine operators. Within a company the

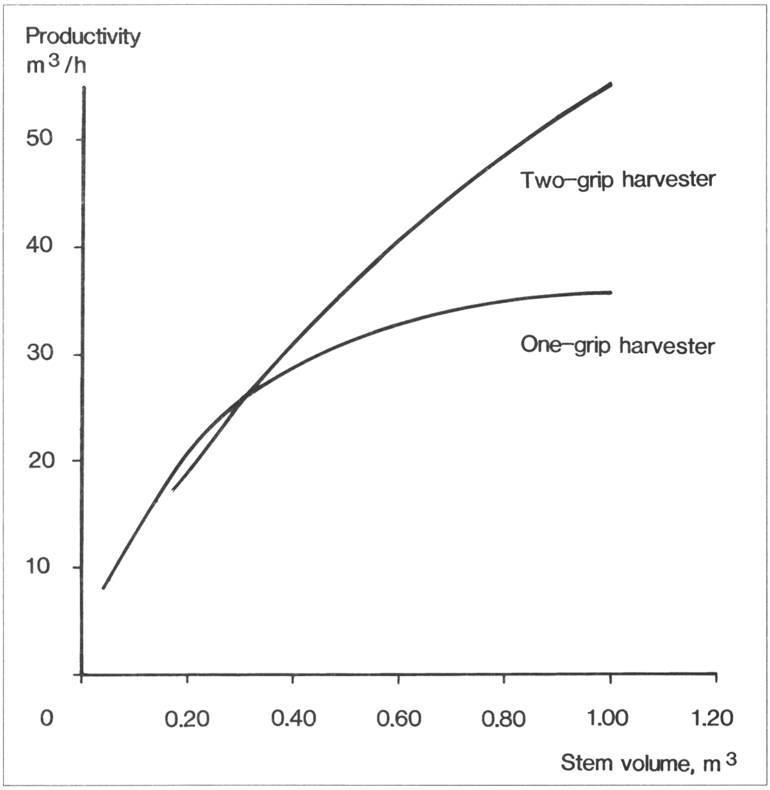


Figure 4. A descriptive example of the effect of stem volume on the productivity of typical one-grip and two-grip harvesters in Finland as expressed in m^3 per effective hour. Interruptions excluded. Data from Lilleberg (1990) and Rieppo (1990).

tree size is fairly even, making it easier to select a multi-function machine with the optimum capacity as regards performance and capital investment.

In southern Finland the average volume of trees is 0.11–0.12 m^3 in late thinnings (Lilleberg & Raitanen 1989) and 0.2–0.7 m^3 in final cuttings. However, the size range around the average tree in the same logging site tends to be wide; while the volume of the smallest merchantable stem may be only 0.02 m^3, the largest stem logged from the same stand may be 2 m^3. Consequently, the dimensioning of a multi-function machine is a compromise. It follows that in final cuttings the largest trees must frequently be left for cutting by chainsaw. Figure 4 presents an example of the productivity of two different harvesters when clear-cutting Scots pine in Finland. Each machine has an optimum tree size range where its economic competitiveness is greatest.

7. Qualitative differences in important *tree characteristics* between the Brazilian plantation timber and the Finnish timber seem to be minor as regards the functioning of harvesters. Smooth operation of a harvester requires rather straight stems. Finnish hardwoods tend to be too crooked and their branches too sharp-angled for the delimbing device of multi-function machines, whereas Brazilian eucalyptus trees are characterized by a straighter and more symmetrical stem. The stem form of eucalyptus should not cause insurmountable prob-

lems, although the sharpness of the branch angle may lower the delimbing quality of top logs.

Experiments with the Finnish Lako harvester in *Pinus radiata* plantations in New Zealand show that the diameter of branches is an indicative criteria for the suitability of a multi-function machine in a given stand. The Lako harvester performed best when the branch diameter of pine was less than 4 cm. More heavily branched trees were often difficult and at times impossible to delimb. Productivity of feed roll processing dropped 30–40 % for malformed trees with branches over 6 cm (Raymond et al. 1988). Thus, to allow uninterrupted infeed of stem through a delimbing device, branches should not be thicker than 50–60 mm, depending on the equipment, and in no case thicker than 70 mm. The stroke delimbing principle is less sensitive to stem straightness and branch thickness than the feed roll processing, although in trees with moderate branch thickness the latter is generally more productive.

From the technical point of view, conditions in the Brazilian plantations are thus favorable for mechanized logging systems based on modern Finnish technology. A serious technical disadvantage, especially in off-road and on-road transport, is currently the short length of pulpwood bolts. To take full advantage of rationalization and new technology in the forest, on the road, and at the mill, the length of pulpwood logs must be increased considerably.

4. Technology of timber harvesting in Brazil

The harvesting of plantation timber was started in Brazil with technology originally developed for native forests. This technology was soon found inappropriate and had to be modified or replaced by other alternatives. Depending on the labor supply, infrastructure, capacity to invest, available equipment, and forest management, each company tried to develop a harvesting system most suitable for its specific conditions. As a result, great differences are today found between companies as to the methods applied, productivity and cost of harvesting (Malinovski 1990).

Where the trafficability of terrain allows, the off-road transport of timber is based on the use of tractors. However, in steep terrain tractor transport must be complemented with or replaced by cable yarding despite its lower productivity and higher operation costs. Since tractor haulage is prevailing in Brazil and exclusive in Finland, cable yarding technology is left outside the present study.

The major system options are presented below, although it should be emphasized that details vary from case to case:

— In the *whole-tree system* the trees are felled with a chainsaw or feller-buncher and then dragged with a skidder, on or partially off the ground, to the road side with branches intact. Delimbing takes place after the off-road transport at the landing, primarily by pushing the load with a backing skidder through a simple steel grating called delimbing gate. Bucking to assortments is made with a chainsaw either at the landing prior to truck transport or alternatively at the mill yard. This system is used mainly for harvesting pine.

— The *tree-length system* is identical to the former except for delimbing being carried out with a chainsaw at the stump. The use of the system is restricted to pine plantations. Compared to the equipment used in the new developed log-length systems, whole-tree and tree-length skidders are usually simpler and therefore require less professional skills from the operators and mechanics.

— In the *log-length system* both delimbing and bucking to assortments are carried out at the stump with a chainsaw. Timber is transported to the landing with load-carrying tractors, i.e. forwarders, which are either self-loading or loaded with a separate tractor. In level, bearing terrain even trucks may drive directly to the stump for loading so as to combine off-road and on-road transport. The log-length system is used almost exclusively in the eucalyptus plantations, but is less common in pine plantations.

41. Techniques and productivity of cutting

Timber is harvested from pine plantations primarily by using *motor-manual cutting and the tree-length system*. The cutter is then responsible for felling and delimbing the trees with a chainsaw for subsequent ground skidding, but not for bucking the stems. In the first thinnings the small stem volume reduces the cutter's productivity to 11–12 m^3 per man-day. When the stem volume increases to 0.20 m^3 and further to 0.50 m^3, the productivity of combined felling and delimbing grows to 23 m^3 and 40 m^3 per man-day correspondingly.

Felling for whole-tree skidding can be mechanized with the Brazilian-made three-wheel Implenor Bell *feller-buncher*, which achieves a productivity of 1000–1100 trees of 0.50 m^3 or 500–550 m^3 during an eight-hour shift, thus replacing some 10 chainsaw operators. An advantage of the feller-buncher is that it collects trees into proper skidder loads, thus increasing the productivity in skidding (Figure 5).

When *the log-length system* is used, as is the case usually in eucalyptus plantations, the chainsaw operator carries out all the phases of cutting at the stump: felling, delimbing, bucking, and some bunching (Figures 6 and 7). Skilled cutters use mainly a chainsaw, but the ax is also used quite frequently for delimbing. A team of two workers, one felling and bucking with a chainsaw and the other delimbing with an ax, is a common work arrangement. Considerably less effort is required for delimbing eucalyptus than

Figure 5. Implenor Bell feller-buncher in a late thinning operation in Brazil (Photo Jorge Malinovski).

Figure 6. The log-length system in a clear-cutting operation of a eucalyptus stand in Brazil. A team of two cutters, one using a chainsaw and the another using an ax (Photo Jorge Malinovski).

pine, the former having a shorter crown and thinner branches. A typical productivity level in cutting eucalyptus wood for fiber is 13 m^3 per man-day for 0.10 m^3 trees and 16 m^3 per man-day for 0.17 m^3 trees. The productivity remains considerably lower in energywood operations owing to undeveloped work methods, inexperienced temporary workers, and less efficient management and work organization.

42. Techniques and productivity of off-road transport

In Brazil, the off-road transport of plantation timber is based primarily on the use of conventional 60–90 kW farm tractors. Their technical performance and reliability are usually sufficient in the prevailing gentle terrain conditions. Some small enterprises and contractors may use oxen or horses. In steep terrain mules and even manpower are still used to carry energywood to the roadside.

Farm tractors can be equipped either for ground skidding full trees and stems or forwarding logs, depending on the harvesting system applied. Skidders are able to operate on somewhat steeper slopes than forwarders. A simple skidding device is composed of *a steel bar attached to the three-point linkage* of a farm tractor, and a set of 1.2–1.5 m chains for tying the load to the bar (Figure

Figure 7. Manual bunching of pulpwood logs in a clear-cutting site of eucalyptus in Brazil (Photo Matti Sirén).

8). A more efficient alternative is *a grapple skidder*, which can even combine haulage and delimbing simply by backing its load of whole trees through *a delimbing gate* at the landing site (Figure 9). The delimbing result is then better for *Pinus elliottii* than for *Pinus taeda*, since the former has thinner branches and a more obtuse branch angle. When working in steep terrain, the farm tractor can be equipped with a winch and tower for cable yarding (Figure 10).

In the log-length system *a farm tractor hauls a load-carrying trailer*, which is seldom self-powered but usually equipped with brakes (Figure 11). Few companies use Brazilian-made *special*

Figure 8. Simple Brazilian equipment for ground skidding. A steel bar with a set of chains attached to the three-point linkage of a Massey Ferguson farm tractor. The driver is not protected with a safety frame (Photo Pentti Hakkila).

forest tractors (Figure 12). The load size is 7–10 m^3 for a farm tractor and 10–12 m^3 for a forest tractor. In pulpwood operations the farm tractor has an average productivity of 11–12 m^3 per machine hour and 21 500 m^3 per year, whereas in energywood operations the productivity remains considerably less, 7–8 m^3 per machine hour.

Farm tractors in Brazil are only seldom self-loading. *Separate loader tractors* or, in some energywood operations, even manual labor is used for loading and unloading forwarder-type farm tractors. Large centralized operations and a high removal of timber per hectare improve the competitiveness of separate farm tractor-mounted boom loaders. The longer the distance of transport, the more feasible is the use of a separate loader, although the option is applicable only in clear-cuttings. Freed from the boom loader, the transport vehicle becomes lighter, which allows a larger load of timber and may seem to reduce soil compaction. On the other hand, separate loaders themselves are a cause of soil compaction as they move back and forth on the site. Since a loader tractor typically serves 3–4 transport tractors, the system tends to increase the interdependence of machines, thus creating an extra link in the harvesting schedule.

Furthermore, the efficient operation of separate loaders initially requires manual bunching. Since bunching is physically strenuous and frequently a source of back complaints amongst the cutters, it may become necessary to compromise over the requirements of manual bunching, especially if the length of pulpwood logs is to

Figure 9. A grapple skidder, equipped with a safety frame, delimbing whole pine trees by backing its load through a delimbing gate at a landing site in Brazil (Photo Jorge Malinovski).

Figure 10. A cable yarding system. Winch with return cable mounted on a Massey Ferguson farm tractor in a Brazilian pine plantation in steep terrain (Photo Jorge Malinovski).

Figure 11. A Valmet farm tractor equipped with a safety frame, trailer and crane for off-road transport in Brazil. (Photo Jorge Malinovski).

Figure 12. A four-wheel Engesa forest tractor forwarding long pulpwood logs of eucalyptus in Brazil (Photo Jorge Malinovski).

Figure 13. Loading a Volvo timber truck with a separate tractor at the logging site in Brazil (Photo Jorge Malinovski).

be increased. In Finland the strenuous nature of manual bunching used to be a serious disadvantage with the log-length method until the problem was largely, if not totally, solved during the early 1980s through the development of long-reach booms for forwarders.

A specific log-length harvesting option for easy terrain integrates off-road and on-road transport by *driving a truck directly to the stump* (Figure 13). Loading at the stump takes place usually with a separate tractor-mounted loader, but manual loading of trucks is not uncommon in the transport of energywood. Since the use of a truck trailer is then not possible, load size remains small and, therefore, the distance from the plantation to the mill may not be long.

43. Techniques and productivity of trucking

The average trucking distance varied from 30 to 220 km amongst the pulp companies interviewed. For energywood the average distance was between 10 and 55 km according to company. Transport distances are expected to grow slightly with increasing wood demand toward the end of the century.

Trucking is possible year-round. However, heavy rains may temporarily interrupt trucking, on average for 3 weeks annually. Energywood producers seem to be affected more than pulpwood producers, probably as a result of the lower standard of roads. In

Figure 14. A heavy Volvo truck, equipped with two Randon trailers, hauling eucalyptus pulpwood in Brazil (Photo Jorge Malinovski).

one charcoal company the total time of transport interruptions was 12 weeks per year. The roads require constant maintenance, which adds some 5 % to the total cost of harvesting.

Pulpwood trucks are usually equipped with one or even two trailers (Figure 14), whereas fuelwood trucks (Figure 15) are lighter. *The maximum allowable mass* of the most common types of timber trucks is seen in Figure 16. For example, it is 15 tonnes for a 2-axle truck without a trailer and 62 tonnes for a 7-axle unit of a truck and two trailers. When transport is restricted to private company roads, a truck with two trailers may be given a special permit for a total mass of as much as 76 tonnes. The maximum height is 4.4 m (Decreto... 1968/1978). Table 4 shows the actual average volume of timber per load and the proportion of timber arriving at the mill with different types of truck in the interviewed companies.

It is uncommon that trucks are equipped with a crane for self-loading. Therefore, pulp companies use *separate tractors for loading* trucks at the landing, while *manual loading* at the stump is still a common practice in energywood operations.

Unloading at the mill is done with front-end loaders, boom loaders, or bridge loaders. To reduce delay time, some companies employ extra trailers. The truck then only changes a loaded trailer for an unloaded one at the mill and returns immediately for a new load. Changeable truck pallets are also used.

In pulpwood operations *the truck crew* consists usually of the driver only, but an assistant is used often to straighten logs when

Table 4. The average load volume and the proportion of timber arriving at the mill by different types of truck amongst the companies interviewed.

Type of timber	Truck without trailer	Truck + semitrailer	Truck + full trailer	Truck + 2 full trailers
	Average load volume, m^3			
Pine pulpwood	17	..	49	66
Eucalyptus pulpwood	18	..	50	66
Eucalyptus energywood	11	..	..	..
	Type of equipment, %			
Pine pulpwood	57	6	3	34
Eucalyptus pulpwood	42	36	8	14
Eucalyptus energywood	97	3	0	0

sawtimber is loaded. In energywood operations, on the other hand, the driver may have several assistants if loading takes place manually at the stump.

Trucks may operate in one, two, or even three shifts and have *an annual machine utilization* from 2000–5000 h, depending on the company and its work organization. Only in energywood operations does the average annual machine utilization tend to remain less than 2000 h. The following figures indicate the annual productivity of different types of truck in pulpwood operations:

	Average transport distance, km	Average productivity, m^3/year
Trucks without a trailer	45	17000
Trucks with a semitrailer	190	15500
Trucks with a full trailer	136	21100
Trucks with two full trailers	72	65000

The annual productivity of a given type of truck is a function of the machine utilization, loading and unloading equipment, transport distance, road conditions, and overall efficiency of the organization. Therefore, differences in the above figures do not purely reflect the performance and capacity of the transport equipment itself. For example, the high annual productivity of the units formed by a truck with two trailers is not due to the large load size and shorter than average transport distances only, but is also affected by high annual machine utilization, efficient loading, and smooth operation of the organization.

Figure 15. A Mercedes Benz truck hauling eucalyptus fuelwood for charcoal production in Brazil (Photo Jorge Malinovski).

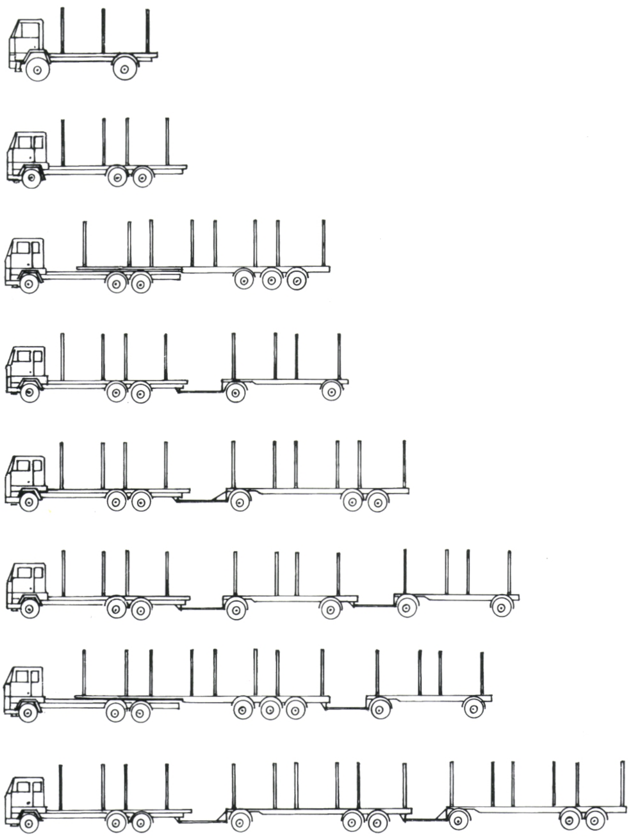
44. Comparison with Finland

441. Background of the Finnish technology

In Finland and other northern European countries harvesting is based entirely on the log-length system, which has achieved such unanimous acceptance that the share of all other alternatives is less than 1–2 % of the total timber harvest. The whole-tree and tree-length systems were abandoned during the early 1970s almost totally.

The most distinctive feature of *the log-length system* is the use of load-carrying, self-loading forwarders for the off-road transport of timber (Figure 17). Hence, an essential precondition for economical operation is that pulpwood is cut to at least 3 m but preferably to 5 m lengths. The superiority of the system in the Finnish conditions is a result of the following factors:

1. About 30 % of all timber is harvested from *thinning cuttings*, where the risk of stand damage is reduced through bucking the stems to final assortments prior to transport. The argument may not be of equal general significance in Brazil, since thinning cuttings are restricted to pine plantations only. On the other hand, if the production of saw timber is increasingly accepted as the ultimate goal of management of pine plantations in the future, thinning cuttings and avoidance of stand damage will definitely gain in importance.



Allowable maximum mass, tonnes	
5 +10	15
5 + 17	22
5 + 10 + 25,5	40,5
5 + 17 + 10 + 10	42
5 + 17 + 10 + 17	49
5 + 17 + 10 + 10 + 10 + 10	62
5 + 17 + 25,5 + 10 + 10	67,5
5 + 17 + 10 + 17 + 10 + 17	76

Figure 16. The maximum allowable axle and total mass of different types of timber trucks in Brazil.

2. The size of removed trees is rather small in Finland: 0.05–0.06 m^3 in the first commercial thinnings, 0.11–0.12 m^3 in later thinnings, and 0.2–0.7 m^3 in final cuttings. With such *a small stem volume* ground skidders cannot build sufficient loads, whereas load-carrying forwarders are rather immune to the stem size. In the Brazilian plantations, especially in the early thinnings of pine and even final cuttings of eucalyptus, tree size is commonly less than 0.2 m^3 and only seldom larger than 1.0 m^3. Therefore, in Brazilian plantations also the small stem volume favors the use of the log-length system.
3. Since forwarders move more slowly, have a better load balance, and have a larger number of wheels, their drivers are less exposed to whole-body vibration and *occupational diseases* than are skidder drivers. This is of utmost importance in Finland, where uneven ground surface and abundance of boulders characterize the forest terrain, and where the labor legislation and ergonomic requirements are strict. In the Brazilian plantations ground obstacles are less frequent and labor legislation more liberal. Consequently, in Brazil this observation is for the present less critical, although not totally irrelevant.

Figure 17. In Finland the log-length system is characterized by the use of load-carrying, self-loading special forwarders for off-road transport. A Valmet 862 forwarder hauling birch veneer logs (Photo Erkki Oksanen).

4. Owing to the small size of private forest holdings, on average about 40 ha, shortage of proper landing areas is often troublesome in Finland. Self-loading forwarders reduce *the landing area requirement* radically, since they are capable of storing timber on the roadside in up to 4 m high piles. This is a noteworthy issue in Finland but hardly relevant in Brazil.
5. In the log-length system the forwarders sort and pile the timber at the landing according to assortment, the number in Finland usually ranging from 4 to 7 per logging site. Preceding sorting and piling by forwarders makes it easy for the trucks to deliver *different assortments flexibly to different destinations* as required. Forwarders thus minimize the handling of logs. The hot schedule is broken through cold decking, loading time is reduced, criss-cross transport is avoided, and subsequent handling of timber at the mill yard becomes easier. As long as only a single timber assortment is produced, as is often the case in Brazil, sorting is naturally not needed. If, however, pulpwood and sawlogs are separated in order to maximize the product value, the possibility of using forwarders for sorting in conjunction with haulage will probably reduce the cost of timber handling at the landing and at the mill. The use of forwarders also prevents the timber from soiling. The log-length system may thus allow a cleaner timber product and better value utilization of wood.

In Finland the technical logging conditions are generally more difficult than in the Brazilian plantations, steep terrain excluded. However, the productivity and safety of chainsaw operators has been greatly improved through vocational training, careful work organization, protective clothing, and other safety measures. At present, in an early thinning of a pine stand the average productivity of a chainsaw operator is about 11 m^3 and in a final cutting 22 m^3 per man-day. The average annual productivity of a chainsaw operator is 2500–3000 m^3. However, since the wages are high and the supply of forest labor is declining, mechanization of cutting is seen as necessary.

Increasing the pulpwood length from 2 m first to 3 or 4 m, and later commonly further to 5 m has been a necessary precondition for rationalization and improved productivity throughout the harvesting system since the early 1960s in Finland. The necessity to increase the bolt length is recognized in Brazil as well. Most if not all companies plan going to up to 5–8 m pulpwood lengths by the year 2000. Aracruz Florestal S/A already uses 6 m lengths for eucalyptus pulpwood. If the expected development materializes to a significant extent and the harvesting systems are adapted accordingly, the productivity of chainsaw operators, multi-function machines, transport vehicles, and mill-yard handling equipment can be improved considerably. On the other hand, manual bunching of timber becomes even more strenous and difficult, if not impossible, and must be replaced by other means.

442. Fully mechanized log-length system in Finland

As tractors replaced horses in off-road transport in the 1960s in Finland, multi-function machines are similarly replacing chainsaw operators in the 1990s. Two main categories of multi-function machines can be distinguished: *processors*, which delimb and buck but do not fell the trees, and *harvesters*, which are also capable of felling and thus represent the fully mechanized cutting of timber.

Harvesters again are divided into two groups. *Two-grip harvesters* 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. *One-grip harvesters* use a same relatively light, crane-mounted processing device for both felling and subsequent delimbing and bucking.

The first multi-function machines in Finland were processors, although since the mid-1980s processors have not been cost-competitive compared to harvesters. Therefore, practically all multi-function machines sold today are harvesters (Figure 18). Amongst the Finnish harvester fleet, one-grip harvesters are the most common (Figure 19). Their advantages are lower investment costs and flexibility, so that they can be used in all kinds of stands from first thinnings to clear-cuttings. The annual production of a one-grip harvester is 20 000–30 000 m^3 in later thinnings and up to 40 000 m^3 in clear-cuttings, i.e. ten times as much as the

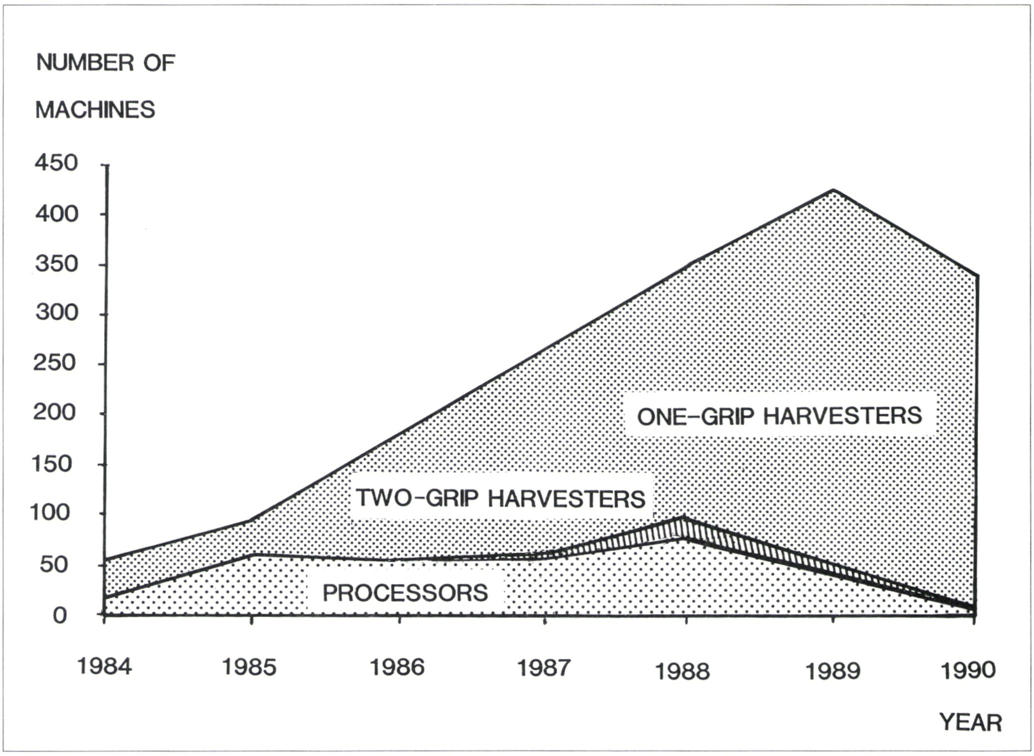


Figure 18. The number of one-grip harvesters, two-grip harvesters, and processors sold in Finland annually during 1984–1990 (Säteri 1991).

productivity of a chainsaw operator.

Moreover, one-grip harvester heads can be easily *mounted on standard farm tractors or excavators* as long as the base machine is equipped with an engine of sufficient power and a hydraulic boom loader (Figures 20 and 21). When average stem size exceeds about 0.4–0.5 m^3, two-grip harvesters become cost-competitive with one-grip harvesters despite their higher capital costs (Figure 4). Thus, the use of two-grip harvesters is profitable in clear-cuttings when trees are large, although these robust machines are less suitable for thinnings.

The technical availability of modern harvesters exceeds 80 %. Their ergonomic properties are excellent, and the ecological result meets requirements. Furthermore, harvesters also *perform volume scaling* of timber through a computerized measuring system at low cost and with sufficient accuracy. However, due to the high operation speed and restricted visibility, optimum bucking of sawlogs remains problematic.

Multi-function machines are *sensitive to stand conditions*. Stem size, removal of timber per unit area, spacing of the remaining trees, disturbing underbrush, stem form, excessive branchiness, and terrain greatly affect their productivity. Since the total time consumed by a harvester for felling and processing a single tree does not depend very closely on the size of the stem, the volume output in cubic meters per hour increases sharply with stem size.

Figure 19. FMG 990 one-grip harvester in a late thinning cutting of a mixed spruce and pine stand in Finland (Photo Pentti Hakkila).

The feed rate of a stem through the delimbing device is in normal operation 3–5 m per second, but thick branches of large trees may cause problems to the delimbing device resulting in interruptions and reduction of productivity.

In the Nordic log-length system, timber is hauled to the road-side with *load-carrying forwarders*. The most common forwarder in Finland is a special forest tractor with a machine mass of about 10 tonnes, load capacity of 10 tonnes, and a hydraulic 10-m-reach crane. Lighter and heavier forest tractors are also used, although the share of the 10-tonne size class was 70 % of the Finnish forwarder market in 1990 (Säteri 1991). Conventional farm tractors equipped with forest auxiliaries such as a winch, hydraulic crane, and self-propelled trailer are used as forwarders by temporary contractors and self-employed forest owners when selling timber delivered to the road-side.

Finnish forwarders meet high ergonomic and environmental requirements. Their balanced load distribution, bogie axles, and 600 or 700 mm wide tires radically reduce soil compaction (Sirén et al. 1987). Their productivity is 8–15 m^3/h depending on external conditions, and the technical availability is over 90 %. However, the annual output is not more than 15 000–25 000 m^3, since the over-capacity of the tractor fleet means that a forwarder works less than 2000 ha year. Good profitability would require at least 10–20 % more operating hours annually.

The hydraulic crane makes off-road transport typically an independent one-man operation. Owing to the long-reach boom of the

Figure 20. A Patu one-grip harvester head mounted on a Fendt farm tractor. Early thinning of a pine stand in Finland (Photo Seppo Ryynänen).

Figure 21. A Lako one-grip harvester head mounted on an Åkerman excavator. Clear-cutting a mature spruce stand in Finland (Photo Arctic Forest Machines).

forwarder, in final cuttings in particular, the cutter is not required to do much bunching. High piles made by the forwarders at the road-side allow fast loading of trucks, and forwarders themselves can be used for truck loading.

In Brazil the plantation timber is transported to the mill primarily by truck. In Finland the long-distance transport similarly always starts with a truck, although over longer distances the *truck transport* is often continued by rail or floating. The maximum allowable total mass of a 7-axle truck and trailer unit is 56 tonnes in the summer and 60 tonnes in the winter when the ground is frozen.

Timber trucks are typically equipped with a full trailer and detachable hydraulic boom loader. However, if the hauling distances remain less than 60 km on average, it is advantageous to install a non-detachable crane on the truck. Only when the distances are long and the work sites large does it become economical to use a separate loader in Finland (Korhonen & Oijala 1991).

443. Comparison of productivity

The efficiency of timber harvesting in Brazil and Finland can be compared from the aspect of *system productivity*. However, it should be emphasized that efficiency can not be judged only on the basis of productivity in cubic meters per man-day. Cost of harvesting and considerations such as work safety in its broad sense, environmental damage, and sustaining the production capacity of a stand and the forest soil must also be taken into account.

The productivity of a harvesting system, as measured in cubic meters per man-day, depends on technical logging and transport conditions, technology applied, degree of mechanization, skill and motivation of the workers, organization, overall management, etc. Thus, it is determined partly by factors outside the control of the logging organization.

Table 5 shows time consumption in different phases of harvesting in Brazil and Finland and, correspondingly, the overall system productivity. As regards Brazil, the table refers to pulpwood harvesting from plantations, whereas energywood plantations with their much less efficient operations are excluded. As regards Finland, the table refers primarily to clear-cuttings and late thinnings, while the less productive early thinnings and the operations of the self-employed private forest owners are not included. Variation in productivity between logging systems, and even within them, is wide both in Brazil and in Finland. Since the relative frequencies of different harvesting solutions are not known, estimates of average productivity are not presented.

Although technical logging conditions are usually more favorable in Brazil, the system productivity is higher in Finland. This is a result of several factors: the chainsaw operators are better trained and they work exclusively on a piece rate basis; the degree of

Table 5. Estimated time consumption and overall system productivity of harvesting from Brazilian pulpwood plantations as compared to the motor-manual and mechanized log-length methods in final cuttings in Finland.

Operation	Motor-manual pulpwood operations in Brazil	Motor-manual log-length system in Finland	Mechanized log-length system in Finland
	Time consumption, man-days/m^3		
Cutting	0.071	0.054	0.006
Off-road transport	0.017	0.011	0.010
Trucking	0.025	0.017	0.017
Supervision	0.010	0.011	0.005
Auxiliaries	0.025	0.010	0.005
Total	0.148	0.103	0.043
	System productivity, m^3/man-day		
Total	6.7	9.7	23.3

cutting mechanization is considerably higher; off-road transport is carried out with special forest tractors and no additional equipment and workers are needed for loading and unloading; the trucks are self-loading and equipped with a large trailer; the technical and operational availability of machines is higher; and, particularly, considerably less assisting labor is needed for supporting services.

Replacing chainsaws with a harvester-type multi-function machine increases the productivity per man-day of cutting tenfold in Finland. It also results in a 5 % increase in the productivity of off-road transport owing to the better bunching of timber. Furthermore, the mechanization of cutting makes it possible to reduce the supervising, measuring, and assisting staff. Consequently, cutting mechanization raises the overall system productivity from stump to mill in the Finnish final cuttings from roughly 9.7 m^3 to about 23.3 m^3 per man-day.

Since technical logging conditions in Brazil favor mechanization, an increase more than tenfold in the productivity of cutting and more than doubling in the overall system productivity of 6.7 m^3 per man-day could be expected through the introduction of harvester-type multi-function machines. A further increase in the system productivity could be achieved by making the off-road transport basically a one-man operation through the use of self-loading forwarder equipment.

The answers received in the present study from energywood producers are not sufficient to draw conclusions regarding average productivity. Variation between companies seems to be wide. Some energywood operations may still rely on the use of the ax for cross-cutting, an ox or mule for haulage to the road-side, and the manual loading of light 2-axle trucks, while others are using rather developed methods and organization. Generally, mechanization in energywood operations could lead to even greater increases in productivity, although social, organizational, and infrastructure constraints probably currently form an insurmountable obstacle to the introduction of high technology in energywood plantations. However, the situation may change when an existing operation is expanded significantly or a totally new large-scale operation is established.

5. Cost of timber harvesting in Brazil

In addition to the direct costs, issues such as reliability of deliveries, work safety, dependence on labor unions or machine service, or flexibility in increasing or reducing deliveries in accordance with seasonal or market fluctuations are also taken into account as cost factors when selecting a harvesting system. On the other hand, social and environmental considerations must not be ignored either.

Changing exchange rates, inflation, and differences in the economic structure impede cost comparisons between countries with different socio-economic backgrounds and different enterprise cultures. To make the costs commensurable, in the present study all cost data was converted to US dollars. The Brazilian companies were asked to give the cost data directly in US currency in May 1990. For the cost data from Finland, the average exchange rate was the 4.4 marks to one US dollar during December 1991.

51. Cost of labor

Availability of forest labor varies between geographic areas of Brazil. Generally, there is a large surplus of unskilled workers. The supply and demand for tractor and truck drivers are generally in balance, although shortages may occur locally. A slight shortage of skilled chainsaw operators, mechanics and particularly supervisors is common. Chainsaw operators and tractor drivers have received little vocational training, usually for less than one month and in no case for more than three months. The supply of forest labor is expected to decrease somewhat during the next five years.

The annual turnover of skilled forest labor is rather small in the pulp industries, generally below 5–10 %, although the assisting unskilled labor is an exception. In the charcoal industry, on the other hand, excessive turnover is a serious problem, with 40 % of chainsaw operators and over 20 % of tractor and truck drivers changing each year. The difference between the pulp and charcoal industries results from differences in wage scales, social benefits, the strenuous nature of the work and, finally, motivation of the workers.

According to employers, the average *effective working time* is 7–8 hours per day, 1800–2000 hours per year. Differences between forest industry groups are not great:

	Average daily working time	Average annual working time
	Hours	
Cutters	7.1	1812
Tractor drivers	7.7	1946
Truck drivers	7.6	1956

The basis of forest wages varies from company to company. Equipment such as chainsaws and tractors is owned by the employer, who is also responsible for their maintenance. Thus, wages do not include any compensation for tools or machines, as is the case in Finland. Time rate or a combination of time rate and piece rate are the principal options. Sole piece rate is quite common in cutting, but it is not used in transport:

Wage basis	Cutters	Tractor drivers	Truck drivers
	Proportion of companies, %		
Time rate	27	60	60
Piece rate	33	0	0
Combination	40	40	40
Total	100	100	100

Forest workers' wages clearly exceed the minimum salary required by law. The wages are higher in the pulp industry than in the charcoal industry. The latter often operates in less developed areas without many other employers competing for the labor. There the manual work is exceptionally strenuous, the level of mechanization low, the general appreciation of forest work low, and the unionization of workers weak.

Wage differences between occupational groups in forestry are distinctive. While unskilled workers in pulpwood harvesting earned in 1990 about US $ 5.1 per day, *the average earnings* of truck drivers were US $ 11.6 per day, the cost of social security excluded:

	Pulp industry	Charcoal industry
	Wage US $ per day	
Minimum salary by law	2.52	1.92
Earnings of:		
unskilled workers	5.09	3.32
chainsaw operators	8.10	5.98
tractor drivers	10.27	7.23
truck drivers	11.64	7.80

The additional obligatory fees for social security are about one third of the salary, covering primarily holidays, pensions, and some education. In addition, employers use considerable sums for voluntary social services that are available for the workers at low cost or totally free of charge. They may include housing, food, medical treatment, schooling, workers' clubs, transport, or security equipment. Consequently, the total *cost for social security* among the interviewed enterprises was 85 % in the pulp industry and 121 % in the charcoal industry.

52. Cost of machine work

The standard equipment for harvesting plantation timber in Brazil consists of chainsaws, farm tractors, and trucks with or without a trailer. Farm tractors are used as forwarders, ground skidders, and prime movers for boom loaders. Equipment such as feller-bunchers and forwarder-type forest tractors is used at present to a much lesser extent.

The daily working time of machines is a result of the organization rather than of the type of equipment. Forest machines work usually in one shift only. However, trucks and truck loaders often operate in two or even three shifts.

Owing to easy terrain conditions and shortage of capital, and particularly because there is practically no second-hand market for used forest machines, the *life-time of tractors and trucks* is long in Brazil. Long life-time also reflects efficient machine maintenance:

	Machine utilization	Life-time	
	h/year	Hours	Years
Farm tractors	2260	10600	4.7
Forest tractors	2470	13100	5.3
Trucks	3100	15500	5.0

Cost factors of machine work are composed of the interest and paying off the capital, service and spare parts, fuel and lubricants, drivers' and assistants' salaries, and other costs such as insurance etc. Because a part of the costs are fixed and must be paid even if the machine is not used, the cost per operating hour greatly depends on the annual machine utilization and the total life-time of the machine. The following table shows the *purchase price and hourly cost of the machines* used most commonly for harvesting and trucking pulpwood in Brazil in 1991:

	Typical purchase price US $	Typical operating cost US $/hour
Chainsaw	570–850	
Farm tractor-type skidder	50000–60000	23
Farm tractor-type forwarder*	70000–80000	29
Farm tractor-mounted loader	60000–70000	24
Forest tractor-type forwarder*	200000–220000	38
Feller-buncher	110000–120000	
Truck without trailer **	67000–80000	
Truck with semitrailer**	110000–150000	
Truck with 2 full trailers**	140000–170000	

* With a crane ** Without a crane

The structure of the machine costs varies between companies owing to differences in the proportions of own and foreign capital, annual machine utilization, drivers' salaries, efficiency of the organization, etc. A typical *cost structure* for forwarder-type farm tractors in pulpwood operations is as follows, although great variations occur:

	%
Amortization and interest	37
Service and spare parts	36
Fuel and lubricants	8
Drivers' salaries	13
Other costs	6
Total	100

The productivity of a harvesting system is affected by *the mechanical availability of equipment*, i.e. scheduled operating time minus mechanical delay time divided by scheduled operating time. It is also affected by *the operational availability of equipment*, correspondingly expressed as scheduled operating time minus operational delay time divided by scheduled operating time. In hot logging schedules, delay or technical failure of one machine tends to reduce the operational availability of another machine. In the questionnaire material, the technical availability of farm tractors was 70 % and that of trucks 85 %. The operational availability was unsatisfactorily 71 % and 69 %, an indication of long waiting times and the vulnerable interdependence of machines. Interruptions naturally increase the cost of harvesting.

53. Cost comparison between Brazil and Finland

Compared with Brazil, the cost of timber harvesting in Finland is substantially higher. This is a result of the higher cost level in Finland in general, as well as the more difficult technical logging conditions.

In the Brazilian pulp industries the average daily wage of a chainsaw operator was US $ 8.10 and the additional cost for social security another 85 % totalling US $ 14.99, the costs of chainsaws and other tools excluded. This is only 16 % of the daily cost of a chainsaw operator in Finland. In the Brazilian charcoal companies the workers' costs are even less. In Finland the costs for a chainsaw operator were composed in 1989 as follows (Metsätilastollinen... 1990):

	Cost of a chainsaw operator in Finland, US $/day
Wage of a chainsaw operator	59.53
Additional cost for social security (60 %)	35.72
Wage and social security	95.25
Compensation for chainsaw costs	21.10
Total cost of a chainsaw operator	116.35

According to the questionnaire material, the average cost of timber procurement for pine and eucalyptus pulpwood from stump to mill in Brazil was U.S. $ 12.55 per m^3, the stumpage price of timber excluded. However, it is possible that the cost of overheads and voluntary social services were not fully reported in the questionnaires. With the average trucking distance of 90 km, almost a half of the cost was incurred by on-road transport:

	Cost of pulpwood procurement in Brazil, US $/$m^3$
Cutting	3.04
Off-road transport	2.71
Loading of trucks	0.59
Trucking (90 km)	5.00
Road construction and maintenance	0.51
Other costs	0.70
Total	12.55

Because timber assortments and external conditions vary greatly from company to company in Finland, it is not feasible to try to calculate an average cost figure for all timber assortments. Instead, cost data for 0.2 and 0.4 m^3 Norway spruce trees in motor-

Table 6. An example of the harvesting and trucking cost of Norway spruce timber from final cutting when motor-manual and mechanized systems are used in Finland (data from Lindroos & Örn 1990, Laajalahti & Pennanen 1990).

Operation	Motor-manual systems		Mechanized systems	
	Stem volume, m^3			
	0.2	0.4	0.2	0.4
	Cost US $/m^3$			
Cutting	8.15	6.06	7.54	5.51
Off-road transport	4.99	4.71	4.72	4.28
Trucking, incl. loading	7.40	7.40	7.40	7.40
Planning, measuring	1.06	0.71	0.36	0.20
Supervising	0.40	0.34	0.21	0.19
Total	22.00	19.22	20.23	17.58

manual and mechanized cutting systems may offer a more feasible basis for comparison. The example in Table 6 presupposes clear-cutting conditions, the removal of 500 trees/ha, an off-road transport distance of 350 m, and a trucking distance of 90 km. Owing to its long live crown, a Norway spruce tree typically has a large number of branches and, therefore, a rather high cost of cutting.

In this indicative example, the total harvesting and trucking cost for Finnish spruce timber from clear-cutting operations is some 60–90 % higher than the average cost of pine and eucalyptus pulpwood from the Brazilian plantations if cutting is carried out by motor-manual methods. The use of one-grip harvesters lowers not only the cost of cutting but also the cost of planning, measuring, supervising and off-road transport. Although a reduction of 8 % takes place in the total cost due to cutting mechanization, the cost level still remains 50–75 % above that in Brazil.

Cutting mechanization means a radical shift from labor-intensive to capital-intensive technology. A one-grip harvester, designed for trees of up to 40 cm at the breast height and mounted on a specially designed base machine, has a purchase price of US $ 300 000–400 000 in Finland. However, separate one-grip harvester heads are also available for conventional excavators and farm tractors, which meet the engine and crane performance requirements. The price of an excavator-mounted one-grip harvester unit amounts to US $ 165 000–200 000, consisting of about US $ 110 000 for the base machine and the rest for the harvester head and necessary changes to the crane. For farm tractor-based one-grip harvesters the price range is wide depending on the equipment. The most expensive units, equipped with a special cabin for continuous forest work and an optional automatic volume measuring device, cost up to US $ 143 500, broken down as follows:

	Price, US $
Four-wheel drive, 60 kW tractor	55000
Long-reach crane	27000
One-grip harvester head	28000
Measuring device	9300
Special forest cabin	6500
Additional hydraulics	7900
Total	133700

The hourly cost and cost structure of a forwarder and special one-grip harvester is seen in Figure 22. The share of capital costs is 38 %, two thirds of which are composed of amortization and one third of interest on the capital. The driver's wages, maintenance and fuel are other large cost items. Chains and chain bars cause extra costs for harvesters. Since in Finland forwarders and harvesters are owned by private contractors, 4–5 % is added to cover the entrepreneur's risk.

The share of capital costs can be reduced with cheaper prime movers such as farm tractors and excavators. However, productivity is then reduced. In Brazilian conditions it might be possible to reduce the capital cost considerably by increasing the annual machine utilization from the average of 2200 h in Finland to up to 3000–3500 h. The driver's wage and social security costs, which in Finland comprise about 30 % of the total operating cost of forest machines, would also be substantially lower in Brazil. However, it should be emphasized that a precondition for the successful and profitable operation of a one-grip harvester is a skillful and motivated driver.

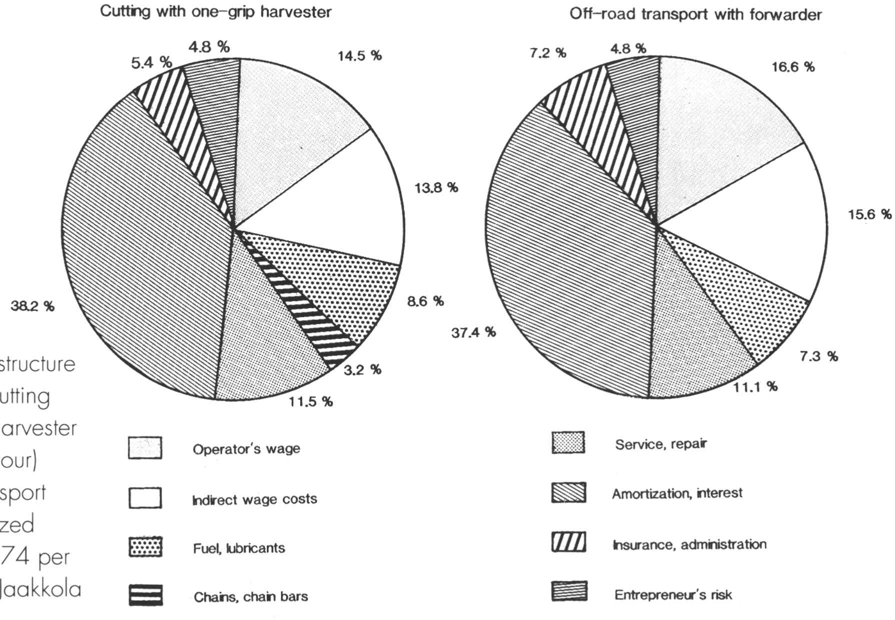


Figure 22. Cost structure of mechanized cutting with a one-grip harvester (US $ 102 per hour) and off-road transport with a medium-sized forwarder (US $ 74 per hour) in Finland (Jaakkola 1990b).

6. Possibilities for logging mechanization in Brazil

Exclusive of the fuelwood and charcoal companies, *harvesting technology in the Brazilian plantations has largely been transferred from northern Europe and North America*. It is well adapted to the prevailing socio-economic conditions, labor situation, and established infrastructure. The transfer of technology, its modification, and integration with traditional labor-intensive methods has been carried out with care.

The most developed forestry departments successfully apply logging schedules and work organizations which differ only slightly from those used in the leading forest industry countries of the northern hemisphere. The whole-tree and tree-length technology used in pine plantations is primarily from the southern United States, whereas the log-length technology in the eucalyptus plantations is typically northern European. As regards the latter, a seemingly minor but actually fundamental difference is that *log lengths are considerably shorter* in Brazil than in Finland or Sweden.

Another major difference is that in Brazil *special forest tractors are replaced by conventional farm tractors* owing to the easy terrain conditions, lower investment costs and, partly, protective trade policy. An emerging, even more distinctive difference is the *lack of harvesters* and other multi-function machines, which at the moment are revolutionizing timber harvesting in northern Europe. However, differences occur between pulp companies in the equipment and efficiency of logging, and the majority of charcoal companies continue to use rather unsophisticated equipment and strenuous, labor-intensive methods.

61. Performance of the present technology in Brazil

Owing to the favorable operational environment, low cost of manual labor, and relatively high productivity of work, *the total cost of harvesting* in the Brazilian plantations is one of the lowest in the world. Therefore, pressure to reduce costs through mechanization is by no means urgent. However, increases in the annual cut and decrease in the forest labor supply are expected to accelerate the growth of costs towards the end of the 1990s. The shortage of skilled chainsaw operators, machine drivers, and supervisors may become more severe and change the cost balance in favor of mechanization. Although higher skills would be required, the total demand for skilled workers would diminish.

In view of this development, logging organizations seem to be concerned about the growing strength of labor unions. Although the degree of unionization is still low, increase in the demand for forest labor will automatically stimulate wage development. As the direct and indirect costs of labor grows, mechanization will become more feasible. Less, although more professional, labor will then be needed.

Since Brazilian companies keep their timber inventories at landings and the mill yard as small as possible, labor unrest could disturb the flow of timber from stump to mill and thus cause costly interruptions in pulp and paper production. Mechanized systems could offer a buffer against labor unrest in the forests, especially if vulnerable hot logging schedules are avoided.

On the other hand, strengthening of the unions will undoubtedly stimulate much-needed *ergonomic development* of equipment and methods, improve work safety and motivation, and thus indirectly increase the system efficiency. Manual bunching of timber in particular is at present a strenuous phase in the log-length system, and with increase in the bolt length it will become even more problematic. The need for manual bunching could be reduced radically by making transport tractors self-loading with a long-reach crane, and naturally by using multi-function machines for felling, processing and bunching. The three-wheeled feller-bunchers used in conjunction with the whole-tree systems are cost-competitive, but not totally satisfactory from the ergonomic point of view.

The present technology allows a high degree of recovery of timber from the plantations. Only a small fraction of stem volume, mainly in the form of under-sized tops, is left as residue on the site. However, potential pine saw timber is used for pulping, leading to incomplete *value utilization* of the timber crops. Although the use of saw logs for pulping is by no means a direct result of improper logging technology, forwarders and the fully mechanized log-length system would probably make it easier to segregate high-quality saw logs from the timber flow to pulp mills.

Ecological considerations are gaining in popularity, not only in the industrialized countries but actually all over the world. In addition to wood production, other values inherent in the forest environment are becoming equally important. Timber harvesting is being watched more and more critically. For example, ecological problems linked with the extraction of timber from the native rain forests of Brazil are well known. On the other hand, the logging technology applied in the southern and south-eastern plantations does not generally create alarmingly adverse consequences such as erosion, impoverishment of soil, rutting, or excessive damage to standing trees. However, risk of erosion exists in steep terrain, and soil compaction may occur under feller-bunchers, transport tractors, tractor-mounted loaders, and trucks trafficking on the logging site.

Increasing attention will be paid in future to the appropriateness of new machines and methods to the forest environment. From this point of view, the latest forwarders and harvesters, although their machine mass may exceed ten tonnes, seem to offer a safe alternative with their reduced ground pressure, long-reach boom, improved load mass/machine mass ratio, and high load capacity. They travel less on the logging site, and owing to fewer machine passes tend to cause less ground disturbance than many lighter machines (Sirén et al. 1987). Compared to a combination of loader tractors and transport tractors in timber transport from clear-cutting areas of eucalyptus, a self-loading forwarder with a long-reach crane would cause less damage to soil and stumps and thus improve the coppicing of a new tree generation. However, it is necessary to emphasize that even environmentally sound equipment may cause devastation if the work is not planned and the machines not operated in the proper way. Therefore, training of the staff at all levels of the organization is a precondition for successful transfer of technology.

62. Lessons of the Finnish experience

Timber procurement is composed of three main phases: cutting, off-road transport, and on-road transport. Many European and North American off-road and on-road transport alternatives have been introduced and established in Brazilian plantation forestry, whereas fully mechanized cutting technology has not been holistically experimented with yet.

Replacement of motor-manual chainsaw technology by fully mechanized technology means an epochal change in the entire forest management system. Therefore, evaluation of the appropriateness of multi-function machines in any country will require much more than machine testing and short-term technological studies.

The Finnish experience in the development and introduction of multi-function logging machines during a period of over 20 years shows that much effort and time may be needed before such a completely new technology can be adopted and run smoothly. Technical development alone is not sufficient. Vocational training, inculcation of attitudes among all parties of forestry, and reorganization will also be necessary.

In Finland, the first multi-function machine prototypes were introduced in the late 1960s, but the progress of cutting mechanization was long and slow. The next two decades were a period of machine and method development during which all the major timber companies experimented with alternative technical options and simultaneously started cautiously integrating new advanced technology in their timber procurement organization. Although economic calculations showed the large-scale mechanization of cutting to be profitable as early as in the start of the 1980s (Eskelinen et al. 1978), for many reasons mechanization did not really gather pace until the late 1980s. The progress being slower than originally expected was largely caused by the following facts, some of which may be relevant in Brazil as well:

1. Owing to the high vocational skills of chainsaw operators and the motivating piece rate system for forest work wages, *motor-manual logging remained cost-competitive* longer than originally expected, especially in thinning cuttings. However, little by little the profitability of mechanization improved as the cost of manual labor increased faster than that of machines. The same development process will probably take place in Brazil, although since the wage cost of a chainsaw operator is still less than one sixth of the Finnish cost level, mechanization may not become feasible on a large scale before the turn of the century.
2. Since the total annual drain of timber from the Finnish forests did not increase significantly during the 1970s and 1980s, serious *shortages of chainsaw operators did not occur* except only temporarily and locally, although the availability of forest workers declined. Job opportunities for permanently employed cutters had to be preserved, and the introduction of multi-function machines was thereby delayed. In Brazil, on the other hand, the expected significant increase in the annual cut during the next few years will allow the introduction of capital-intensive systems without jeopardizing the employment of the companies' permanent forest workers.
3. About 30 % of all industrial timber in Finland is sold delivered to the road-side by *self-employed private small-farm owners*. These forest owners want to carry out the logging with their own light equipment, i.e. chainsaw and farm tractor, and naturally cannot afford to buy or hire expensive multi-function machines. Since very little timber is purchased in Brazil from small holdings, this constraint does not exist there.
4. In Finland about 30 % of all industrial timber is extracted from *thinning cuttings* where the remaining stands are treated for the production of high-quality saw timber. Therefore, damage to remaining trees and forest soil must be kept as low as possible, particularly in spruce and birch stands. The first- and second-generation multi-function machines were too large and clumsy to allow their use in thinning conditions. It was not until the mid-1980s after the introduction of one-grip harvesters that it became technically possible to mechanize thinnings without adverse environmental consequences. Since the latest one-grip harvesters are now suitable for thinnings,

since the exotic pines in Brazil have a deep root system and are rot-resistant when wounded, and since the role of thinnings is of less importance in Brazil, this constraint will not delay the mechanization process in Brazil.

5. Silvicultural operations, such as planting and pre-commercial thinning, are still performed by labor-intensive methods in Finland. Chainsaw operators form the only source of labor temporarily available for these seasonal activities during the summertime. Thus, for forest management reasons it is necessary for a sufficient share of the cutting to remain motor-manual so as to ensure the availability of the *manual labor force for silvicultural operations*. In Brazil, similar shortages of labor for silvicultural activities is not foreseen.
6. Multi-function machines are expensive and apply high technology. Economic operation and reliable maintenance require skillful and dedicated drivers. *Shortage of trained drivers* was long a serious bottleneck on the way toward large-scale cutting mechanization in Finland. Special training courses for multi-function machine operators were only started in 1989. Undoubtedly, lack of experienced drivers and machine technicians might become an even more serious drawback in Brazil, unless training is started in advance.
7. In Finland the forest machines are owned by private contractors rather than by the forest industry enterprises themselves. Particularly in the initial phase of cutting mechanization, *risk of fast technical obsolescence accompanying rapid machine development* and uncertainty of machine employment threatened the contractors. Consequently, small entrepreneurs were reluctant to invest in expensive equipment as long as there were no guarantees in long-term employment and no established practice for logging systems applied, machine performance required, and wages to be paid. In Brazil the forest machines are traditionally owned by the forest industry companies themselves, and thus the initial phases of cutting mechanization should not encounter these problems. However, according to the Finnish experience, after the early introductory phase of mechanization, forest machines operate most reliably and efficiently when they are owned by private entrepreneurs rather than large forest industry companies.
8. *Attitudes towards cutting mechanization* were long prejudiced. Forest workers were concerned with job security, logging supervisors were often reluctant to experiment with totally new systems and methods, and private forest owners were worried about excessive stand damage in thinning operations. Education and demonstrations will be needed in Brazil as well in order to remove prejudice and prepare the parties concerned for a smooth transition.

By the late 1980s, the technical reliability of multi-function machines had been greatly improved. Suitable equipment had been developed for almost any operational environment in Finland. Furthermore, during the long test and introduction period the logging organizations and machine contractors had learned to integrate motor-manual and fully mechanized logging.

Simultaneously, the forest industries encountered a deep cost crisis that forced them to study the cost of harvesting more holistically and, accordingly, to look for more efficient solutions. Although the shortage of experienced drivers, high cost of investment, uncertainty of machine employment, and the problem of seasonal manual labor for silvicultural operations remained, under these circumstances *the mechanization of cutting suddenly started to accelerate*.

In 1991 the *share of mechanized cutting* in the timber harvesting of the Finnish forest industry companies was over 50 %. The degree of mechanization was considerably higher in clear-cuttings than in thinnings. Figure 18 shows the sharp increase in cutting mechanization in view of the number and share of processors, two-grip harvesters and one-grip harvesters sold in Finland during 1984–1990.

It is economical to increase the degree of mechanization further, primarily by replacing chainsaw operators by one-grip harvesters. Here the profitability of mechanization is not based solely on the reduction in cutting cost but also on savings of labor, money, and time in many other operations throughout the timber procurement system. Accordingly, 80 % of cutting, self-employed farmers' activities excluded, is expected to be implemented with multi-function machines by 1995 (Örn 1990). This fast mechanization process is seen as a key issue in controlling harvesting costs and guaranteeing continuous availability of timber for the Finnish forest industries during the years to come.

Quite obviously, there is no immediate reason to launch a similar large-scale cutting mechanization program in Brazil. The low cost of motor-manual cutting, lack of experienced forest machine drivers and entrepreneurs, unpreparedness of the organization, shortage of capital, as well as securing the employment of present logging crews will continue to constrain mechanization during the 1990s. However, as happened already in the forest industry countries of the northern hemisphere, the situation may change in the future equally in Brazil. Since adoptation of new cutting technology requires plenty of time, the Brazilian forest industry is interested in gradually preparing itself for mechanized cutting.

The questionnaire study shows that many companies actually are *considering mechanization experiments*. It will then be important for both the logging organization and the machine manufacturers and dealers to recognize that technological innovation does not have a chance in a new environment unless it fits itself into the existing organizational and institutional structures and makes use of them for its further development. Moreover, the local training institutes need to be incorporated well in advance at appropriate levels into the efforts to increase technological know-how and know-why (Swantz 1989). In fact, many Brazilian forest industry companies have an effective organization for maintenance of chainsaws, tractors, and other equipment. The existing maintenance systems with their repair shops form a favorable starting-point for serving new types of forest machines.

Anything worthy of being called *transfer of technology* must become embedded in the new context in such a way that the intellectual, material and institutional prerequisites for its continuing operational use have been fulfilled. From the start when a transfer of technology project is launched, these three components must be given equal consideration. They are not, however, equally manageable in practice. Hardware can easily be moved to a new location and even installed with careful supervision, but its continuing running tests the success of transfer. The operational and maintenance costs, management, and operational skills easily become bottlenecks. Technological development is a long-term process in which delays and setbacks are to be expected and learning takes place through failure (Swantz 1989).

63. Logging machine manufacture in Brazil and Finland

The tree-length and whole-tree systems, both characterized by ground skidding of timber from stump to road-side, and the log-length system, characterized by off-road transport with load-carrying forwarders, are all commonly used in Brazilian plantation forestry. Since technical logging conditions do not differ greatly from those in northern Europe and the eastern half of North America, it has not been necessary to develop totally new machine solutions specifically for Brazilian plantations.

The present technology has been transferred from the northern hemisphere and modified for local socio-economic and climatic conditions. However, protective import taxation and lack of foreign currency *have closed the machine market from importers.* Therefore, most of the logging machines are made locally by subsidiaries of foreign machine manufacturers or independent Brazilian companies under foreign licence. The emphasis is on products such as chainsaws, farm tractors, and timber trucks, whereas the role of forest tractors and other special equipment is of less importance.

During the 1980s, Finland became the world leader in the manufacture of special forest machinery. This is particularly the case with the fully mechanized log-length technology, whose key elements are the forwarder equipped with a long-reach crane and the crane-mounted one-grip harvester head. Because the Finnish market is limited and dispersed, customers must be found beyond the national borders. Fortunately, the demanding domestic market has created a strong base for the export of forest machines.

Finnish companies have taken over major forest machine manufacturers in countries like Sweden, Canada, the United States, and Brazil. Through expansion into foreign countries they have improved their ability to serve the users of the whole-tree and tree-length methods as well. In regard to the future development of Finnish-Brazilian cooperation, a short introduction to logging machine manufacture in Brazil and Finland is of interest.

631. Major manufacturers in Brazil

While the market for professional chainsaws is diminishing in countries where cutting is being mechanized, it is still growing in Brazil. All chainsaws are of local origin. Husqvarna and Stihl are the most common makes, produced locally by *Electrolux Motores Ltda* and *Andreas Stihl Moto-Serras Ltda*. Oregon chains are made by *Blount Industria de Correntes Ltda*.

Brazil is a large manufacturer of farm tractors. Important tractor makes are Massey Ferguson, Valmet, Ford, and Compania Brasileira de Trator's. In 1989 total production was 34 000 tractors. However, due to the market recession, in 1990 production was reduced to 23 000. The annual demand for forestry purposes is about 600 two- or four-wheel-drive farm tractors, some 250 of them headed for timber harvesting. Tractors used in forestry are manufactured mainly by *Valmet do Brasil S.A.* and *Massey Perkins S.A.*

Several machine manufacturers make forestry accessory equipment for farm tractors. Among the most important of them are *Valmet Implemater Equipamentos Ltda* and *Munck-Jons S.A. Equipamentos Agricolas e Florestais* producing skidding grapples and hydraulic cranes, and *Lencois Equipamentos Rodoviários Ltda* producing trailers for farm tractors.

Only few forest industry companies perform the off-road transport with forest tractors. Accordingly, the demand for and the production of special forest tractors is at present low. A 12-tonne skidder is made by *Müller* and two-axle, 10-tonne forwarders are manufactured by Valmet Implemater Equipamentos Ltda, *Engesa Engenheiros Especializados S.A.* and *Randon S.A. Veiculos e Implementos*.

The manufacture of cutting machines is still in its early phase in Brazil. The main product is simple felling machines. *Implenor* (Implementos Agricolas do Nordeste Industria e Comercio Ltda) makes three-wheeled Bell feller-bunchers. Mobile fuel chippers are made by *Elof Hanson do Brazil Representacoes Ltda*, debarking machines by *Munch-Jons S.A. Equipamentos Agricolas e Florestais*, winches with towers for steep terrain conditions by *Industrias Langer Ltda*, and simple winches by *TMO* (Wiegando Olsen Ltda). Multi-function machines are being tested and developed further by Lencois Equipamentos Rodoviários Ltda.

Trucks are manufactured by several enterprises. Lighter timber trucks are made primarily by *Mercedes Benz do Brazil Ltda*, and heavy timber trucks by *Saab-Scania do Brazil S.A.* and *Volvo do Brazil Motores & Veiculos Ltda.* Cranes for timber trucks are made by Valmet Implemater Equipamentos Ltda, and Munck Jons S.A. Equipamentos Agricolas e Florestais. Truck trailers are made by Randon S.A. Veiculos e Implementos, *Rodoviaria Equipamentos*, and *Guerra* and bodyworks for trailers Lencois Equipamentos Rodoviários Ltda. Safety equipments are made by *Tecmater Equipamentos Florestais Ltda.*

As logging is typically based on conventional farm tractors, the manufacture of special forest machines and accessories is limited and intended only for the domestic market. Practically all plantation timber is harvested and transported from stump to mill with Brazilian-made machines. Although some of them are stripped-down versions of European or North American machines, the price level is not especially low, owing to limited foreign competition.

632. Major manufacturers in Finland

Since harvesting in Finland and the other Nordic countries is based on the use of the log-length method and special machines, the forest machine industry is directed accordingly. Forwarders and multi-function machines are the main products. The development of forest tractor-type forwarders was initiated in the mid-1960s:

- At first, great efforts were put into the improvement of productivity and reliability.
- When the performance of the forwarders reached the target level in the late 1970s, increasing emphasis was given to ergonomic aspects such as vibration, seats, visibility, control levers and pedals, cabins, etc. This development phase resulted in a sophisticated, high-standard tractor cabin characteristic of all Finnish forest machines. However, the cabin is a substantial factor in the price of the Finnish forwarders. When machines are exported to countries with less strict ergonomic requirements, the price can be reduced by compromising over the cabin specifications.
- Finally, since the early 1980s development efforts have been focussed particularly on making forwarders more environmentally sound by means of improved power transmission systems, balanced mass distribution, a larger number of driving wheels, wider tires, long-reach cranes, light materials such as aluminium, etc.

Development of Finnish forwarders over the past 25 years was largely due to the development of hydraulics. From the viewpoints of machine operation and system design, the hydraulic timber crane is of utmost importance. Several manufacturers make cranes for farm tractors, forest tractors, and trucks. In fact, a large proportion of the world production capacity in vehicle-mounted timber cranes is in the hands of the Finnish logging machine industry. The leading manufacturer is *Partek Oy Partek Cargotec*. Its Timber Handling Division with an annual turnover of US $ 94 million in 1990 owns in Finland Loglift Oy Ab and in Sweden Hiab Forest Ab, Ab Forshaga Mekaniska Verkstad, and partially Logcranes Ab. Among other important Finnish-owned crane manufacturers are *Cranab Ab* in Sweden and *Kesla Oy, L. Marttiini Ky Konepaja,* and *Rovaniemen Konepaja Ky* in Finland.

The manufacturers of forwarders and multi-function machines have increasingly moved from small machine shops to fewer large international companies, who make use of top technology and engineering skills and, due to the scale of operation, are in a better position to export. The bulk of the production of Nordic logging machines is in the hands of three Finnish manufacturer groups:

— *FMG Timberjack Group* with its annual turnover of US $ 400 million is the largest forest machine manufacturer in the world, controlling a considerable share of the global forest machine market. It produces machinery for the log-length system through FMG Timberjack Oy in Finland and FMG Timberjack Ab in Sweden, and machinery for the whole-tree and tree-length systems through FMG Timberjack Inc. and Peerless Page Industries Ltd. in Canada and Peerless Corporation in the United States.

— *Valmet Logging* of Valmet Corporation had an annual turnover of US $ 180 million in 1990. The consortium is composed of Valmet Metsäkoneet Oy in Finland, Valmet Logging Ab and Cranab Ab in Sweden, Valmet Implemater Equipamentos Ltda in Brazil, and Valmet Logging Americas Inc. in the United States.

— *Norcar Forest Machine Group* had a turnover of US $ 70 million in 1990. It consists of the parent company Norcar and two subsidiaries, Ponsse Oy and Kajaani Automatiikka Oy, all located in Finland. In 1990, Norcar Forest Machine Group entered into a marketing and manufacturing alliance with Blount Inc., which has the rights to market and service all Norcar forest machines in North and South America.

Each of these three forest machine consortiums produces a variety of forwarders, complete harvesters, separate one-grip harvester heads for attachment to various kinds of timber cranes, and other equipment. Rather than single machines, they manufacture and offer to logging organizations and machine entrepreneurs complete logging schedules from stump to road-side, based usually on the teamwork of a harvester and a forwarder.

A number of smaller manufacturers are also in the forwarder and harvester market. In fact, in 1990 as many as 33 different one-grip harvester head models were made in Finland, designed for mounting on the crane of a farm tractor, forest tractor, or conventional excavator. Among the manufacturers are Kesla Oy, *Kindai Oy, Kone-Ketonen Oy, Nokka Forest Oy, Orion-Group Oy Normet, S.Pinomäki Ky* and *Arctic Forest Machines Ltd.* The main product of the last-mentioned is the Lako one-grip harvester head, which is especially suitable for excavator-type base machines.

In addition to forest machines, Valmet Corporation produces through its *Valmet Tractors International* in Finland conventional farm tractors, which are used for timber transport mainly by self-employed forest owners and part-time contractors. The Valmet Corporation has considerable farm tractor production also in Brazil and Portugal. Several companies in Finland make farm tractor accessories for logging purposes: trailers, cranes, winches, processor and harvester heads, debarkers, and fuel chippers.

The majority of timber trucks are imported from Sweden. An exception is the Sisu truck made by *Oy Sisu-Auto Ab*, a producer of heavy timber trucks for difficult conditions. Almost all truck crane and trailers are made locally.

64. Applicability of Finnish technology in Brazil

Finnish logging technology offers a wide range of machine options and system alternatives for small-scale farm-owner operations as well as for large-scale industrial operations. Regardless of the scale of operation and degree of mechanization, the equipment is typically designed for the log-length method. In comparison with the whole-tree and tree-length methods, popularity of this Nordic technology is expected to increase in different parts of the world with:

- Shift of emphasis from the exploitation of large-sized trees from native forests to smaller trees from intesively managed forests
- Intensification of silvicultural management of forests, particularly with the introduction of thinnings
- Increasing pressure towards more environmentally sound harvesting technology and multiple use of forests
- Improved value utilization of timber crops, for example, careful separation of the best logs from the timber flow for lumber and plywood production and recovery of small-sized trees
- Tightening of work safety and ergonomic requirements on machines and work.

In Brazil the log-length method is applied primarily in the eucalyptus plantations. Pulpwood logs are then typically made 2.2 or 2.4 m long, which is too short for the efficient operation of machines. It is important to note that in Finland *increasing the log length* from the earlier 2 m to the present 3 m or more commonly 5 m was a key factor in the successful rationalization of the cutting, transport, storage, and mill yard handling of timber during the 1970s and 1980s. For improved operational efficiency of harvesting, a significant increase in the length of pulpwood logs will be equally important in Brazil too. To make this possible, modifications in the mill yard systems and transport vehicles may be needed. The expected capacity expansion in the industry will open up opportunities for the required changes. In fact, many companies are preparing themselves at present for increased log lengths.

Smooth loading of tractors requires the initial bunching of logs. Manual bunching is strenuous work and becomes almost impossible when logs are made, say, 5 m long. If farm and forest *tractors are made self-loading* with a hydraulic crane, off-road transport will not necessarily require the pre-bunching of logs. Equipping the off-road transport vehicles, either farm or forest tractors, with an efficient timber crane would offer the following operational advantages in Brazil:

- Strenuous manual bunching could be reduced
- Interdependence of separate loader tractors and transport tractors would be avoided, resulting in increased operational availability and productivity of vehicles
- The number of tractors needed at a work site would be reduced when the transport tractor is able to carry out loading and unloading by itself. Consequently, the number of operators would also be reduced. However, better crane-handling skills would be required from the remaining drivers
- Risk of soil disturbance would be reduced with a decrease in the number of machine passes
- The overall productivity of logging systems would be improved

From the technical point of view, many of the Finnish multi-function machines, one-grip harvesters especially, seem to be suitable for the Brazilian plantations. The operational environment in the large even-aged plantations is exceptionally favorable for the use of modern harvesters. *Mechanization of cutting* through the introduction of harvesters would probably increase the productivity well over ten-fold, although the high cost of the equipment impairs the profitability of mechanized systems as compared to conventional motor-manual systems.

The most efficient harvesters are built on a prime mover designed specifically for a multi-function machine. They are also the most expensive and have the highest operating costs, in Finland generally US $ 90–110 per hour. For a medium-sized forwarder the costs are US $ 70–80 per hour and for a complete fully-mechanized system thus US $ 160–190 per hour. When harvesters are imported to Brazil, freight and import taxes will further increase their price. However, the following factors will help to reduce the operating cost:

— Under the conditions prevailing in Brazil, harvesters and forwarders could be operated the year round in 1.5–2 shifts. Full employment would reduce the interest cost per cubic meter of timber as compared to Finnish conditions.
— In Finland, 28 % of the total operating cost of a multi-function machine and as much as 32 % of that of a forwarder comprises the direct and indirect costs of the driver. For a fully mechanized logging system formed by these two machines, the cost of the two drivers is thus US $ 50 per hour. In Brazil, owing to the lower wage level, the costs of the two drivers would be considerably less, perhaps US $ 10 per hour in total.

Fully mechanized logging systems *require skillful operators, full employment, well-organized work sites and a fast and reliable service and supply of spare parts.* Fortunately, key components such as the engine, transmission system, hydraulic systems etc. are generally from well-known international manufacturers and, consequently, in many cases readily available locally. Nevertheless, a reliable system for the distribution of all spare parts, including the electronic functions of the machines, is necessary for cost-effective operation.

A less expensive and less productive alternative is offered by a separate harvester head mounted on the crane of a conventional farm or forest tractor. A farm tractor-mounted harvester is well suited to Brazilian logging systems as regards drivers' and foremens' experience, established machine service, and lower capital expenditure, but it is not particularly suitable for handling large trees from final cuttings.

Another cost-effective base machine option for a harvester head is offered by a conventional tracked excavator with a minimum engine power of about 80 kW and a minimum machine mass of 8–9 tonnes. Among the advantages of using an excavator as a prime mover are the relatively low capital and operating costs, reliability and strength due to the over-dimensioning of the crane, good visibility from the cabin, low ground pressure and, furthermore, suitability for delimbing whole stems for tree-length skidding. However, some changes must be made in the standard crane. The use of excavators is restricted to clear-cuttings.

Before a fully mechanized logging system can become operational and profitable in a new country, time is needed for modifications, method development, driver training, restructuring the organization, and changes in attitudes. Therefore, although the labor-intensive technology continues to be cost-competitive and cheap rural labor is still readily available, large Brazilian companies should launch a cautious testing, development, and training program to find efficient and economical solutions using cutting mechanization for their specific conditions.

The first fully mechanized logging system in Latin America was introduced by Forestal Colcura S.A. in Chile in June 1991. It is

Figure 23. A fully mechanized logging system in clear-cutting of a eucalyptus stand in Chile. Norcar HS 15 harvester and Norcar S 15 forwarder (Photo Kristian Stén).

intended for harvesting 3-meter pulpwood from eucalyptus plantations, a part of which is located in steep terrain. The system comprises a 13-tonne Norcar HS15 single-grip harvester driven by two experienced operators from Finland and Sweden and a 11-tonne Norcar S15 forwarder driven by two local operators (Figure 23). The experience achieved during the first five months of the introduction period shows that the system is not only technically appropriate but also cost-competitive against any other proven harvesting alternative under the prevailing conditions. The productivity has been about 19 m^3/h for the harvester and about 16.5 m^3 for the forwarder in clear-cutting areas with an average stem volume of 0.2 m^3. The productivity is reduced when the slope exceeds 30 %, but the machines have been found technically capable of operating on slopes of at least 40 %. The total cost of cutting and off-road transport from stump to road-side is about US $ 6/m^3, including the scaling. From the environmental point of view the result has been very satisfactory.

The recent reduction in import taxes on the one hand, and the expected increase in the use of plantation timber on the other, are opening up new possibilities for the import and manufacture of foreign logging machines and the introduction of more efficient harvesting systems in Brazil. The Finnish mechanized logging systems provide a proven alternative for efficient logging and offer a comfortable, safe, and motivating work environment for the machine operators. Since these machines have gone through a long period of development, resulting in greatly improved performance and reliability, the technical risks are now smaller than during the first two decades of cutting mechanization in Finland. It must be understood, however, that technology has been transferred successfully only when the recipient organization is able to reproduce the total operation from the planning stage to the final result (Swantz 1989). Mechanized logging requires new skills from the operators, mechanics, supervisors, and dealer organizations. Therefore, training of staff will be of the utmost importance at all levels of the organization.

Integration of practical field testing by forest industry companies and scientific studies by research organizations would then be advisable. Such development cooperation should not be restricted to the technical performance of the system only. In addition, the socio-economic, organizational and environmental consequences of mechanization should also be taken into consideration in the system evaluation.

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The Finnish Forest Research Institute.
Research Papers 404

ISBN 951-40-1201-1 ISSN 0358-4283