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Linear optimization model was used to calculate seven wood procurement scenarios for years 1990, 2000 and 2010. Productivity and cost functions for seven cutting, five terrain transport, three long distance transport and various work supervision and scaling methods were calculated from available work study reports. All method's base on Nordic cut to length system. Finland was divided in three parts for description of harvesting conditions. Twenty imaginary wood processing points and their wood procurement areas were created for these areas. The procurement systems, which consist of the harvesting conditions and work productivity functions, were described as a simulation model. In the LP-model the wood procurement system has to fulfil the volume and wood assortment requirements of processing points by minimizing the procurement cost. The model consists of 862 variables and 560 restrictions.

Results show that it is economical to increase the mechanical work in harvesting. Cost increment alternatives effect only little on profitability of manual work. The areas of later thinnings and seed tree- and shelter wood cuttings increase on cost of first thinnings. In mechanized work one method, 10-tonne one grip harvester and forwarder, is gaining advantage among other methods. Working hours of forwarder are decreasing opposite to the harvester. There is only little need to increase the number of harvesters and trucks or their drivers from today's level. Quite large fluctuations in level of procurement and cost can be handled by constant number of machines, by alternating the number of season workers and by driving machines in two shifts. It is possible, if some environmental problems of large scale summer time harvesting can be solved.

Keywords wood procurement, future scenarios, productivity, cost.
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Preface

To celebrate its 40th anniversary, the Metsämiesten säätiö Foundation financed an extensive research programme carried out in the period from 1989 to 1992 and entitled "*Effects of the Structural Changes in the Forest Industry on the Various Occupational Categories*". Several research institutes were involved in the programme. The research team consisting of the authors of this study was assigned to prepare scenarios for resource requirements in timber procurement for the period 1990 to 2010. The project was headed by Professor Esko Mikkonen. Mr Arto Rummukainen, Lic.(Agr.For.), developed the structure of the procurement model, analyzed and computed the model input data and the limitations of the linear model including the final results together with Mr Heikki Alanne, M.Sc.(Agr.For.). Mr Alanne made the data input and output routines, carried out with the Excel spreadsheet software, and formulated the optimization sections of the model for the XA linear programme. The research report was written by Mr Arto Rummukainen, except for the section discussing the structure of the linear model, the equations used in the model and the validation of the model, which were authored by Mr Heikki Alanne. Mr Esko Mikkonen wrote preliminary manuscript for the chapter dealing with model selection. For the releasing of whole research program of Metsämiesten säätiö Foundation at the Forest Week in Tampere, authors wrote a broad publication for Finnish conditions (Rummukainen et al. 1993).

The views of experts in timber harvesting concerning the future development of timber procurement in the short term were collected by Mr Jouni Vantaala, M.Sc.(Agr.For.), to be used as reference data. Ms Outi Mikkonen, M.Sc.(Agr.For.), was involved in the project working on a hourly basis. Many of the researchers involved in the other projects included in the programme also contributed to this project. Of special importance was collaboration with Mr Arto Koistinen, M.Sc.(Agr.For.), of the Finnish Work Efficiency Institute, Mr Heikki Seppälä, M.Sc.(Agr.For.), of the Finnish Forest Research Institute, and Dr Veli-Pekka Järveläinen of the University of Helsinki.

Warm thanks to Mr Erkki Eilavaara (M.Sc.(Agr.For.), representative of the Forest Employers Association), Mr Ilppo Greis (M.Sc.(Agr.For.), employer representative of Forest Centre Tapio), Mr Markku Maukonen (Departement manager of Finnish Truck Owners Association), Dr Pekka Mäkinen (senior researcher in the Finnish Forest Research Institute), Mr Mauno Pesonen (M.Sc.(Agr.For.), researcher in the Finnish Forest Research Institute), Mr Harri Rumpunen (M.Sc.(Agr.For.), representative of the Transport User's Association of Forest Branch), Mr Seppo Ryynänen (M.Sc.(Agr.For.), office manager in Work Efficiency Institute, Field Research Station Office, Rajamäki) and Mr Mark Waite (M.Sc.(Agr.For.), researcher in University of Helsinki, Department of Forest Resource Management) for their trouble when they made calculations from their original unpublished materials specially for this study.

Other important contributors representing parties outside the research programme included Metsäteho, where Mr Vesa Imponen, M.Sc.(Agr.For.), in particular was of great assistance by placing his knowledge at our disposal. Ideas that helped this project along were presented by Professor Pentti Hakkila, Mrs Marja-Liisa Juntunen (M.Sc.(Env.)), Dr Pekka Mäkinen and Dr Heikki Smolander of the Finnish Forest Research Institute in the course of discussions held at the time when the study was actually in progress. Late Mr Paul Service translated the manuscript in English.

We wish to express our gratitude to the Metsämiesten säätiö Foundation for introducing an interesting subject of study and for ensuring the necessary resources for its implementation. Excellent facilities for the execution of the project were provided by the Helsinki University Department of Forest Resource Management, formerly Department of Logging and Utilization of Forest Products, and by the Department of Forest Production, formerly the Forest Technology Department, of the Finnish Forest Research Institute. We also wish to extend warm thanks to the numerous other people who helped us with the preparation of the present study.

List of Symbols and Terms

Terminology follows Nordic forest work study recommendations (Nordisk ... 1978).

Dividing of the time:

Effective time = E

The time required to perform a specified work element which directly or indirectly changes the work object in regard to its form, position or state.

+ shorter than 15 min delay times = D_{15}

= Gross effective time = E_{15}

+ machine service time = D_s

+ machine repair time = D_r

+ personal delay time = D_p

+ operational delay time = D_w

+ tool delay time = D_t

= Work place time = W

+ moving time = B_m

= Total working time = T

Time units:

cmin	= centiminute
h	= hour
d	= day
m	= month
a	= year

Volume units:

m^3 = cubic metre

Wood assortment's volume = wood assortment's solid volume with bark.

Stem volume = stem's merchantable solid volume with bark.

Density units:

Density of stand = stand's volume or number of stems divided by the treated area.
m^3/ha or r/ha (r = number of stems)

Density of drain = volume of removed stems divided by the treated area. m^3/ha.

Wood assortment density in off-road transport = volume of the wood assortments which are transported at the same time divided by length unit of strip road. m^3/100 m strip road.

Time consumption units:

Time consumption = time duration of chosen work phase divided by number or volume of trees which has been treated in this work phase. Abbreviation of time consumption is C***, where *** is abbreviation of work phase, wood assortment, machine, working method or other corresponding.
h/m^3, cmin/m^3, cmin/dm^3 or cmin/r

Productivity units:

Productivity = treated number or volume of stems divided by time, which elapsed to perform this work phase.
Abbreviation of productivity is P***, where *** is abbreviation of work phase, wood assortment, machine, working method or other corresponding.
m^3/h

1 Introduction

1.1 Predicting the Future

Since the 1980s, one-grip harvesters have made it possible to mechanize the final stage of the timber procurement process. Further improvement of the machinery, improved operator skills, the successful introduction of automatic scaling by logging machines and good financial performance permitted the use of forest machines in virtually all conditions ranging from clear cutting to first thinning. The profound change in the amount and character of forest work, which took place as a result of mechanization, arouses a question to find out how much work there will be in the forest in the future and who will do it.

For some 20 years now, Metsäteho has prepared forecasts concerning the volume of forest work and related costs using simulation and optimization models (Mikkonen et al. 1975, Eskelinen et al. 1978, Imponen et al. 1985). The main theme of these studies predicting increasing mechanization proved correct but the forecasts predicting the rate of change sometimes differ greatly from what actually happened towards the end of the prediction period because both the machinery and the forest organizations underwent major changes in the 1970s and 1980s before assuming their current form.

Predicting the future is particularly common in economics. The latest forecast for the Finnish economy as a whole predicts a slow growth rate, accompanied by a sluggish increase in employment made possible by new fields of industry (Avautuva ... 1993). However, the authors have identified a number of critical conditions that must be satisfied before the predicted development can materialize. For the short term, it is possible to prepare fairly reliable forecasts because many aspects are closely linked to the existing structures. Forecast periods extending over several years involve so many optional paths of development, such as rapid political changes, that any such prediction is bound to be based on subjective views rather than mathematical trends.

1.2 Purpose of the Study

The primary objective of this study is to make scenarios on future resource requirements in timber procurement and the changes in prevailing conditions up to 2010. To this end, a timber procurement model was devised to make it possible to examine the resources required for timber procurement and to optimize them under given restrictions. The model is based on nordic shortwood methods.

The model covers the current and foreseeable optional courses of action in both industrial and small-scale harvesting by private woodlot owners, transportation and wood yard operations. Primarily, the model is based on forestry economic criteria in national level, so the individual calculations for one forest owner, or on areal or company level, for instance, may result slightly different outcome.

The results computed by means of the model are compared with the views of the future held by the decision-makers in the industrial procurement organizations, a separate study of which was completed previously (Vantaala 1990).

2. Preparation of the Procurement Model

2.1 Timber Procurement Models

Timber procurement consists of a series of operations that actually modify the raw timber or carry it from one location to another, such as cutting, preparation of timber assortment, off-road and on-road haulage, as well as financial and administrative actions such as timber trading, stand marking for cutting purposes, storage, scaling, work supervision (Eräiden...1984). Usually, timber procurement is carried out in Finland by timber procurement companies, the woodlands operations departments of the forest industry companies, the Finnish Forest and Park Service in its own forests, woodlot owners and private forestry associations, which charge a fee for such services. The range of optional courses of action is further increased when all the alternative trading, design and scaling methods are included. Another fact that complicates the preparation of a model is that the various operations can be carried out at different times and in a variable sequence. Major seasonal fluctuations in the amount of work by type are observed due to the climatic conditions, customs and even laws.

Simulating timber procurement by means of models is difficult because of the high number of variables and their divergent inter-dependencies. As a result, reality must be simplified both in terms of the number of operations and their impact. Factors that have a real effect also have to be ignored because of the problems related to the acquisition of input data and in order to prevent the model from becoming too extensive.

As far as timber procurement is concerned, factors that undergo slow changes over several decades are the structure and growth of the forests, possibly including land ownership. Large pulp and paper mills and major sawmills have a economic service life ranging from a couple of years to about 20 years, which is equal to the period required to pay back the investments. The volume of timber used and the quality of the raw material vary from year to year, if not more often. Old mills, particularly sawmills, are closed down within a space of a few months. The existing harvesting and transport fleet have an economic life of 5 to 10 years. Old machines can be scrapped but the development and procurement of completely new models will take at least a couple of years. As a result, the harvesting techniques can be selected from among methods that are capable of being employed with the existing equipment. Cutting down the number of machines and manpower is so easy and quick as to be inexcusable, while at the same time it is getting extremely difficult to recruit professionally qualified extra staff. At present, it is the harvesting organizations that are undergoing the fastest changes.

Armstrong (1985) suggests methods for reducing errors due to subjectivity, the following of which were also used in this study. Sound input data is the most important single prerequisite for making predictions. Any forecast that consists of several components must be prepared as a summary of all the individual forecasts to ensure that the special data included in the component parts are not lost. Various optional courses or levels of development should be experimented with in order to test sensitivity to change. Any prediction of future development should always be based on several methods.

In the U.S.A., a couple of computation programmes for selecting the most economic harvesting methods are used. The Harvesting System Analyzer (HSA) is a Pascal-language menu-controlled application that computes the time and cost required by given machines in selected stands marked for cutting (Hendricks 1985). The stand is described by a few entries indicating the type of timber, terrain and distances. The Auburn Harvesting Analyzer (AHA) is a simpler spreadsheet application designed to compare productivities and costs between various chains of machines in given conditions (Reisinger et al. 1988). These applications are used by both the forest industry

and the harvesting companies.

An overview of the development of modelling in timber procurement is provided by Mikkonen (1983). Usually, the first operation to be modelled is long-distance haulage, where linear models are used to optimize the most economical transportation route between storage areas and processing points. Pulkki (1984) computed the most economical transport options for the forest industry in eastern Finland using a location-database heuristic programming system. Korpilahti (1990) added the time factor to his own models. The harvesting cost forecasts made by means of Metsäteho's simulation and optimization models were already mentioned in the previous chapter (Mikkonen et al. 1975, Eskelinen et al. 1978, Imponen et al. 1985).

Methods have also been devised to steer the selection of the harvesting method by means of simulation models where natural change is simulated using random fluctuations (Stuart 1980). Heinämäki (1991) studied the optimum use of forklift trucks at timber terminals using the linear models. Imponen (1992, and Imponen et al. 1992) used the linear model to compute the financial and organizational effects of mechanised cutting from the point of the view of the harvesting organization.

Since the early 1970s, the forest departments of Finnish companies have had access to optimization models for haulage operations that were previously used to compute the optimum haulage areas for the various mills, mainly to serve as a basis for strategic decision-making. The current models developed from these usually provide for several timber assortment types and modes of transportation. To a great extent, they make use of the transport algorithm or LP model. Certain companies have developed "forest models" to examine the entire procurement chain from the stump to the mill. They can include linkages to product conversion and even marketing. These models are designed for the mainframe environment, serving mainly long-term planning and strategic decision-making. To date, they have been of little operative importance.

2.2 Model Structure

2.2.1 Linear Model and Problem Description

A genuine timber procurement system includes a large number of variables and limitations but usually only a few of these actually define the performance of the system. The selected variables and the degree of success in the design of the model determine how effectively an optimization model, which is necessarily always simplified, can simulate reality. For the purposes of this study, timber procurement was understood as a raw material flow process that consists of consecutive stages, each of which draws upon different resources. The procurement model was built up with due regard to timber usage, the physical features of the operating area and the methods of harvesting and haulage.

Linear optimization satisfies most of the theoretical requirements imposed on a sound planning algorithm. For one thing, it is highly practical. It is easy to use, the results allow simple interpreta-

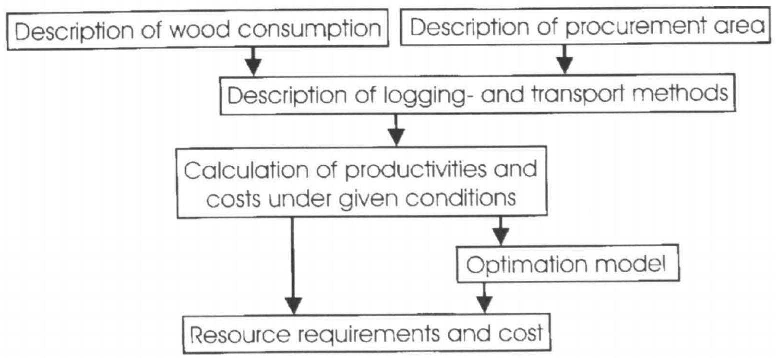


Fig. 1. The structure of wood procurement model.

tion, and it operates in most data processing environments (Mikkonen 1983). The chief weakness of the linear model is one-sided problem presentation. Therefore the use of the optimization model requires post and sensitivity analysis.

The general form of the mathematical programming is as follows (Hillier & Lieberman 1974, Simmons 1972):

Object function $f(x_1, x_2,...,x_n)$ must be maximized/minimized subject to limitation $g_j(x_1, x_2,...,x_n) \Leftarrow b_j$ where $j = 1,...,m$.

Linear optimization is used for analyzing the special problems associated with mathematical programming, where functions f and g_j are linear, i.e. first-degree functions. The problem of linear programming can be expressed in the standard form of the LP model:

Maximize / minimize:

$$z = c_1x_1 + c_2x_2 + ... + c_nx_n$$

Subject to limitation:

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + ... + a_{1n}x_n &\le b_1 \\ a_{21}x_1 + a_{22}x_2 + ... + a_{2n}x_n &\le b_2 \\ \vdots \quad \vdots \quad & \quad \vdots \quad \vdots \\ a_{m1}x_1 + a_{m2}x_2 + ... + a_{mn}x_n &\le b_n \end{aligned}$$

$$x_1 \ge 0, \quad x_2 \ge 0, \; ... \;, \quad x_n \ge 0,$$

where $m \le n$ and the limiting equations are linearly independent.

The model is used as an iterative process where the basic solution is first calculated without any determining limitation. If necessary, the input values are then modified by imposing limitations specific to each run and rerunning the program until a feasible solution is achieved. To attain reliable results, the input data must be correct. Allowance must be made for individual limiting factors according to each situation calculated. To obtain more data from the computation process, the results are interpreted by means of sensitivity analysis and shadow-price analysis.

Procurement is described in this study by means of a simulation model consisting of mathematical dependencies and executed with the Excel spreadsheet software from the Microsoft Corporation (Excel 1992). To compare the cost of the optional systems, standard linear optimization (LP) was selected and executed with the XA–LP software of Sunset Software Inc. (XA ... 1987). The input data consisted of the harvesting conditions and productivity functions of the systems. The output of procurement systems have to supply the given raw wood needs of mills. In the linear model, the cost function used in the optimization model minimized the cost of procurement required to fulfil needs of mills. The resource requirements are computed from the solutions for minimum costs.

2.2.2 *Performance of Procurement Simulation*

For procurement simulation purposes, Finland was divided into three areas: western Finland, eastern Finland and northern Finland (Fig. 2). By this division, it is possible to take account of changing procurement conditions and include more operating areas without making the model too extensive to handle. In terms of time, the model divides the year into four procurement periods whose duration can be freely selected. This makes it possible to take into account the operating conditions in the various periods and to examine the variations in procurement volumes from period to period.

The timber utilization volumes are derived from the total consumption of timber by the forest industry, of which only the percentage of domestic timber is taken into account in the calculation of procurement volumes. Timber utilization is divided by area into timber assortments and end-uses as percentages of total consumption. The total volume by timber assortment and end-use is distributed among 20 imaginary processing points located in each area. The desired long-distance haulage modes complete with distances and unloading systems are then selected for the procurement areas.

For each operating area, descriptions are provided of the volume of timber to be cut, its density, tree species distribution, timber assortment distribution, stem size distribution, branchiness, off-road haulage distance and its degree of difficulty for the following types of stands marked for cutting: first thinning, other thinnings, clear cutting yielding mostly medium sized trees, clear

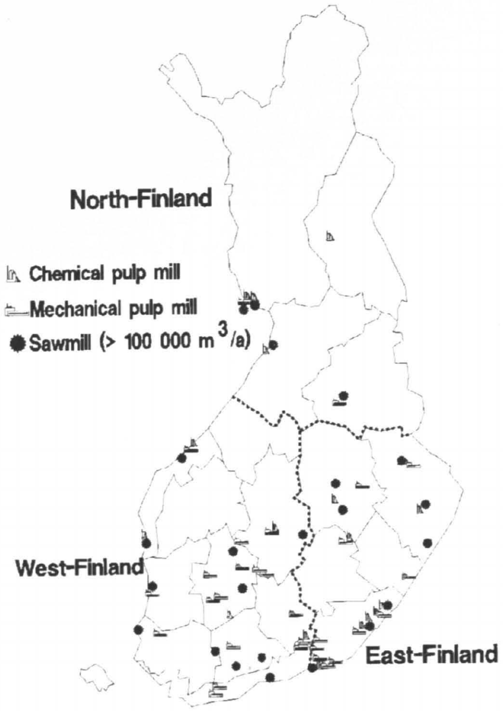


Fig. 2. Division of Finland into three sub areas used in this study and location of main forest industry (The Finnish... 1991 and Ylitalo et al. 1990).

cutting yielding mostly large trees (sawlog-dominated), cutting for seed and shelter tree position, and removal of seed and shelter trees. Local values have been computed from the statistics on the scaling of standing trees (Lassheikki 1989).

Methods were selected for cutting, off-road and long-distance haulage as well as related administrative actions and then combined into sensible operating chains. The working methods are described by mathematical models prepared on the basis of the available research data, where productivity is expressed as a function of the given work-difficulty factors.

2.2.3 *Resource Optimization*

The variables in the optimization matrix consist of the timber volumes to be harvested and exchanged (given by timber needs of the mills), the timber volumes to be harvested and transported by different methods, and the human and machine resources employed. The cost factor used in the objective function for each variable is the related unit cost, either FIM/m^3 or FIM/h. The objective function gives a solution where the costs of timber procurement to supply the mills are minimized within the limitations imposed by the timber volumes and availability of resources. The objective function and variables for the model are presented in appendix 1.

The limitations used in the model are the timber volumes per processing point and period, the ratio of small-scale private harvesting to industrial-scale harvesting, periodical fluctuations in harvesting and mill yard operations, the restrictions on harvesting imposed by the periods and methods available and the restrictions imposed by long-distance haulage systems by period and processing point. The manpower and machine resources required by harvesting and haulage restrict the use of various harvesting and haulage methods where appropriate. The values of these limitations are used as inputs in the model. They ensure that the result given by the model is practicable in reality.

3 Basic Model Data

3.1 Description of Timber Consumption

The volumes of timber used by the forest industry in 1990 were obtained from the statistics (Yearbook of Forest Statistics 1990 and 1992, and Ylitalo et al. 1990). Of this total consumption, use of the domestic raw timber by timber assortment and end-use was examined separately (Yearbook of Forest Statistics 1990). Consumption of timber by assortment and end-used by the industry was broken into percentages by area by dividing the total volume of a specific type of timber between the areas in proportion to the area-specific capacity as a percentage of total industrial capacity. The location data and maximum production capacities were obtained from The Finnish Timber and Paper Directory (Hannula 1991).

The figures indicating local consumption by timber assortment and end-use were divided between 20 imaginary processing points (Hannula 1991). Except for northern Finland, several mills had to be combined into a single processing point. To do so, the total capacity of a branch of industry in a given area was divided into processing points of suitable size in proportion to the capacities of individual mills. For example, some sawmills were selected to process pine and some fir. An example of the processing points with the 1990 and 2010 consumption figures is presented in Appendix 2. Fig. 2 shows the areas and the location of the most important mills.

The description of the procurement areas for the imaginary processing points is arbitrary. The size of the procurement area was calculated as the area of a circle drawn around a mill by timber assortment. If timber consumption by any single processing point represents that of several points, the area was calculated according to a single processing point to ensure that such over-consumption does not mix up the haulage distances. The size of a procurement area is determined by the average hectare yield of each wood assortment. Yield was determined on the basis of the rotation time in the area, the area percentages of development classes and yields by cutting objectives (Lassheikki 1989, Yearbook of Forest Statistics 1989). The figure was adjusted by adding to the necessary area watercourses and areas used for purposes other than timber production (Yearbook of Forest Statistics 1990).

The procurement area was arbitrarily increased by the company's share of the total procurement by all the companies in the area. The procurement area was shaped as a segment of a circle drawn around the mill. This was necessary because many mills are located on the coast or near national borders, meaning that the procurement area cannot be a full circle. Because the mills are usually situated either in or near population centres, the procurement area was increased by means of a "restriction" radius around the mill. The average haulage distance, as the crow flies, was calculated as a section of the radius of the procurement area so that the area outside and inside such a section is equal. The distance obtained thereby was modified by the bending coefficient:

$$d_a = \frac{\sqrt{\frac{A \cdot 360}{s \cdot \pi} + r_s^2}}{\sqrt{2} \cdot m_a} \qquad (1)$$

where
d_a = average transport distance of the procurement area, km
A = wood procurement area, km^2
s = shape of the procurement area: sector, °
r_s = radius surrounding the mill with no wood procurement, km
m_a = bending coefficient.

This number is about 5 % larger than the correct average transport distance, which can be obtained by taking the integral of average radius weighted by area over the limits of radius surrounding the mill to radius of the whole sector. As a rule, the transportation route twists and turns both in the forest and near the population centres and so departs greatly from the shortest distance between two points. The longer the transportation distance, the greater the stretch heading straight towards the mill, meaning that the true distance differs less from the straight-line distance. Theoretically, the bending coefficient can, for example, be expressed as a ratio of the length of the divider of a rectangle to that of the sides. The divider represents the distance as the crow flies whereas the sum of the length of the sides represents the real distance to be covered. The bending coefficient is low when the length of the road section leading straight towards the mill is great as compared with the twists and turns at the beginning and end of the journey. A ratio of the rectangular sides of 1 to 2 gives a bending coefficient of 1.33. Using his own transport model, Pulkki (1984) calculated, for the bending coefficient, an empirical value of 1.34 for the haulage of pulpwood over the average distance of 200 km in eastern Finland. According to Pulkki (1984), the corresponding figure for rail haulage is 1.51 and for floating 1.76. Both include carriage by road at the beginning of the transportation chain.

Optional transportation modes were selected for the processing points according to mill location and operating conditions. As a rule, the haulage distances were computed using Pulkki's (1984) bending coefficients. For carriage by rail or floating, the length of the initial leg (by road) was determined from the distance data provided by Alve (1988), Laajalahti and Pennanen (1989), and Pulkki (1984). The floating option was not considered for western and northern Finland. Similarly, railway and floating options were not considered for minor processing points or average haulage distances of less than 100 km. For each processing point, the unloading system was defined arbitrarily, including the trans-shipment system for rail and float carriage, along the lines suggested by Alve (1988). Descriptions of the procurement areas assumed for the various processing points are given in Appendix 2.

3.2 Description of the Area

Of all the commercial timber felled in Finland, as divided for the purposes of this study, 45 % is cut in western Finland, 35 % in eastern Finland and 20 % in northern Finland (Yearbook of Forest Statistics 1990). The forest areas by area, development class distributions, and areas subject to cutting or silvicultural operations have been calculated as sum totals and averages of the values compiled by forestry boards in the area concerned (Yearbook of Forest Statistics 1989). For each area, six typical stands were marked for cutting: first thinning, other thinnings, clear cutting yielding medium sized trees, clear cutting yielding mostly sawlogs, cutting for seed and shelter tree position, and removal of seed and shelter trees.

For the stands, descriptions are provided for the volume of timber by stem type, stand density, timber assortment, out-turn distribution according to stem size class, area of the stand, branchiness class by timber assortment (Metsä- ja...1990), off-road haulage distance and terrain class (Tavoiteansioon...1990). At first, the stands were defined by scaling standing trees (Lassheikki 1989). However, such scaling data is distorted because this method is best suited for clear cuttings. The extent to which trees are scaled while standing varies from one company to another. Trees intended for delivery cutting are hardly ever scaled while standing. It can be assumed that statistical errors are most common in stands marked for thinning because that is where this method of scaling is used most rarely.

Stand-specific data on harvesting conditions is not readily available so that the typical stands were arbitrarily modified on the basis of data gathered from several sources (appendix 3) (Puunkorjuu... 1990, Alve 1988, Yearbook of Forest Statistics 1989, Tapion... 1990, Voipio 1990). In general, the size of the stand and felled volumes were lower than those suggested by the statistics (Lassheikki 1989). For each type-stand it was created stem distribution tables for all three tree species. Each table show the number of stems and the average tree volume in 20 breast height classes. The smallest class is 7...9 cm diameter at breast height. Classes grow up to 43 cm diameter by 2 cm intervals. The largest class includes all trees, which diameter is larger than 45 cm at breast height. This division into classes was necessary to find the basis for calculating the productivities of cutting and scaling works. The felled volume of the stands according to stem diameter distribution was modified for stands marked for thinning along the lines suggested by the calculations made by Lilleberg and Raitanen (1989).

Haulage distances were adjusted on the basis of data available on individual companies (Puunkorjuu ...1990). The fact that the data on stands measured using the standing scaling technique (Lassheikki 1989) were distorted became evident during initial calculations when the computed logging out-turn gave a hardwood volume that was lower by several orders of magnitude than that indicated by the industrial statistics (Ylitalo et al. 1990). Tree species distributions in typical stands in northern Finland were adjusted arbitrarily to better agree with the industrial statistics.

The out-turn of the typical stands is divided into timber species using Mr. Mark Waite's (M.Sc. (Agr.For.)) (Researcher in University of Helsinki, Department of Forest Resource Management) Sortim program. The program determines the stem shape by means of stem curves given by Lahtinen and Laasasenaho (1979). User of the program inputs tree species, breast height diameter and accepted minimum diameters (in cm) and lengths (in dm) of logs and pulpwood. The program calculates the utilizable volume of logs, pulpwood and top waste wood.

3.3 Description of Procurement Methods

3.3.1 General

The 26 procurement systems used in this study consisted of logical combinations of various logging, off-road and long-distance transport modes and administrative procedures. For each type of stand marked for cutting, 13 to 19 commonly used methods were selected. Mathematical productivity models were prepared for each submethod on the basis of available productivity studies. It was impossible to find comparable up to date productivity material for all work methods. For instance manual cutting method material is basically about ten years old (chapter 3.3.2.1.1). Some studies give time consumption, some productivity. Most productivities are shown in publications as hand smoothed curves with no original data points. The range of variation of original observations varied much.

The variability of original data leads to problems in describing the productivities of work methods. For instance the productivities versus stem sizes had to be extrapolated from 20 to 2000 dm^3 stem volumes for all methods used in regeneration cutting stand types. The reasonability of all extrapolations was checked for the conditions of all six type stands. The number and importance of depended factors given by publications varied much. For all these reasons the form of the productivity models are not uniform and elegant. For the same reasons it usually was not possible to calculate statistical reliability factors for the models. Each model's ability to follow the dependency curve of original publication is usually shown in figures. The models are mostly only case models, which can not be fitted with new time study data for predicting new conditions.

For each stand type, options are provided for action by both industrial procurement organizations and private woodlot owners. The felling systems considered were: a logger, woodlot owner at two different standards of professional skills, 8-tonne and 10-tonne one-grip harvesters operating separately and as part of a wider system, and a two-grip harvester. The scaling methods were: scaling at road-side, scaling bunches, scaling of standing trees by the logger, automatic scaling by logging machine. The transport fleet options were: a farm tractor fitted with a hydraulic skidding grapple or hydraulic loader and a trailer, 8-tonne and 10-tonne forwarders operating separately and as part of a wider harvesting chain, and a light crawler forwarder.

In linear model the time consumption of manual and harvester cutting was calculated stem by stem using the stem distribution of each type stand. The time consumption of terrain transport was calculated using the average conditions of each six type stand.

3.3.2 Productivity and Time Expenditure Models for Cutting

3.3.2.1 Labour-Intensive Cutting

3.3.2.1.1 Professional Loggers

Calculation Bases

In the absence of up-to-date scaling data and information on the productivity of work carried out at the various planning stages, productivity was computed inversely from the employment contracts in force in 1990 (Metsä- ja...1990). To

a great extent, the contracts are based on the productivity relations arrived at in the comprehensive work study for determining piece rates by Kahala (1980) and productivity levels suggested by long-term follow-up statistics. Over the years, new work operations and methods have been added as a result of collective bargaining. The productivity equations applied to cutting operations carried out by private woodlot owners are based on the productivity models developed for professional loggers, from which a certain percentage is subtracted in the way explained below.

The productivity functions for effective time expenditure in timber logging by professional loggers were computed for pine, spruce and hardwood in accordance with the tables included in the collective labour contract for forest work (Metsä- ja ... 1990) in the summer season and in winter conditions with a 45 to 64 cm thick blanket of snow for six cutting operations, namely:

First thinning
- scaling of standing trees by the logger, 5-metre pulpwood bunched on a 10-metre zone
- scaling at road-side, 3-metre pulpwood bunched on a 10-metre zone

Other thinnings
- scaling of standing trees, 5-metre pulpwood bunched on a 10-metre zone
- scaling at road-side, 3-metre pulpwood bunched on a 10-metre zone

Clear cutting
- scaling of standing trees, 5-metre pulpwood bunched on a 10-metre zone
- scaling at road-side, 3-metre pulpwood bunched on a 10-metre zone.

For each working method, cutting wages were computed per cubic metre by which the mean daily earnings were then divided (Tilastokatsaus 1990). This gave the daily output which was divided by the average effective working hours of a logger (Pajuoja 1986), the result being productivity per effective hour. Productivities per effective hour were calculated for all stem sizes. According to the employment contract, the largest stem size class is 626 dm^3. For stems larger than this, productivity values were extrapolated up to 2000 dm^3. The productivities of the cutting methods were tabulated by stem size class. Using the Statgraphics 4.0 (1989) statistics application, the cutting productivity functions by timber assortment were incorporated into this data. The cutting methods used in first thinning were processed as a separate set of equations independently of the methods used in other thinnings and clear cutting because the form of the first-mentioned equations differed so much from the others.

Productivity Models for Effective Working Hours

Productivity equations calculated for effective working hours in cutting operations carried out by professional loggers:

First thinnings:

Pine

$$PE_{mmeI} = e^{-0.613 + 0.0491(mi) - 0.0883(ka) + 0.281\ln(vk) - 0.0136\sqrt{(vk)}} \quad (2)$$

Spruce

$$PE_{kmeI} = e^{-0.978 + 0.0543(mi) - 0.0933(ka) + 0.320\ln(vk) - 0.0160\sqrt{(vk)}} \quad (3)$$

Broad-leaved

$$PE_{lmeI} = e^{-0.789 + 0.0650(mi) - 0.0955(ka) + 0.343\ln(vk) - 0.0180\sqrt{(vk)}} \quad (4)$$

Clear-cuttings and thinnings, excl. first thinnings:

Pine

$$PE_{mmeA} = e^{0.327 + 0.104(mi) - 0.0730(ka) - 0.101(ht) - 0.235\ln(vk) + 0.0703(\ln(vk))^2 - 0.42 \cdot 10^{-6}(vk)^2 + 0.0487 \cdot 10^{-12}(vk)^4} \quad (5)$$

Spruce

$$PE_{kmeA} = e^{-0.0468 + 0.0824(mi) - 0.0720(ka) - 0.124(ht) - 0.131\ln(vk) + 0.0571(\ln(vk))^2 - 0.305 \cdot 10^{-6}(vk)^2 + 0.0319 \cdot 10^{-12}(vk)^4} \quad (6)$$

Broad-leaved

$$PE_{lmeA} = e^{0.458 + 0.0984(mi) - 0.0745(ka) - 0.127(ht) - 0.00167(vk) - 0.391\ln(vk) + 0.110(\ln(vk))^2 + 0.284 \cdot 10^{-6}(vk)^2} \quad (7)$$

where

$PE_{*me\#}$ = productivity of professional logger, m^3/h (effective time)
* m = pine, k = spruce, l = broad-leaved
\# I = first thinnings, A = clear-cuttings and thinnings, excl. first thinnings
mi = method of scaling: 0 = scaling at road-side or scaling of pulpwood in bunches, 1 = scaling of standing trees
ka = snow depth class: 0 = no snow, 3 = 45–64 cm
vk = volume of merchantable bole, dm3
ht = method of cutting: 0 = clear-cutting, 1 = thinnings, excl. first thinning.

The coefficients of determination with regard to the scatter plots computed from the labour contract (Metsä- ja ...1990) are 98.4 % to 99.7 % according to tree species and cutting method.

The number of observations for each tree species is 44 for first thinning-stands and 144 for all other type stands.

Expenditure Models for Effective Working Hours and Work-Site Time

The effective time expenditure models are obtained from productivity equations by dividing the selected time unit by the productivity equation. From the effective working time computed with the models, it is possible to obtain productivities in terms of work-site time by adding to the effective working hours interruptions for 17.6 %, which is obtained from the 15 % interruption time computed from the work-site time (excluding meal breaks) included in Kahala's (1980) work study for the determination of piece rates. Here work-site time is equivalent to production time (see list of symbols) excluding personal breaks for meals.

Then the time expenditure functions for work-site time can be expressed as:

$$CW_* = 1.176\frac{1}{\frac{(\text{productivity function for effective time})}{60}} \qquad (8)$$

where
CW_* = consumption of total working time for alternative species and cutting methods, min/m^3.

Productivity Models for Working Hours

The equations for working hours are converted into cutting productivity equations as follows:

$$PW_* = \frac{60}{CW_*} \qquad (9)$$

where
PW_* = productivity of cutting, m^3/h (work time)
CW_* = time expenditure of cutting, min/m^3 (work time).

The productivity of working hours calculated by means of productivity equations is usually lower in first thinning than suggested by Kahala's (1980) time study (examples given in Fig. 3). The difference is greatest with birch. With small stems, the equations are closer to the values obtained by Kahala (1980). In clear cutting, the productivities computed with the equations are identical to the results produced by Kahala (1980). Since 1980, new duties related to scaling, marking and access planning have been included in first thinnings that naturally reduce cutting productivity.

3.3.2.1.2 Private Woodlot Owners

The productivity of small-scale private cutting operations varies a great deal according to the logger's skills, experience, age, working methods and tools. The figures suggested by the Finnish Work Efficiency Institute in its latest guides are 0.53 to 1.88 m^3/h for spruce (work-site hours) as well as 0.65 to 2.32 m^3/h for pine and birch, while the usable volume of the stem varies from 25 to 500 dm^3 (Metsänomistajan...1989 and Valkonen 1990) (see the TTS curves in Fig. 3). The models for the productivity of private cutting consisted of the following professional-logger models from which 25 % was subtracted:

First thinning
- road-side scaling, 3-metre pulpwood bunched on a 10-metre zone

Other thinnings
- road-side scaling, 3-metre pulpwood bunched on a 10-metre zone

Clear cutting
- road-side scaling, 3-metre pulpwood bunched on a 10-metre zone

The productivity values applied by the Finnish Work Efficiency Institute (Valkonen 1990) fall between the minus 25 % productivity models for professional loggers in snow-free conditions and in conditions with a 50 cm blanket of snow (Fig. 3). In clear cutting, the Institute values remain below the productivities achieved when scaling standing trees.

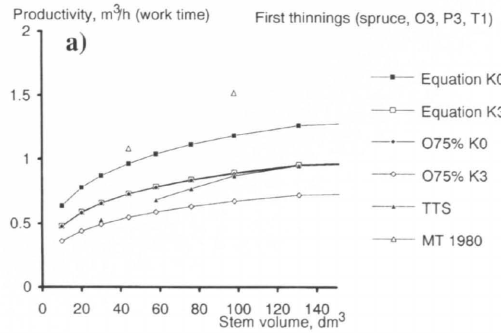
3.3.2.2 Mechanized Logging

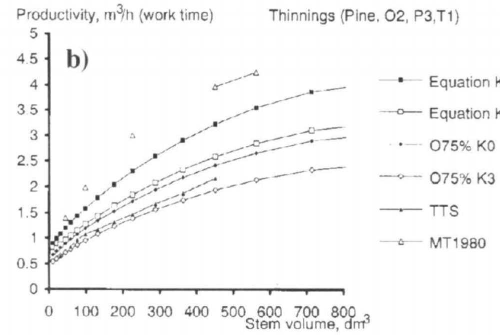
3.3.2.2.1 One-Grip Harvesters

Time Expenditure Models for Clear Cutting

Effective Time Expenditure

The most important single factor affecting time expenditure by loader harvesters is the stem volume (Lilleberg 1990). Using Lilleberg's (1990) data, mathematical time expenditure models were calculated for ordinary one-grip harvesters (weight





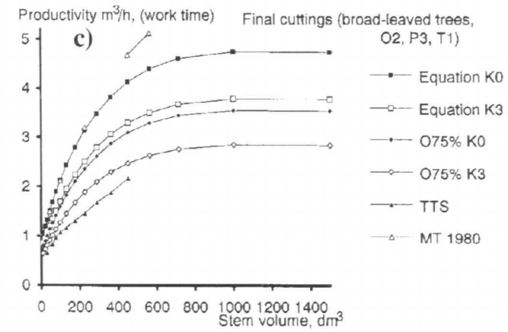


Fig. 3. Productivity curves of cutting by professional loggers: cutting arc-string scaled spruce in first thinnings (A), road-side scaled pine in thinnings excl. first thinnings (B) and broad-leaved trees in clear-cuttings scaled as standing trees (C). In each sub-figure curve *K0* notifies productivity in summertime and curve *K3* productivity in winter with 50 cm snow blanket. Productivity curves for private woodlot owners for summer (*O75%K0*) and for winter (*O75%K3*) represent productivities which equal 75 % of the productivities of professional logger. For the sake of comparison curve *MT 1980* describes the productivity of the professional logger measured by Kahala (1980) and curve *TTS* productivity for private woodlot owners estimated by Valkonen (1990). More accurate explanations in text.

10 to 12 tonnes, maximum cutting capacity 35 to 55 cm). The best correlation between stem volume and time expenditure was provided by an equation of the fourth degree. Because of the nature of the basic data, the effect of other working conditions is calculated by adding the additional time expenditures as percentages to the results yielded by the model. The basic equation for effective time expenditure by one-grip harvesters when clear-cutting softwood is:

$$C_{hkh10a} = 33.09 + 0.107(vk) + 0.777\cdot10^{-4}(vk)^2 - 0.805\cdot10^{-7}(vk)^3 + 0.22\cdot10^{-10}(vk)^4 \qquad (10)$$

where
C_{hkh10a} = time expenditure in clear cutting of conifers by one-grip harvester (10 t), cmin/tree (effective time)
vk = stem volume, dm^3.

The clear-cutting equation is calculated with 27 observations extracted from Lilleberg's (1990) time expenditure curve. The high order of dependent variable was needed to fit exactly the original curve (Fig. 4). According to Lilleberg, time expenditures due to hardwood, snow, undergrowth and marking method should be added to the model. In the present study, these additions include time expenditure due to handling hardwood, another additional time expenditure and the effect of breaks lasting less than 15 minutes. According to Lilleberg (1990), the average additional time expenditure caused by handling hardwood is 15 %. All the other additions due to circumstances such as snow, undergrowth, etc., must then be included in the second additional time expenditure. A 50 cm blanket of snow does not result in a significant additional time expenditure. All the additional times are calculated as percentages of the time expenditure indicated by the basic equation. According to Lilleberg, breaks lasting less than 15 minutes account for 11.7 % of the time expenditure with these medium-size loader harvesters.

Production Time Expenditure

The production and working time expenditures are computed by adding the necessary additional times as percentages to the effective time expenditure. In this study, the stand-specific effective time expenditure is calculated by summing up stem-specific time expenditures to which the interruptions are added as percentages. In this model, the user interface makes it possible to enter the following additional time expenditures (percentages calculated of the effective time expenditure) for the following: service and maintenance (+5.32 %), repairs (+12.80 %), personal breaks (+6.72 %), organization-related interruptions (+1.65 %), and equipment-related interruptions (+0.13 %). The time expenditure percentages suggested by Lilleberg (1990) are given in brackets. To obtain work time expenditure, the time required for moving from one site to another is added to the production time expenditure. According to Lilleberg (1990), the average transfer distance for one-grip harvesters between clear-cutting areas is 47 km and its duration 2.2 h per stand.

Time Expenditure Models for Selective Thinning

Effective Time Expenditure

The best model for correlation between effective time expenditure and stem size calculated on the basis of Lilleberg's study (1990) is of the second degree:

$$C_{hkh10v} = 34.7 + 0.13(vk) + 0.125\cdot10^{-5}(vk)^2 \qquad (11)$$

where
C_{hkh10v} = time expenditure in thinnings of conifers by one-grip harvester (10 t), cmin/tree (effective time)
vk = stem volume, dm^3.

The equation is calculated with 27 observations extracted from Lilleberg's (1990) time expenditure curve (Fig. 4). A productivity comparison between one- and two-grip harvester is shown in Fig. 5. As in the clear-cutting model, other factors affecting effective time expenditure are added to the effective time expenditure computed from the basic equation. The additions are calculated as percentages of the time expenditure obtained from the basic equation. According to Lilleberg (1990), hardwood increases time expenditure by 15 %. Operating time expenditure is obtained by adding to the sum total the percentage of breaks of less than 15 min computed from the basic equation. With Lilleberg (1990), this figure was 11.7 %.

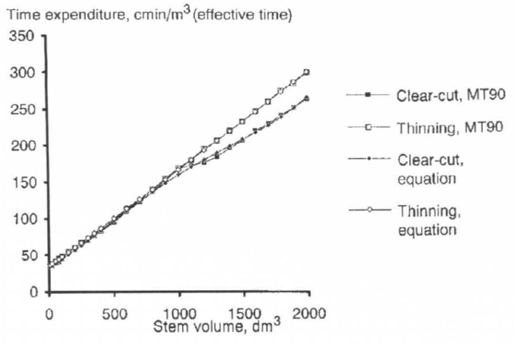


Fig. 4. Cutting clear-cuttings and thinnings by one-grip harvester. Comparison of time expenditure curves: *clear-cutting* (equation 10), *thinning* (equation 11) and *MT90* -curves from Lilleberg's study (1990).

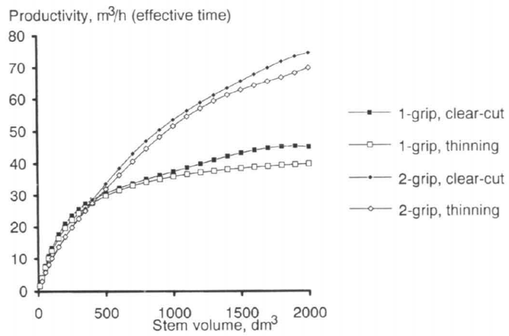


Fig. 5. Cutting clear-cuttings and thinnings by one- and two-grip harvesters. Comparison of productivities by stem volume: *1-grip, clear-cut* (equation 10); *1-grip, thinning* (equation 11); *2-grip, clear-cut* (equation 14) and *2-grip, thinning* (equation 15).

Production Time Expenditure

Production and work time expenditures are computed in the same way as in the clear-cutting models. According to the Lilleberg's results (1990), the percentages of breaks are as follows: service and maintenance 4.77 %, repairs 12.39 %, personal breaks 6.06 %, organization-related interruptions 4.00 % and equipment-related interruptions 1.16 %. The transfer time expenditure necessary for the calculation of working time expenditure was, according to Lilleberg (1990), 2 hours per stand while the corresponding distance was 30.1 km.

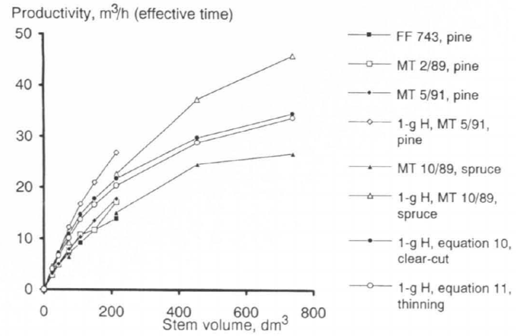


Fig. 6. Cutting clear-cuttings and thinnings by small-harvesters. Comparison of productivity by stem volume -curves: *FF 743* (Sirén 1990); *MT 2/89* (Mäkelä 1989b); *MT 5/91* (Terävä 1991); *1-g H, MT 5/91* (Terävä 1991); *MT 10/89* (Mäkelä 1989a); *1-g H, MT 10/89* (Mäkelä 1989a); *1-g H, clear-cut* = productivity calculated by time expenditure equation 10; *1-g H, thinning* = productivity calculated by time expenditure equation 11.

3.3.2.2.2 Small-Sized Harvesters Productivity Models for Clear Cutting

Effective Time Expenditure

A large number of concise time studies have been published on small-sized harvesters (weight 4 to 8 tonnes, maximum cutting capacity 32 to 40 cm). For the purposes of this study, the productivities calculated from the diameter-specific time expenditures in the studies of Mäkelä (1989a and 1989b), Sirén (1990) and Terävä (1991) were plotted in the productivity diagram of ordinary 10-tonne one-grip harvesters (Fig. 6). The studies by Mäkelä (1989b) and Terävä (1991) also included comparative data on 10-tonne one-grip harvesters.

For this study, the time expenditure curves determined according to Lilleberg (1990) were used for calculating productivity curves that are almost identical in shape to the average curve derived from the small-sized harvester productivity curves in the said studies. In the small-sized harvester studies, the productivity per effective hour was 20 to 33 % lower than that achieved with an ordinary one-grip harvester used in this study and 33 % lower than the productivity of the reference harvesters in the studies of Mäkelä (1989b) and Terävä (1991).

In the interest of simplicity, the values used in the productivity model for small-sized harvesters were selected from the one-grip harvester productivity equation reduced by 33 %. The comprehensive study compiled by Lilleberg (1990) probably gives a more reliable productivity level than limited time studies. However, the productivity ratios suggested by the comparisons included in these studies are most likely correct because the conditions and the extent of the data were identical.

Because of their low power and limited delimbing and cutting capacity, small-sized harvesters are incapable of handling large stems. According to Terävä (1991), a certain efficient small-sized harvester cannot cope with stems with a volume of over 200 dm^3 on a continuous basis. A stem diameter of 35 cm typical of these machines is equivalent to a usable volume of stem of 500 to 700 dm^3. Small-sized harvesters are generally regarded as less reliable than one-grip harvesters (Sirén 1990), but this has not been reflected in the test results obtained in short time studies where the machines are often new. The percentage of breaks lasting less than 15 minutes of the operating time varied from 5 to 15 % (Sirén 1990, Terävä 1991), the corresponding figure for standard loader harvesters being 12 to 15 % (Lilleberg 1990).

According to Terävä (1991), a more difficult terrain increases the time expenditure for small-sized harvesters. A change from Terrain Class 1 to Terrain Class 2 has little effect (Tavoiteansioon...1990) whereas time expenditure in Class 3 is 200 % and in Class 4 370 % of that of Class 1 terrain. It should be pointed out, however, that Mäkelä (1990) has measured lower cutting time expenditure on peat land than on mineral-based terrains. This is due to fact that the low load-bearing capacity of the soil does not hamper track-mounted small-sized harvesters as effectively as standard 10-tonne one-grip harvesters. In terms of load-bearing capacity, the current off-road haulage classification (Tavoiteansioon...1990) no longer corresponds to the capabilities of small machines.

With reference to the above, the model for effective time expenditure by small-sized harvesters in clear-cutting areas is as follows:

$$C_{hkh7a} = 1.5 \cdot [33.09 + 0.107(vk) + 0.777 \cdot 10^{-4}(vk)^2 - 0.805 \cdot 10^{-7}(vk)^3 + 0.22 \cdot 10^{-10}(vk)^4] \quad (12)$$

where
C_{hkh7a} = time expenditure in clear cutting of conifers by small one-grip harvester (7 t), cmin/tree (effective time)
vk = stem volume, dm^3.

To obtain effective time expenditure, the additional time due to work-difficulty factors are added as percentages to the time expenditure calculated from the basic equation. The significant factors are either added to, or subtracted from, the effective time expenditure obtained from the basic equation. Any additions are calculated as percentages of the time expenditure indicated by the basic equation. For hardwood, the addition is 15 % as suggested by Lilleberg (1990). On the basis of the above-mentioned studies, the additional time for breaks of less than 15 minutes necessary for obtaining operating time expenditure is estimated at 15 %.

Production Time Expenditure
As with 10-tonne one-grip harvesters, production time expenditure is obtained by adding breaks to the effective time expenditure and working time expenditure by adding transfer time to the production expenditure. Using the said studies, the following additional expenditures of time were decided: service and maintenance 6 %, repairs 15 %, personal breaks 6 %, organization-related interruptions 2 %, and equipment-related interruptions 0.5 %. The transfer time selected for small-sized harvesters was identical to that of loader harvesters operating in similar conditions: transfer distance 47 km and time 2.2 hours per stand.

Production Models for Selective Cutting

Effective Time Expenditure
In accordance with the above, the effective time expenditure model for selective cutting of softwood by small-sized harvesters is as follows:

$$C_{hkh7v} = 1.5 \cdot [34.7 + 0.13(vk) + 0.125 \cdot 10^{-5}(vk)^2] \quad (13)$$

where
C_{hkh7v} = time expenditure in thinnings of conifers by one-grip harvester (7 t), cmin/tree (effective time)
vk = stem volume, dm^3.

The additional time required by handling hardwood is 15 %. The operating time expenditure is obtained by adding to the sum total of time required by individual stems the percentage of breaks lasting less than 15 minutes, this being 14 %.

Production Time Expenditure
The production time expenditure is obtained by adding the following percentages to the effective time expenditure: service and maintenance (5 %), repairs (15 %), personal breaks (6 %), organization-related interruptions (4 %), and equipment-related interruptions (1 %). The percentage values of the various interruptions defined in connection with the determination of time expenditure by small-sized harvesters are given in brackets. On the same basis, the transfer distance is defined as 30.1 km and transfer time 2 hours per stand.

3.3.2.2.3 Two-Grip Harvesters
Productivity Models for Clear Cutting

Effective Time Expenditure
The equations for effective time expenditure by two-grip harvesters were obtained by manually making equal the mean values for clear and selective cutting arrived at in the two time studies completed by Rieppo (1990a and 1990b), which was then converted into a mathematical form:

$$CE_{hko12a} = 48.1 + 0.156(vk) + 0.125 \cdot 10^{-3}(vk)^2 - 0.261 \cdot 10^{-6}(vk)^3 + 0.124 \cdot 10^{-9}(vk)^4 + 0.217 \cdot 10^{-13}(vk)^5 \quad (14)$$

where
CE_{hko12a} = time expenditure in clear cutting of conifers by two-grip harvester (12 t), min/tree (effective time)
vk = stem volume, dm^3.

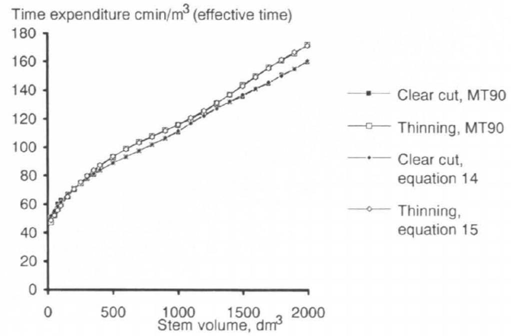


Fig. 7. Cutting clear-cuttings and thinnings by two-grip harvesters. Comparison of time expenditure by stem volume -curves: *Clear-cut* (equation 14), *Thinning* (equation 15), *Clear-cut MT90* and *Thinning MT90* (curves equalized from Rieppo's (1990a and 1990b) studies.

The equation is calculated with 27 observations extracted from the manually smoothed curve from Rieppo's (1990a and 1990b) data. The curve calculated with equation and the smoothed curve are shown in Fig. 7. The degree of added difficulty caused by handling hardwood was estimated by Rieppo (1990a and 1990b) and Lilleberg (1990) to be 15 % of the effective time expenditure. This percentage, together with other additional difficulty factors, is added to the time expenditure yielded by the basic equation. According to Rieppo (1990a and 1990b), breaks lasting less than 15 minutes account for 12 % of the effective working hours. This gives the operating time expenditure.

Production Time Expenditure
As with loader harvesters, the production time expenditure is obtained by adding to the sum total of individual stem handling times in the stand the percentages of breaks and interruptions computed therefrom. According to Rieppo (1990a and 1990b), the following times can be added: service and maintenance 5.10 %, repairs 12.63 %, personal breaks 6.38 %, organization-related interruptions 2.81 %, and equipment-related interruptions 0.64 %. To obtain the working time expenditure, transfer time must be added to the production time expenditure. Kahala and Mäkelä (1985) arrived at a one-grip harvester transfer distance of 43 km and time of 2.1 h. Two-grip harvesters need to move about more than one-grip harvesters because suitable stands with a greater stem size and density are fewer. Therefore the selected distances and times are slightly higher than for loader harvesters: transfer distance 50 km and time 2.6 h.

Productivity Models for Selective Cutting

Effective Time Expenditure
On the basis, which was also given for the clear-cutting model, the effective time expenditure model for selective cutting of softwood by two-grip harvesters is as follows:

$$CE_{hko12v} = 44.7 + 0.16(vk) + 0.173 \cdot 10^{-3}(vk)^2 - 0.106 \cdot 10^{-6}(vk)^3 + 0.219 \cdot 10^{-9}(vk)^4 + 0.102 \cdot 10^{-16}(vk)^5 \quad (15)$$

where
CE_{hko12v} = time expenditure in selective cuttings of conifers by two-grip harvester (12 t), cmin/tree (effective time)
vk = stem volume, dm^3.

It was extracted 27 observations from Rieppo's (1990a and 1990b) manually smoothed curve to calculate the equation 15. The comparison of equation curve and smoothed curve is shown if Fig. 7. As in the case of clear cutting, the effect of the work-difficulty factor is taken into account as a percentage of the effective time expenditure calculated by means of the model. Additional time required by hardwood is 15 %. To obtain the operating time expenditure, 15 % representing interruptions of less than 15 minutes is added.

Production Time Expenditure
As in the case of clear cutting, the production time expenditure is obtained by adding the following percentages to the operating time expenditure computed for the stand: 5.10 % for service and maintenance, 12.63 % for repairs, 6.38 % for personal breaks, 2.81 % for organization-related interruptions and 0.64 % for equipment-related interruptions.

To obtain the working time expenditure, transfer time is added to the production time, the transfer time being identical to that selected for two-grip harvesters used in clear cutting, or 2.6 h. The corresponding transfer distance is 50 km.

3.3.3 Productivity and Time Expenditure Models for Off-Road Haulage

3.3.3.1 Off-Road Haulage by Forwarders

3.3.3.1.1 10-Tonne Self-Loading Forwarders

Productivity of Softwood Haulage per Effective Hour

The productivity models for off-road haulage of softwood logs, 3 m coniferous pulpwood and 5 m coniferous pulpwood in summer conditions were obtained with regard to terrain class, cutting method, timber species density and haulage distance by fitting regression curves to the productivity number series computed by Kahala and Kuitto (1986) from the average time expenditure tables for haulage. After harvesters, the time expenditure relations of the subsequent haulage operations change slightly so that productivity increases (Kuitto 1990). The best functions for softwood by timber assortment were as follows:

$$PE_{hakt10t} = e^{2.12+0.470\ln(l)-0.143(\ln(l))^2+0.211\sqrt{l}-0.0671c-0.081h-0.00155d+0.889\cdot10^{-6}d^2} \quad (16)$$

$$PE_{hakt10k5} = e^{1.97+0.476\ln(l)-0.135(\ln(l))^2+0.196\sqrt{l}-0.0656c-0.123h-0.00158d+0.868\cdot10^{-6}d^2} \quad (17)$$

$$PE_{hakt10k3} = e^{2.04+0.483\ln(l)-0.129(\ln(l))^2+0.185\sqrt{l}-0.0815c-0.0964h-0.00233d+0.158\cdot10^{-5}d^2} \quad (18)$$

where

$PE_{hakt10*}$ = productivity of off-road transportation for different softwood assortments (*) by 10-ton forwarder, m^3/h (effective time)
* t = saw logs, k5 = 5-metre pulpwood, k3 = 3-metre pulpwood

l = timber recovery per strip road length, $m^3/100$ m

c = terrain class of off-road transport (1 ... 3) (Tavoiteansioon ... 1990)

h = dummy-variable for cutting method: 0 = clearcutting, 1 = thinning

d = transport distance, m.

The number of observations given by Kahala and Kuitto (1986) is 240 for each wood assortment. Fig. 8 gives a few examples of how compatible the models are with the data presented by Kahala and Kuitto (1986).

Effective Time Expenditure Models

The effective time expenditure models are arrived at by dividing the selected time unit by the productivity model, here by 1/[productivity equation/60]. Conversely, the productivity models are obtained from the time expenditure models by dividing the appropriate figure, here 60, by the time expenditure model.

The relative time expenditure for the haulage of deciduous pulpwood is, in normal conditions, higher than that for coniferous pulpwood, the difference being 7 to 10 % for 5 m pulpwood and 11 to 17 % for 3 m pulpwood. With logs, there are no differences between timber species (Kahala and Kuitto 1986). A dummy variable that reduces time expenditure by 8 % (5 m) and 13 % (3 m), respectively, was inserted in the equations for hardwood pulpwood.

$$CE_{hakt10t} = \frac{1}{\frac{PE_{hakt10t}}{60}} \quad (19)$$

$$CE_{hakt10k5} = (1-0.08(e))\cdot\frac{1}{\frac{PE_{hakt10k5}}{60}} \quad (20)$$

$$CE_{hakt10k3} = (1-0.13(e))\cdot\frac{1}{\frac{PE_{hakt10k3}}{60}} \quad (21)$$

where

$CE_{hakt10*}$ = time expenditure of off-road transport for different assortments (*), snow depth less than 20 cm, m^3/h (effective time)
* t = saw log, k5 = 5-metre pulpwood, k3 = 3-metre pulpwood

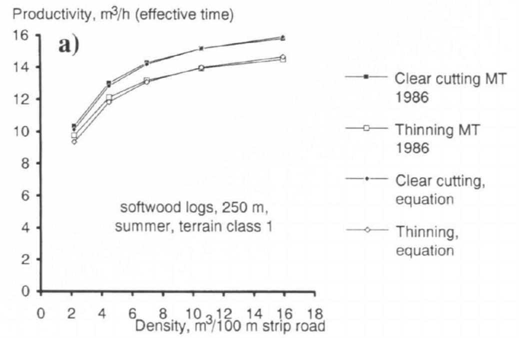
d = off-road transport distance, m

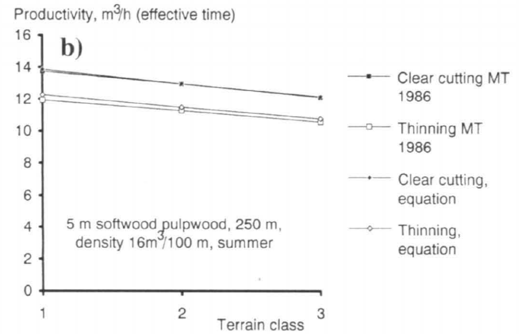
e = dummy-variable for wood assortment: 0 = softwood, 1 = hardwood.

The winter data presented by Kahala and Kuitto (1986) included no sites with a deep a blanket of snow, which reduces productivity as a result of impeded access. When the snow was 30 to 50 cm deep, the productivity of off-road transport was improved by an average of 5 to 10 % from the summer figures because snow levels the surface and the frozen ground increases the load-bearing capacity of the soil. With the increase in the haulage distance, the benefit offered by winter conditions is further highlighted as the percentage of off-road haulage is increased. A linear reduction in effective time expenditure according to distance was calculated from the values suggested by Kahala and Kuitto (1986) to take account of the effect of winter conditions.

On these assumptions, the following effective time expenditure models by timber assortment for winter conditions with a 30 to 50 cm-deep blanket of snow were obtained:

$$CE_{hakt10tl} = \left[\frac{97.5-0.0167(d)}{100}\right]\cdot\frac{1}{\frac{PE_{hakt10t}}{60}} \quad (22)$$





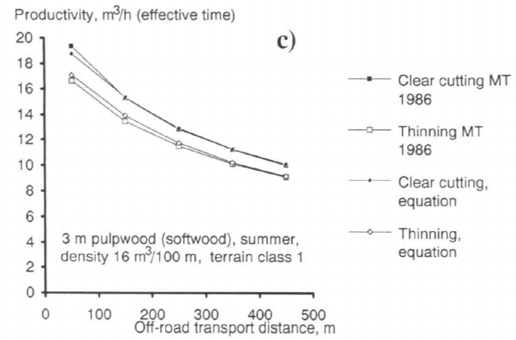


Fig. 8. Off-road transportation of timber by 10-tonne forwarder. Comparison of productivity curves. Sub-figure A: Productivity by wood assortment density in transportation of softwood saw-logs. *MT 1986* -curves base on Kahala and Kuitto (1986) and Equation -curves base on equation 16. Sub-figure B: Productivity by terrain class in transportation of 5-metre softwood pulpwood. *MT 1986* - curves base on Kahala and Kuitto (1986) and Equation -curves base on equation 17. Sub-figure C: Productivity by transport distance in transportation of 3-metre softwood pulpwood *MT 1986* - curves base on Kahala and Kuitto (1986) and Equation -curves base on equation 18.

$$CE_{hakt10k5l} = \left[\frac{98.5-0.0167(d)}{100}\right]\cdot(1-0.08(e))\cdot\frac{1}{\frac{PE_{hakt10k5}}{60}} \quad (23)$$

$$CE_{hakt10k3l} = \left[\frac{96.0-0.02(d)}{100}\right]\cdot(1.013(e))\cdot\frac{1}{\frac{PE_{hakt10k3}}{60}} \quad (24)$$

where

$CE_{hakt10*l}$ = time expenditure of off-road transport for different assortments (*), snow depth 30 ... 50 cm, m^3/h (effective time)
* t = saw log, k5 = 5-metre pulpwood, k3 = 3-metre pulpwood

d = off-road transport distance, m,

e = dummy-variable for assortment: 0 = softwood, 1 = hardwood.

The operating time expenditure is obtained by adding to the above values the expenditure of time for breaks and interruptions lasting less than 15 minutes. According to Kahala and Kuitto (1988), such breaks accounted for 6.5 % of the operating time both when the ground was bare and covered by snow. As a result, the operating time expenditure is obtained by multiplying the effective time expenditure by the factor:

$$a_{e15} = 1 + \frac{\frac{100}{93.5}\cdot 6.5}{100} = 1.0695 \quad (25)$$

where

a_{e15} = factor to transform effective time expenditure to operating time expenditure.

The same factor can therefore be applied irrespective of whether the ground is bare or covered by snow.

Work Time Expenditure Models

According to the data presented in the follow-up study by Kahala and Kuitto (1986), operating time accounted for 83.4 %, equipment and organization-related interruptions for 8.2 %, personal operator breaks for 4.3 % and transfers from site to site for 4.1 % of the working hours. When calculated as percentages of the operating time, these values are equivalent to the following additional percentages that must be added to the operating time to obtain work time expenditure: equipment and organization-related interruptions 9.36 %, personal breaks 5.16 %, and transfers from site to site 4.92 %, the total being 19.90 %.

3.3.3.1.2 8-Tonne Self-Loading Forwarders

Mäkelä (1989a, 1989b and 1990) has compared the performance of a 10-tonne forwarder with that of a 8-tonne wheeled forwarder and a 4-tonne track-mounted forwarder in first thinning conditions. Due to their limited loading capacity, small-sized forwarders must take the logs to the storage location more often than larger machines, which reduces their productivity as a result of the increased haulage distance. The effect of tree density on the loading time remains more a less constant irrespective of the size of the forwarder because with modern forwarders, the ratio of loader performance to log-carrying capacity is practically the same. Relatively speaking, the obstacles presented by hills, rocks and stumps slow down small-sized forwarders more effectively than large ones. The reduced load-bearing capacity of the soil increases time expenditure by wheeled forwarders more than by track-mounted machines because of the lower surface pressures exerted by the latter.

The results obtained by Mäkelä (1989a and 1990) were plotted in the same diagram as the productivity models computed for the 10-tonne forwarder in similar conditions (Fig. 9). The model for the 10-tonne forwarder is identical in shape to the curves calculated from the equations (16, 17 and 18) but at a higher level of productivity. As expected, the productivity of 8-tonne and 4-tonne forwarders decreases more rapidly with increasing distance than that of 10-tonne forwarders.

To determine the productivity model, mean value curves for 8-tonne and 4-tonne forwarders were made equal manually and their ratio to the curve for the 10-tonne forwarder was calculated. The percentage declines almost linearly with increasing distance, this decline being sharper for track-mounted forwarders than 8-tonne wheeled forwarders. The coefficient of determination of the linear adjustment equations to be used later on

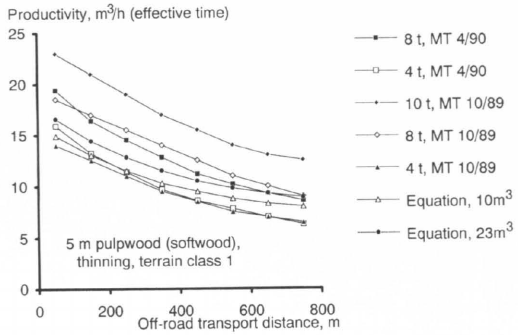


Fig. 9. Productivity by transport distance of off-road transportation by forwarders. Effect of size of forwarder on productivity. In legend the first number explains size of the load in tons. *MT 4/90* -curves base on Mäkelä (1990), *MT 10/89* -curves on Mäkelä (1989a) and *Equation* -curves on 10-tonne forwarder equations when removed density is 10 or 23 m³/100 metre strip-road (see text).

is 94 % to 96 % in respect of the differences in productivity. The productivity of small-sized forwarders, in terms of percentage of 10-tonne forwarder productivity, suggested by Mäkelä (1989b) is identical to that computed for the 4-tonne forwarder in this study, while the corresponding figure in proportion to distance calculated for 8-tonne forwarders declines even more sharply. Productivity computed from the data published by Kahala and Kuitto (1986) was selected for the productivity level to be used in subsequent models because their data is more comprehensive despite the fact that the productivities measured by Mäkelä (1989a, 1989b and 1990) were slightly higher.

On the basis of the above, a linearly declining portion of the 10-tonne forwarder model is used as the productivity model for 8-tonne forwarders in the calculations as follows:

$$PE_8 = (82.9 - 0.014 \cdot d) \cdot PE_{10} \qquad (26)$$

where
PE_8 = productivity of off-road transport by 8-tonne forwarder, m^3/h (effective time)
PE_{10} = productivity of off-road transport by 10-tonne forwarder, m^3/h (effective time)
d = transport distance, m.

The productivities and time expenditures for operating and work times are computed at the same interruption and transfer values that were used for 10-tonne forwarders.

3.3.3.1.3 4-Tonne Self-Loading Forwarders

On the basis of the above, a linearly declining portion of the 10-tonne forwarder model is used as the productivity model for 4-tonne track-mounted forwarders in the calculations as follows:

$$PE_4 = (64.4 - 0.019 \cdot d) \cdot PE_{10} \qquad (27)$$

where
PE_4 = productivity of off-road transport by 4-tonne forwarder, m^3/h (effective time)
PE_{10} = productivity of off-road transport by 10-tonne forwarder, m^3/h (effective time)
d = transport distance, m.

The productivities and time expenditures for operating and work times are computed at the same interruption and transfer values that were used for 10-tonne forwarders.

3.3.3.2 Off-Road Haulage by Farm Tractor
3.3.3.2.1 Trailer and Hydraulic Loader

Effective Time Expenditure

The time expenditure models for farm tractors with trailers were computed from the data compiled by Mikkonen (1984) on entrepreneurs who use farm tractors. Of the three size categories, small-sized tractors were selected as the most suitable machines. By Mikkonen's definition, these are rear-wheel- driven tractors with an output of 40 to 60 kW and fitted with a lightweight hydraulic loader and non-tractive trailer. Since the study was made, tractors have been further improved so that productivities in similar conditions would today be higher. Mikkonen's study was concerned with qualified operators working on a full-time basis. In this study, the tractor fleet consists of the harvesting equipment used by private woodlot owners whose operator skills are not up to professional standards. The productivity of softwood haulage in clear cutting in summer is from Mikkonen (1984). Productivities at densities in excess of 16 m³/(100 m striproad) were estimated. The effect of snow on productivity was calculated at the ratio suggested by the results obtained by Mikkonen (1984) for medium-sized tractors by correcting the values for the small-sized tractor. Small-sized tractors are hampered by snow more than large ones but this distortion is offset by the improved off-road performance of new machines.

The input data was used to first calculate productivity models from which the time expenditure models were then construed. Models for the productivity of off-road haulage of logs and pulpwood were computed for clear cutting conditions:

$$PE_{mpta} = e^{1.46 - 5.31 \cdot 10^{-3} s - 0.201 \cdot 10^{-9} (s)^5 + 0.428 \ln(l) - 0.124 (\ln(l))^2 + 0.162 \sqrt{l} + 0.104 \ln(d) - 0.0535 \sqrt{d}} \qquad (28)$$

$$PE_{mpk3ta} = e^{2.18 - 0.158 \cdot 10^{-3} s^2 - 0.010 \sqrt{s} + 0.280 \ln(l) - 0.0328 (\ln(l))^2 - 0.0446 \sqrt{d}} \qquad (29)$$

where
PE_{mpta} = productivity of off-road transport of saw logs in clearcutting, m^3/h (effective time)
PE_{mpk3ta} = productivity of off-road transport of 3-metre pulpwood in clearcutting, m^3/h (effective time)
d = off-road transport distance, m
l = timber recovery per strip road length, $m^3/100$ m
s = depth of snow, cm.

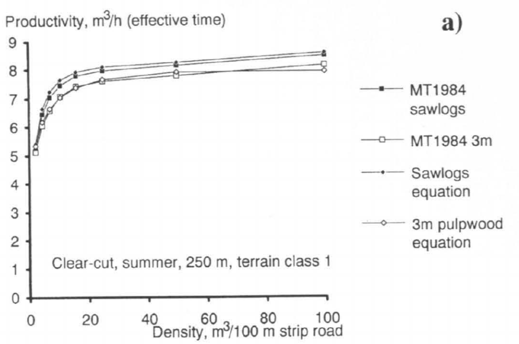
The coefficient of determination of the equations in respect of Mikkonen's (1984) scatter plots are 96.1 % for logs and 95.8 % for 3 m pulpwood (Fig. 10). The number of Mikkonen's (1984) smoothed average productivity observations is 160 for both logs and 3 m pulpwood. The differences between the pulpwood productivity model and observations were found to be greatest at short distances and in snow conditions.

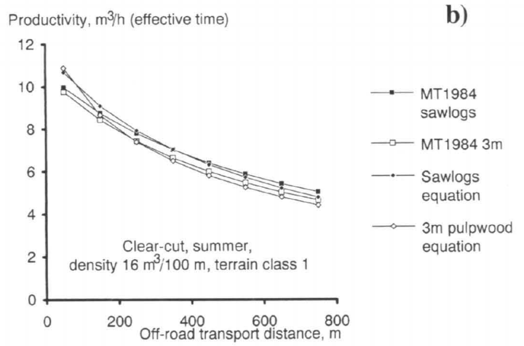
According to Mikkonen (1984), loading takes a longer time in thinning than in clear cutting operations. At short distances, relative time expenditure is slightly greater than at long distances. Productivity computed per effective hour is converted into time expenditure by dividing the selected time unit by the productivity equations, here 1/[(productivity equation)/60]. In thinnings, time expenditure is greater than in clear cutting, the difference being approx. 7 % for logs and 2.5 % for 3 m pulpwood. The effective time expenditure equations are as follows:

$$CE_{mpt} = (1 + 0.07(h)) \cdot \frac{1}{\frac{PE_{mpta}}{60}} \qquad (30)$$

$$CE_{mpk3} = (1 + 0.025(h)) \cdot \frac{1}{\frac{PE_{mpk3ta}}{60}} \qquad (31)$$

where
CE_{mpt} = time expenditure of off-road transport of saw logs by farm tractor with trailer and hydraulic knuckle boom loader, min/m^3 (effective time)
CE_{mpk3} = time expenditure of off-road transport of 3-metre pulpwood by farm tractor with trailer and hydraulic knuckle boom loader, min/m^3 (effective time)
PE_{mpta} = productivity of off-road transport of saw logs in clearcutting, m^3/h (effective time)
PE_{mpk3ta} = productivity of off-road transport of 3-metre pulpwood in clearcutting, m^3/h (effective time)
h = dummy-variable for method of cutting: 0 = clearcutting, 1 = thinning.





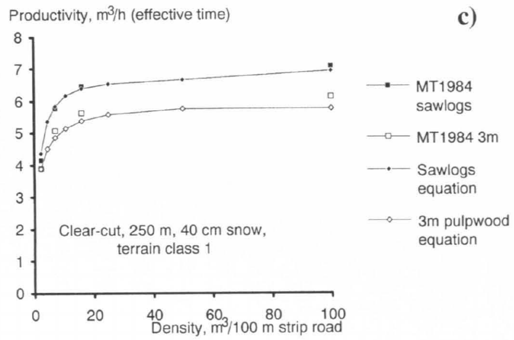


Fig. 10. Productivity of off-road transportation by small farm tractor equipped with trailer and hydraulic loader. Comparison of productivity by removed density (A), by transport distance (B) and by snow condition (C) -curves. *Sawlogs*-curves base on equation 28 and *3m pulpwood*-curves on equation 29. All *MT 1984* -curves base on Mikkonen's (1984) study. Working conditions are described in figures.

Production Time Expenditure

The operating time expenditure is obtained by adding to the effective time expenditure the time expended on breaks and interruptions lasting less than 15 minutes. According to Mikkonen (1984), this accounted for 4.3 % of the operating time. The work time expenditure is obtained by adding to the operating time expenditure the time required by other interruptions and transfers from site to site. In Mikkonen's study (1984), interruptions accounted for 19.5 % and transfers for 5.3 % of the operating time. As a result, the time expenditure equations can be formulated as follows:

$$CE_{15*} = 1.045 \cdot CE_{*} \qquad (32)$$

where
CE_{15*} = operating time expenditure for the particular working method, min/m^3
CE_{*} = effective time expenditure for the same working method, min/m^3.

$$CT_{*} = 1.248 \cdot CE_{15*} \qquad (33)$$

where
CT_{*} = total working time expenditure for the particular working method, min/m^3
CE_{15*} = operating time expenditure for the same working method, min/m^3

3.3.3.2.2 Hydraulic Skidding Grapple

Effective Time Expenditure

The productivity models for farm tractors fitted with hydraulic skidding grapples are based on the unpublished data gathered by Mr. Seppo Ryynänen (M.Sc.(Agr.For.), office manager of Work Efficiency Institute, Field Research Station Office, Rajamäki). In this study, a medium-sized farm tractor with a hydraulic skidding grapple carried logs and 3 m pulpwood in a second thinning in summer conditions. The best model for the productivity of haulage was:

$$PE_{15mk} = e^{2.51+0.577\ln(l)-0.0753(\ln(l))^2+1.15\cdot 10^{-11}l^5-0.248\ln(d)-0.056\sqrt{d}} \qquad (34)$$

where
PE_{15mk} = productivity of off-road transport by farm tractor with hydraulic skidding grapple, m^3/h (effective time incl. delays shorter than 15 min)
d = off-road transport distance, m
l = timber recovery per strip road length, m^3/100 m.

The coefficient of determination of the model in respect of Ryynänen's unpublished material's scatter plot is 98.7 % (Fig. 11). The number of Ryynänen's smoothed average productivity observations is 40. At very short distances, the

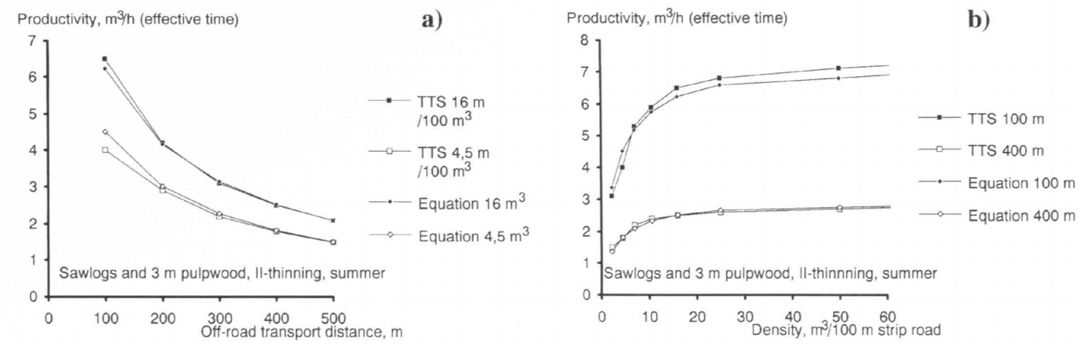


Fig. 11. Productivity of off-road transportation of saw-logs and 3 metre pulpwood by small farm tractor. Comparisons of productivity by transport distance (A) and removed density (B). *TTS* -curves base on data given by Mr Ryynänen (see text) and *Equation* -curves on equation 34. Working conditions are descibed in figures.

model fails to conform with the original data. The productivity values can be converted into time expenditure by dividing the selected time unit by the production model, which yields the following time expenditure equation:

$$CE_{mk} = \frac{1}{\frac{PE_{15mk}}{60}} \qquad (35)$$

where
CE_{mk} = time expenditure in off-road transport of saw logs and 3-metre pulpwood by farm tractor with hydraulic skidding grapple, min/m^3 (effective time)
PE_{15mk} = productivity of off-road transport by farm tractor with hydraulic skidding grapple, m^3/h (effective time).

Work-difficulty factors can be added as percentages to the computed time expenditure.

Production Time Expenditure

No significant data on work and production times are available on the hydraulic skidding grapple. The grapple is a simple device so that its reliability in operation per time unit is probably higher than that of a trailer-loader combination. The longest interruptions affecting such a combination are due to the hydraulic system and tyres (Mikkonen 1984). A unit using the hydraulic skidding grapple features fewer tyres and less hydraulics. As a result, interruptions were estimated at 15 % of the effective working hours, which is equal to two-thirds of that of a tractor-trailer combination. Transfer times were estimated at 5 %, as with the tractor-trailer unit. Then the productivity equation for working hours is obtained as:

$$PT_{mk} = \frac{PE_{15mk}}{1.20} \qquad (36)$$

where
PT_{mk} = productivity of off-road transport by farm tractor with hydraulic skidding grapple, m^3/h (total working time)
PE_{15mk} = productivity of off-road transport by farm tractor with hydraulic skidding grapple, m^3/h (effective time).

and the corresponding work time expenditure model is:

$$CT_{mk} = \frac{1}{\frac{PT_{mk}}{60}} \qquad (37)$$

where
CT_{mk} = time expenditure in off-road transport of saw logs and 3-metre pulpwood by farm tractor with hydraulic skidding grapple, min/m^3 (total working time)
PT_{mk} = productivity of off-road transport by farm tractor with hydraulic skidding grapple, m^3/h (total working time).

3.3.4 Productivity and Cost Models for Long-Distance Haulage

3.3.4.1 Productivity and Time Expenditure Models for Haulage by Truck

The quantity of timber transported by truck is expressed in terms of volume units. However, the maximum load and freight rates are determined by weight. To bridge this gap, it is necessary to use specific densities which vary according to season owing to moisture content fluctuations and other such factors. The maximum permissible total weight of a timber truck is 56 tonnes, which may be increased, subject to a special permit, to 60 tonnes when the soil is frozen. The haulage output depends, then, on the timber species involved and the time of the year. The haulage of one load from the site to the processing point and the return trip to pick up a new load constitutes round-trip time from which productivity is calculated as a ratio of the transported quantity to time expenditure.

Alve (1988) has conducted an extensive study on time expenditure by timber trucks. For the purposes of the said study, the round-trip was broken up into the following constituent parts:

$$T_{ak} = (e_{aka} + e_{akk} + e_{apa} + e_{akt} + d_{ak}) \quad (38)$$

where
T_{ak} = time expenditure of one round-trip in truck transport, cmin
e_{aka} = time expenditure of loading, cmin
e_{akk} = time expenditure of hauling load, cmin
e_{apa^*} = time expenditure of unloading, cmin
* method of unloading
s = bridge crane
k = wheeled loader
o = vehicles own loader
n = make up in bundles and dumping
e_{akt} = time expenditure of driving without load, cmin
d_{ak} = time expenditure of delays, cmin.

Time expenditure for timber haulage by truck is obtained by dividing the duration of the round-trip by the quantity of timber transported:

$$CT_{ak} = \frac{T_{ak}}{V_{ak}} \quad (39)$$

where
CT_{ak} = time expenditure of transporting timber by truck, m^3/cmin (total working time)
T_{ak} = time expenditure of one round-trip, cmin
V_{ak} = volume of the load, m^3.

According to Alve (1988), a vehicle spends an average of 92 min per load at the storage site when the volume of the cargo is 47 m^3. This gives the loading time required for one cubic metre, which is 196 cmin. The volume units are converted into mass units using the specific densities (Table 1) measured by Marjomaa and Oijala (1990).

According to Oijala and Pennanen, the unloaded weight of the vehicle is 19 500 kg. Subject to a total weight of 56 000 kg, it can load cargo up to 36 500 kg. If the total weight is 60 000 kg, the cargo can be 40 500 kg. On these assumptions, the time required for loading is:

$$e_{aka} = \frac{M_{max}}{D_{ta}} \cdot dh_{ak} \quad (40)$$

where
e_{aka} = time expenditure of loading, cmin
M_{max} = maximum payload of vehicle, kg
D_{ta} = density of the wood assortment at the moment of transport, kg/m^3
dh_{ak} = time expenditure of loading, cmin/m^3.

Table 1. Average densities of wood assortments transported by trucks in the whole of Finland. (Marjomaa & Oijala 1990).

Wood assortment	Density of timber assortment, kg/m^3 Febr.	May	August	Nov.	Average
Pine logs	870	832	804	845	842
Spruce logs	838	787	762	805	804
Birch logs	955	910	888	932	925
Coniferous pulpwood	870	830	735	808	817
Birch pulpwood	920	869	829	876	880

The driving times when the vehicle is fully loaded and empty depend on the distance to be covered and the quality of the roads. According to Alve (1988), the average speed increases sharply up to a haulage distance of 50 km, to stabilize around 60 km/h at longer distances. Kukko et al. (1990) have worked out non-linear functions on the basis of Alve's (1988) scatter plots and curves. They do not give number of observations.

$$V_{akk} = -0.446 + 31.7\log(d_{akk}) \quad (41)$$

$$V_{akt} = 5.97 + 30.6\log(d_{akt}) \quad (42)$$

where
V_{akk} = average speed of the loaded truck, km/h
V_{akt} = average speed of the unloaded truck, km/h
d_{akk} = transport distance loaded, km
d_{akt} = transport distance unloaded, km.

Driving times when loaded and empty are obtained by multiplying the average speed by haulage distance.

The time required to unload the vehicle is determined by the timber species, unloading point and available equipment. According to Alve (1988), unloading an articulated truck takes approx. 3000 cmin with a wheeled loader, 5500 cmin with a bridge crane and 4000 cmin when tipped. The mean unloading time is 4300 cmin. According to Korpilahti (1989), unloading takes 4900 cmin at a mill, 3900 cmin at a log dump site on ice or at lakefront, and 3700 cmin when the cargo is unloaded onto a railway wagon or stockpile using the vehicle's own crane, the overall average being 4300 cmin per cargo. The unloading time required by the selected unloading device can be substituted in equation 38.

According to Alve (1988), interruptions included in the haulage time expenditure excluding meal breaks amount to 2200 cmin/load and interruptions not included in the haulage time expenditure to 3400 cmin/load. Half of this time is expended on maintenance and repairs. In equation 38, the duration of interruptions is 4600 cmin.

3.3.4.2 Cost Model for Haulage by Rail

The transportation chain by rail consists of loading, haulage, unloading, empty legs and various interruptions. Normally the logs are loaded using the vehicle's own crane, while unloading is usually carried out with a loader or bridge crane. On the railway, the logs are carried in freight wagons that are coupled to suitable trains. At junctions, the wagons can be switched to another train. Switching may be required both at the dispatch station and the destination to form a train and break it up. A single freight wagon is the smallest and an entire train the largest haulage unit. The higher the number of log-carrying wagons coupled together, the less switching work is required. A whole train is even more economical because there is no need to break it up at any point and because the route can then be planned direct from the loading point to the unloading point. Traditionally, railway companies have high fixed expenditure due to track maintenance. Also, it is difficult to allocate costs to various types of cargo because the personnel works simultaneously on several shipments. In Finland, the Government underwrites the cost of track maintenance (FIM 1.2 billion in 1990) for which the State Railways pay a track use charge (FIM 1 million in 1990). The business operations, i.e. haulage including related supportive services, must be self-financing (total turnover in 1990 FIM 3.4 billion). Freight transport accounts for 62 % of the total turnover (VR ... 1991).

It is impossible to generate relevant time expenditure models for rail transports. Therefore the following calculations are based on transportation cost. The rates applied by the State Railways to timber freight are based on distance, specific density of timber and the size of the consignment measured in terms of the quantity of timber loaded onto the cars (Vaunukuormien... 1992). Discounts are allowed for wagon groupings and transports where the entire train is chartered for the purpose. The transportation costs of major customers are determined by annual volumes and are agreed upon on a case-by-case basis.

Using the rate tables for freight wagons, it is possible to compute the effect of distance and type of timber on the cost of transportation. The size of the cargo subject to the rates refers to the degree to which the wagons are filled, and so it cannot be used to predict cost ratios for loads larger than a single wagon-load. The following model for transportation cost was computed at car-loads exceeding 60 m^3:

$$Crr = at \cdot (4.52 + 10.48pl + 0.157dtr - 0.19 \cdot 10^{-4}dtr^2 + 3.72\ln(dtr)) \quad (43)$$

where
Crr = rail transport cost, FIM/m^3
at = discount factor
pl = dummy-variable for tree species: 0 = coniferous, 1 = birch
dtr = transport distance, km.

The model was calculated for fresh timber per single wagon-load. Discounts for larger shipments must be given as percentages of the basic model. The coefficient of determination of the model in respect of the rate table is 99.5 %, while the number of observations is 33. The model slightly overestimates the cost of haulage over short distances (Fig. 12).

The productivity model used for simulation was multiplied by 0.6 because companies are allowed substantial discounts on the rate tables according to freight volumes.

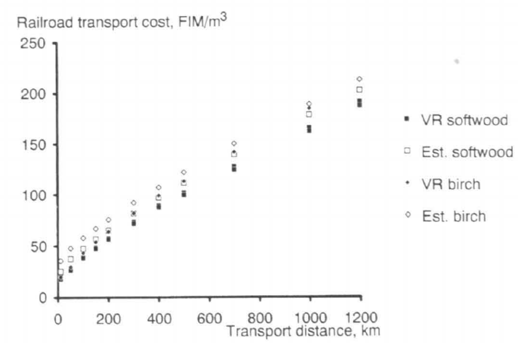


Fig. 12. Rail transport cost by transport distance. Comparison of official softwood and birch tariffs (*VR*-curves) (Vaunukuormien...1992) and their estimates based on equation 43 (*Est.*-curves).

3.3.4.3 Cost Model for Floating

Loose floating on the Kemijoki River ended in 1992 for reasons related to hydro-electric development and conservation. Floating in bundles is a realistic alternative in the Saimaa and Kymi water-systems. In addition, logs felled on the coast and archipelago are floated by sea and inland waterways. In 1989, well over 5 million m^3 of timber was floated in bundles, with the Saimaa water-system accounting for over 70 % of the total. In the late 1980s, the volumes of floated timber began to decrease (Nieminen and Oijala 1991). This was due to the fact that floating affects timber quality and it cannot be carried out throughout the year. At head waters, floating is organized by log-floating associations which charge fees from floaters according to volume. The large log rafts are towed either by the floaters themselves or outside contractors.

As in the case of transportation by rail, it is complicated to devise relevant time expenditure models for floating operations (Pulkki 1984), which is why the cost dependencies for floating are here calculated for the conditions prevailing in the Saimaa water-system. In 1990, a total of 3.1 million m^3 of timber was floated there, with 55 % of the total being dumped into water by log-floating associations and 45 % by the companies themselves. A mere 6 % of the total was dumped on ice. (Niputustilasto...1991 and Savo-Karjalan...1990). The most important destinations where logs are floated to are the mills in the southern Saimaa area near Imatra and Lappeenranta.

Floating costs consist of bundling, raft assembly, towing, passage through canal locks and raft disassembly. During towing, it may be necessary to wait out winds indefinitely in sheltered locations. Additional costs are incurred in winter when the timberyards on ice must be maintained and supervised (Savo-Karjalan...1990). Interest losses are also incurred while the timber is being floated. Most of the floating costs are due to the maintenance of the channels, fleet and operational capabilities. By and large, these are fixed costs irrespective of the volumes floated, i.e. the more timber is floated, the more economical it becomes. To a great extent, the costs are determined by the characteristics of the floatways: the highest efficiency is achieved on routes with no canals. Usually the logs are bundled on timber trucks which must be fitted with removable columns. Simpler, cheaper and lighter columns can be used if there is a loader and bundling cradle at the dumping site (Nieminen and Oijala 1991). In the following equation bundling is assumed to be made in truck.

The following was determined as the cost model for floating:

$$C_f = y(c_i) + c_r + c_u + d_f(c_f + c_{ff}) + c_c(0.0247 - 0.173 \cdot 10^{-2} d_f + 0.304 \cdot 10^{-4} d_f^2) \qquad (44)$$

where
C_f = floating cost, FIM/m^3
y = dummy-variable for season; 0 = summer, 1 = winter
c_i = building and supervising cost of ice dump, FIM/m^3
c_r = cost of bundle binds and building raft, FIM/m^3
c_u = cost of unloading raft, FIM/m^3
c_f = overhead cost: administration, equipment and interest, FIM/m^3-km
c_{ff} = work and material cost, FIM/m^3-km
c_c = cost of passing one channel, FIM/m^3
d_f = floating distance, km.

The data on the cost of haulage onto the ice and raft assembly have been taken from the reports filed by log-floating associations. The volumes and costs per floatway were used to calculate shipments by individual associations from points of departure to the various destinations (Savo-Karjalan...1990). For log floating carried out by the companies, two shipments were calculated, one from upstream and one from downstream the Laitaatsilta Bridge to the mills located in southern Saimaa (Niputustilasto...1991). The cost of transportation from the dumping sites to the processing points were estimated using the costs determined by the log-floating associations except that the costs for the longest floating distances were slightly lowered. Fixed expenditure was allocated over each individual haulage. The number of channels per distance was calculated by weighing the number of channels along the said routes by the volume of the timber floated. The scatter plot obtained thereby was made equal by means of a non-linear regression equation (model 44) with a coefficient of determination of 44 % (only 19 observations). Accordingly, constituent costs for 1990 were as follows:

c_i = 5,96 FIM/m^3
c_r = 2,59 FIM/m^3
c_u = 3,02 FIM/m^3
c_f = 0,0132 FIM/m^3-km
c_{ff} = 0,0243 FIM/m^3-km
c_c = 0,256 FIM/m^3.

For individual locations, the costs yielded by the model are uncertain due to the significant effects of floatways and volumes.

3.3.5 Time Expenditure and Cost Models for Administrative Measures

3.3.5.1 Time Expenditure Models for Stand Design, Timber Scaling and Work Supervision

3.3.5.1.1 General

The method of stand design is determined by the method of scaling (and vice versa); for example, stand design is part of the scaling of standing trees. The extent to which work supervision is required depends on the skills of the personnel and the working methods employed. Below, separate models have been defined for the time expenditure for travel, preparation and site tours common to all the methods of scaling and supervision. The number of tours depends on the working methods. The time required for computing the scaling results, payroll and payments accounting depends more on the method of scaling than the data system used. The quickest way is direct data transmission from the scaling unit to a central computer. Time expenditure models for the most important scaling methods are presented below. The time expenditure equations for the scaling of standing trees and scaling in bunches are given in the reference Rummukainen et al. (1993).

3.3.5.1.2 Travel Time

Pennanen (1978) and Halinen (1984) have measured the total time required for travel by car and on foot and calculated its correlation with the size of the stand marked for cutting. According to Berg (1991), time expenditure for travel by car increases with increasing distance. When Berg's equation is used for computing time expenditure for travel by car, and walking speed in the forest is assumed to be 4 km/h, the additional time required for preparations in the conditions assumed by Halinen (1984) is obtained as 16 to 26 min. When applied to the time expenditure suggested by Pennanen (1978), the travel time given by the equations falls 2 to 8 min short. Over the past ten years, the number of people riding in any single car has dropped and both the roads and cars have improved. Using Berg's (1991) time expenditure for travel by car and a walking speed of 4 km/h, the following equation for travel time expenditure is obtained:

$$ct_{kaj} = [c_{kv} + (404 + 83.4 d_a)] + 6000 \cdot \frac{d_j}{4} = (c_{kv} + 404 + 83.4 d_a + 1500 d_j) \qquad (45)$$

where
ct_{kaj} = time expenditure of travel and preparations, cmin
c_{kv} = time expenditure of preparations, cmin
d_a = travelling distance with car (round-trip), km
d_j = walking distance (round-trip), km.

Substituting the average driving distance of 85 km, walking distance of 0.6 km and preparation time of 10 minutes in accordance with Halinen (1984) gives a travel time expenditure of 94 minutes.

The time expended on travel and preparations must be computed for all travellers if more than one employee is required for the job at hand at any one time. The travel and preparation times also depend on how may trips to a given stand have to be made. This can be calculated by subtracting the duration of one visit from the maximum working hours and computing how many days it takes to perform the all the work required on the stand for a given number of workers. The travel time expenditure is then obtained by multiplying the time expenditure for one visit by the number of visits and travellers. According to Halinen (1984), the total duration of a day used for scaling is 44 000 cmin.

3.3.5.1.3 Stand Definition and Harvesting Planning

According to Halinen (1984), time expenditure for harvesting planning per area unit decreases with increasing stand size and is clearly greater for thinnings than for clear cutting. Currently, the time expenditure for stand design by foreperson is declining all the time because workers and contractors are increasingly being given responsibilities related to planning. At the same time, changes in piece and payment rates reduce the need for planning. Because of the foreseeable developments, the time expenditure model based on Halinen's (1984) data is here reduced by more than a third:

$$cw_{ls} = 0.7 \cdot (9788 - 1759a_l + 240a_l^2 + 3536h_t) \qquad (46)$$

where
cw_{ls} = time expenditure of stand definition and harvesting planning, excl. travel time, cmin/ha (work place time),
a_l = area of the stand, ha
h_t = dummy-variable for cutting method: 0 = clearcutting, 1 = thinning
0,7 = factor for reducing the time expenditure because of the foreseeable developments in methods and implements.

The model is calculated with 15 observations extracted from Halinen (1984) time expenditure curve. The model seems to be less accurate in explaining thinning data than clear cutting data (Fig. 13).

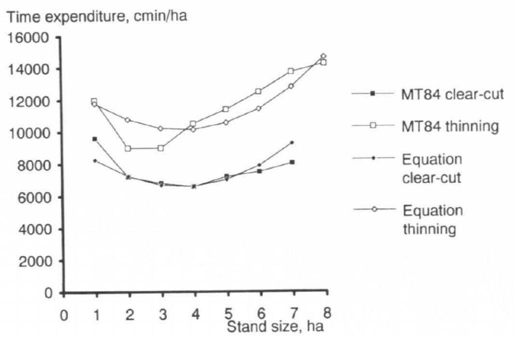


Fig. 13. Time expenditure of stand design as a separate operation without travels in clear-cutting and thinning. Comparision of Halinen's (1984) time study result (*MT84* -curves) and it's estimate calculated with equation 46 (*equation*-curves).

3.3.5.1.4 Guidance and Work Supervision

The time required for guidance and work supervision varies from company to company and from supervisor to supervisor. The number of visits by a foreperson to a single site is higher for labour-intensive sites than mechanized sites because on the latter the contractor is himself responsible for the performance of the work and occupational safety. When work on a stand is started, the foreperson visits the site to explain factors related to methods, quality and location. Final inspection will not be carried out until work on the site is completed. Often, this is associated with scaling and other such activities.

The point of departure in the calculations is that site planning and possible advance measurements are carried out before felling is started. The number of site tours by foreperson is obtained by dividing the volume of timber on the stand by the quantity felled by a logger or machine during the interval between two site tours and by adding one (the first) visit. The duration of an individual site tour is constant and always carried out by one person. The value selected for the actual duration of a single tour was 2500 cmin. The following calculations are based on the assumption that a site where motor saws are used is visited by a foreperson approx. once every two weeks, in addition to the first and final tour. On a labour-intensive site, this is equivalent to 150 m^3 of felled timber at a mean daily output of 10 to 20 m^3. For mechanized felling, the corresponding volume selected was 2000 m^3, which is equivalent to slightly over one site tour per month in addition to the initial and final visits.

Total time expenditure on site tours per stand is obtained by computing the travel time for each visit by a foreperson. The general equation for time expenditure for work supervision on stands, the travel times being based on equation 45:

$$ct_{jvk} = ce_{jv} + np \cdot (t_{kv} + 404 + 83.4d_a + 1500d_j) + \text{int}\frac{V_l}{v_{vt}} \cdot [ce_{jv} + np \cdot (t_{kv} + 404 + 83.4d_a + 1500d_j)] \qquad (47)$$

where
ct_{jvk} = time expenditure of one guidance and supervision visit, incl. travel time, cmin
ce_{jv} = time expenditure of terrain work by one guidance and supervision visit, cmin
v_{vt} = timber volume, which will be felled between foreperson's two visits, m^3
V_l = outturn of the stand, m^3
np = number of forepersons
t_{kv} = time expenditure of preparations, cmin
d_a = travelling distance with car (round-trip), km
d_j = walking distance (round-trip), km.
"int" is for applying only the integer part of the remainder of the division.

Using the values suggested by Halinen (1984), as explained in connection with equation 45, the equation for travel time is obtained as:

$$ct_{jvk} = (3904 + 83.4d_a + 1500d_j) + \text{int}\frac{V_l}{v_{vt}} \cdot (3904 + 83.4d_a + 1500d_j) \qquad (48)$$

where
ct_{jvk} = time expenditure of one guidance and supervision visit, incl. travel time, cmin, 2500 cmin has been applied here as a duration of terrain work of one guidance and supervision visit and 1000 cmin as a duration of preparation time

v_{vt} = timber volume, which will be felled between foreperson's two visits, m^3
manual work 150 m^3
harvester work 2000 m^3
V_l = outturn of the stand, m^3
d_a = travelling distance with car (round-trip), km
d_j = walking distance (round-trip), km.
"int" is for applying only the integer part of the remainder of the division.

It is assumed in the equation that the duration of a site tour by a foreperson including travel does not exceed that of a work day. Below, travel times have been computed from the office to the site while in practice a foreperson visits several sites in sequence. The equations are based on pure working hours so that potential extra preparation or travel times can be compensated for in the form of various interruptions. For example, no account has been taken of the closing of deals or the input by employees other than those directly involved with scaling.

3.3.5.1.5 Scaling of Standing Trees by Loggers

A team of two employees defines the boundaries of the stand, makes the necessary plans and measures the specimen trees during a single tour of the site. A foreperson visits the site alone to give instructions and supervise the work, computes the results of scaling and draws up the accounts. Specimen trees are scaled in connection with the definition and planning of the stand, the time expenditure for which depends, according to Halinen (1987b), on the volume of the stand and stem size. He only gives results for a stand size of 50 to 150 m^3 and a stem size of 20 to 80 dm^3 where this method is most commonly used. For the purposes of this study, the results have been extrapolated to include larger stands as well. In practice, logs prepared from large stems are usually measured one by one at the road-side.

The time required for scaling trees increases slightly with increasing stem size because larger stems are more widely spaced, which increases the percentage of transfer times. This effect is reduced with increasing stem size. A more significant dependence is the relative decrease in scaling time as stands get bigger. The model computed from Halinen's (1987b) results has been adjusted by a factor 10 % to account for improved working methods and tools.

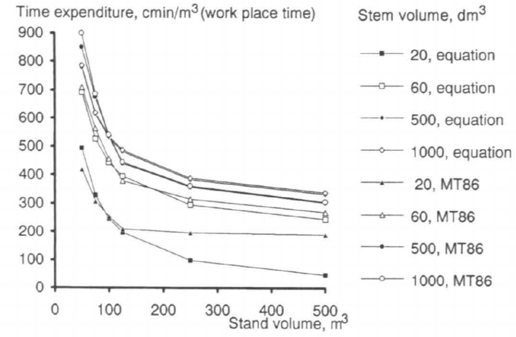


Fig. 14. Time expenditure of specimen tree scaling. Comparision of Halinen's (1987b) time study result (MT86 -curves) and it's estimate calculated with equation 49 (equation -curves).

$$cw_{mpl} = 0.9 \cdot \left[295 - \frac{5937}{v_r} + \frac{24780}{V_l}\right] \qquad (49)$$

where
cw_{mpl} = time expenditure of measuring tree length test trees, cmin/m^3 (work place time)
v_r = average bole volume, dm^3
V_l = outturn of the stand, m^3
0,9 = factor for reducing the time expenditure because of the foreseeable developments in methods and implements.

The error of the model is greatest for the smallest trees (Fig. 14).

Travel and preparation times must be computed for both individuals, i.e. doubled. Time expenditure for stand definition and design is obtained from equation 46 and specimen tree scaling time from equation 49. The basic duration of travel and preparation for a single person per day is obtained from equation 45. Total work time expenditure inclusive of travel is obtained from an equation where the new variables are the total duration of the working day (including travel to and from work) and the number of workers in the team:

$$ct_{mrsm} = np \cdot ct_{kaj} + cw_{ls} \cdot a_l + cw_{mpl} \cdot V_l + \text{int}\left[\frac{\frac{a_l \cdot cw_{ls} + V_l \cdot cw_{mpl}}{np}}{ld - ct_{kaj}}\right] \cdot np \cdot ct_{kaj} \qquad (50)$$

where
ct_{mrsm} = time expenditure of scaling of standing trees by logger, incl. stand definition, harvesting planning and measuring tree length test trees, cmin
np = number of foreperson
ld = total length of one working day, incl. travel time, cmin
cw_{ls} = time expenditure of stand definition and harvesting planning, equation 46, cmin/ha

a_l = area of the stand, ha
cw_{mpl} = time expenditure of measuring tree length test trees, equation 49, cmin/m^3
V_l = outturn of the stand, m^3
ct_{kaj} = time expenditure of travel and preparations, equation 45, cmin
"int" is for applying only the integer part of the remainder of the division.

Time expenditure for guidance and work supervision per employee is calculated from equation 48. Computation of the results of scaling takes 20 to 30 min depending on the size of the stand and experience of the operator (Halinen 1987a). After this study was completed, new planning and control systems were introduced by several companies, these greatly facilitating routine functions. Accordingly, the computation time used below is 1000 cmin and accounting time 500 cmin. Time expenditure by office employees per individual stand where standing trees are scaled by the logger is then:

$$CT_{mm}=ct_{mrsm}+ct_{jvk}+ct_{las}+c_{ttil}=ct_{mrsm}+ct_{jvk}+1000+500 \quad (51)$$

where
CT_{mm} = time expenditure by office employees per individual stand when using scaling method scaling of standing trees by logger, cmin
ctm_{rsm} = time expenditure of scaling of standing trees by logger, incl. stand definition, harvesting planning and measuring tree length test trees, cmin
ct_{jvk} = time expenditure of one guidance and supervision visit, incl. travel time, cmin
ct_{las} = time expenditure of computation, 1000 cmin
c_{ttil} = time expenditure of accounting, 500 cmin.

This equation for time expenditure by office employees per stand gives the time required for stand design, supervision, computation of the results of scaling and accounting in average travel conditions (Halinen 1984). The percentage of scaling work carried out by the logger is included in the time expenditure of the logger.

3.3.5.1.6 Scaling at Road-Side

A foreperson defines the boundaries of the stand and marks the trees to be felled during one site tour. A team of two workers then scales the logs one by one and the pulpwood in bunches. Finally, the foreperson computes the results of scaling and prepares the accounts.

Scaling of Individual Logs

Pennanen (1978) studied time spent on scaling individual logs by a team of two workers who calculated the results using pocket calculators. Ylänen (1983) compared the traditional method of measurement with tongs and a tape (a team of two) to pocket calculators and electronic tongs and data storage systems (one person). Halinen (1987a) found similar differences between mechanical and electronic methods. The effective scaling time required per log depends on the operator and the method of measurement and hardly at all on the size of the storage arrangement or trunk size. With electronic data storage units, preparation and computation times per storage arrangement remain nearly constant. For the production time expenditure on scaling individual logs, the following equation is obtained, to which the average conditions suggested by the studies completed by Pennanen (1978) and Ylänen (1988) have been added:

$$cw_{tkm}=(1+d_{ktm})\cdot\left[d_{kpl}\cdot\frac{v_{tt}}{v_{tkpl}}+(d_{tl}+d_{tv})\cdot\frac{v_{tt}}{v_{tp}}\right] \quad (52)$$

where
cw_{tkm} = time expenditure of scaling logs individually, cmin/m^3 (work place time)
d_{ktm} = percentage of delays, % (15 %)
d_{kpl} = time expenditure of scaling one log, cmin/log (effective time) (12 cmin/log)
v_{tt} = total volume of the logs to be scaled, m^3
v_{tkpl} = average volume of log, m^3 (0,23 m^3)
d_{tl} = computing time of one storage pile, cmin/pile (300 cmin/pile)
dt_v = travel and preparation time of one storage pile, cmin/pile (350 cmin/pile)
vt_p = average volume of one storage pile, m^3 (50 m^3).

When the above mean values are applied to a single-handed team that uses electronic scaling units, the following simplified equation is obtained:

$$cw_{tkm}=1.15\cdot\left[12\frac{v_{tt}}{0.230}+650\frac{v_{tt}}{50}\right] \quad (53)$$

where
cw_{tkm} = time expenditure of scaling logs individually, cmin/m^3 (work place time)
v_{tt} = total volume of the logs to be measured, m^3.

Scaling of Pulpwood in Bunches

According to Pennanen (1978), time expenditure for scaling in bunches and computation by a team of two workers is mainly determined by the size of the storage arrangement to be measured. In this study, the mean size of the bunches was 39 m^3 within a range of 3 to 161 m^3. When 3 m pulpwood is measured in bunches, the equation for production time expenditure is as follows:

$$cw_{pm}=(1+d_{kpm})\cdot\left[ce_{pmm}+ce_{pml}+ce_{kv}\frac{v_{tl}}{v_{vm}}\right] \quad (54)$$

where
cw_{pm} = time expenditure of scaling pulpwood in bunches, cmin/m^3 (work place time)
d_{kpm} = percentage of delays, %
ce_{pmm} = time expenditure of scaling bunches, cmin (effective time)
ce_{pml} = time expenditure of computing, cmin (effective time)
ce_{kv} = travel and preparation time of one bunch, cmin/bunch
v_{tk} = total volume of pulpwood to be measured, m^3
v_{vm} = average volume of one bunch, m^3.

Non-linear equations with regard to the mean bunch size can be computed for effective time expenditure required by bunch scaling and computation of results in accordance with the study by Pennanen (1978) (Fig. 15). According to Halinen (1987a), the use of electronic scaling units cuts down the time expenditure for scaling to 95 % and that for computation to 35 % as compared with the values suggested by Pennanen. On these assumptions, the equations for time expenditure for scaling in bunches and the related computation of results are obtained as follows when electronic equipment is used:

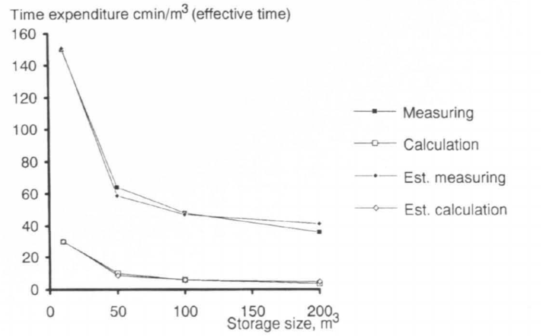


Fig. 15. Time expenditure of scaling timber in bunches. Comparison of Pennanen's (1978) time study results (Measuring and calculation -curves) and their estimates calculated with equation 55 (Est.measuring -curve) and equation 56 (Est.calculation -curve). Estimate curves does not include deduction of electronic measuring device (see text).

$$ce_{pmm}=0.95\cdot\left[36.5+1153\frac{1}{v_{kp}}\right]\cdot v_{kt} = 34.7\cdot v_{kt}+\frac{1095v_{kt}}{v_{kp}} \quad (55)$$

where
ce_{pmm} = time expenditure of scaling pulpwood in bunches, cmin (effective time)
v_{kt} = total volume of pulpwood to be measured, m^3
v_{kp} = average volume of one bunch, m^3.

$$ce_{pml}=0.35\cdot\left[3.29+269\frac{1}{v_{kp}}\right]\cdot v_{kt} = 1.15\cdot v_{kt}+\frac{95v_{kt}}{v_{kp}} \quad (56)$$

where
ce_{pml} = time expenditure of computing scaling results for pulpwood in bunches, cmin (effective time)
v_{kt} = total volume of pulpwood to be measured, m^3
v_{kp} = averge volume of one bunch, m^3.

Total time expenditure for field work in scaling logs and pulpwood also includes the travel time required by one individual:

$$ct_{jmm}=ct_{kaj}+cw_{tkm}+ce_{pmm}+\mathrm{int}\left[\frac{cw_{tkm}+ce_{pmm}}{ld-ct_{kaj}}\right]\cdot ct_{kaj} \quad (57)$$

where
ct_{jmm} = field time expenditure of scaling at road-side, incl. travel, cmin
ld = total length of one working day, incl. travel time, cmin
cw_{tkm} = time expenditure of scaling logs individually (equation 53), cmin
ce_{pmm} = time expenditure of scaling pulpwood in bunches (equation 55), cmin
ct_{kaj} = time expenditure of travel and preparation (equation 45), cmin
"int" is for applying only the integer part of the remainder of the division.

The selected time expenditure for accounting is 1500 cmin. This gives the following time expenditure by office employees per stand scaled at the road-side:

$$CT_{jm} = ct_{mrsm}+ct_{jmm}+ct_{jvk}+ce_{pml}+c_{ttil} = ct_{mrsm}+ct_{jmm}+ct_{jvk}+ce_{pml}+1500 \quad (58)$$

where
CT_{jm} = time expenditure of office employees by carrying out harvesting of one at the road-side scaled stand, cmin
ct_{mrsm} = time expenditure of stand definition, harvesting planning and measuring tree length test trees, incl. travel, cmin
ct_{jmm} = field time expenditure of scaling at road-side, incl. travel, cmin
ct_{jvk} = time expenditure of one guidance and supervision visit, incl. travel time, cmin
ce_{pml} = time expenditure of computing scaling results for pulpwood in bunches, cmin
c_{ttil} = time expenditure of accounting, cmin.

3.3.5.1.7 Automatic Scaling by Logging Machine

A foreperson defines the boundaries of a stand and plans the harvesting operations on a single tour of the site. A team of two workers then checks the results. Finally, the foreperson carries out the final inspection and makes the necessary plans for long-distance haulage. At the office, he computes the results of measurements and prepares the accounts.

According to Halinen (1984), time expenditure per area unit for planning the harvest in a stand as used for labour-intensive cutting operations is too high for stands to be felled by machines when the trees to be removed are selected by the operator. No research data is available on the differences in time expenditure. Here, time expenditure is 60 % of that of a labour-intensive cutting operation (equation 46), which gives the following equation:

$$cw_{lksm} = 0.42 \cdot (9788-1759a_l+240a_l^2+3536h_t) \quad (59)$$

where
cw_{lksm} = time expenditure of stand definition and harvesting planning (excl. travel) on a mechanical harvested stand, cmin/ha (work place time)
a_l = area of the stand, ha
h_t = dummy variable for cutting method: 0 = clear-cutting, 1 = thinning
0,42 = factor for reducing the time expenditure because of the foreseeable developments in methods and implements.

When travel times are added to equation (59), the time expended on planning a stand for mechanized felling is obtained as follows:

$$ct_{ksm} = ct_{kaj} + cw_{lksm}\cdot a_l + int\left[\frac{cw_{lksm}\cdot a_l}{ld - ct_{kaj}}\right]\cdot ct_{kaj} \quad (60)$$

where
ct_{ksm} = time expenditure of stand definition and harvesting planning (incl. travel) on a mechanical harvested stand, cmin,
ld = total length of one working day, incl. travel, cmin
cw_{lksm} = time expenditure of stand definition and harvesting planning, (equation 59), cmin/ha
a_l = area of the stand, ha
ct_{kaj} = time expenditure of travel and preparations for one visit, (equation 45) cmin
"int" is for applying only the integer part of the remainder of the division.

The methods used in verification measurements have not yet been standardized (Perttola & Rieppo 1991). At the beginning of automatic scaling by a logging machine, measurements made on a small batch of timber from each stand were verified and the results compared with the machine listing. With the improved accuracy and reliability and increasing popularity of automatic scaling, it is unlikely that verification measurements will be performed on all stands in the future. According to a foreperson interviewed in the early spring of 1991, verification measurements take 2 hours of site time per stand. Work is expected to become quicker and easier when the new methods win more ground, and so a value of 9000 cmin was selected as standard. Verification measurements are carried out in increments of 10 % of the felled volume. Mathematically, this is performed by dividing the time expended on verification measurements between the individual stands as a percentage per stand size of the estimated annual machine output. For the purposes of this study, annual output by a logging machine was chosen as 20 000 m^3, and so verification measurements are performed on 2000 m^3. Time expended on verification measurements by a team of two workers, including travel time, is then:

$$ct_{ktm} = \frac{V_l}{v_{tmv}}\cdot\left[np\cdot ce_{ktm} + np\cdot(3904+83.4m_a+1500m_j)\right] \quad (61)$$

where
ct_{ktm} = time expenditure of verification measurements (incl. travel) on mechanical harvested stand, cmin
V_l = outturn of the stand, m^3
v_{tmv} = volume of the verification measurements, m^3 (here applied 2000 m^3)
np = number of persons, (here applied 2)
ce_{ktm} = time expenditure of verification measurements, cmin (here applied 9000 cmin)
m_a = travel distance by car (round-trip), km
m_j = walking distance (round-trip), km
"int" is for applying only the integer part of the remainder of the division.

The equation is based on the assumption that verification and related trips are completed during one work day. Computation of the results of measurements is included in the scaling time expenditure because the results must be obtained immediately to be able to determine whether the logging machine's scaling instruments need to be calibrated. Time expenditure by the foreperson is calculated from equation 48, where the volume felled during the interval between two site tours of a mechanically cut stand is 2000 m^3. Accounting time expenditure is 1000 cmin.

Time expenditure for inspecting a mechanically felled stand and planning long-distance haulage including travel times at a constant operating time expenditure of 2500 cmin is as follows:

$$ct_{ktlop} = ct_{kaj} + ct_{ktl} \quad (62)$$

where
ct_{ktlop} = time expenditure of inspecting and planning long distance hauling on a mechanically harvested stand, incl. travel, cmin
ct_{kaj} = time expenditure of one travel and preparation for one visit, cmin (equation 45)
ct_{ktl} = constant time expenditure of inspecting and planning long distance hauling, (here applied 2500 cmin).

By summing up the time expended on the various operations, employee time expenditure for stands scaled by the logging machine is obtained as:

$$CT_{jm} = ct_{ksm} + ct_{ktm} + ct_{jvk} + ct_{ktlop} + c_{ttil} \quad (63)$$

where
CT_{jm} = time expenditure of office employees by carrying out harvesting of a mechanically harvested stand, cmin
ct_{ksm} = time expenditure of stand definition and harvesting planning, cmin (equation 60)
ct_{ktm} = time expenditure of verification measurements, cmin (equation 61)
ct_{jvk} = time expenditure of one guidance and supervision visit, cmin (here applied 2000 m^3 cutting between visits) (equation 47)
ct_{ktlop} = time expenditure of inspecting and planning long distance hauling, cmin (equation 62)
c_{ttil} = time expenditure of accounting, cmin (here applied 1000 cmin).

3.3.5.1.8 Scaling by Logging Machine in All-Round Contracting

In all-round contracting, the contractor assumes responsibility for felling and off-road haulage, possibly also for long-distance haulage and the purchase of the stand (Mikkonen 1987, Autoja... 1992 and Rajamäki & Terävä 1992). If the responsibility for the performance of the work were more extensive than today, the amount of work to be carried out by the employees of the buyer company would be affected. However, all-round contracting has not yet assumed its final form and methods so that the following calculations consist of estimates as to potential future developments.

Instructions necessary for beginning the felling operation are provided by the foreperson during a single visit to the site. Verification measurements are carried out by a team of two. Quality is checked in connection with verification. The final inspection, computation of the results of the measurements and accounting are performed by the foreperson.

Time expenditure for commencing work on a stand selected for mechanized felling including travel times at a standard presentation time (1500 cmin) is as follows:

$$ct_{kokalk} = ct_{kaj} + ct_{koka} \quad (64)$$

where
ct_{kokalk} = time expenditure for commencing work on an all-round contracting stand, incl. travel, cmin
ct_{kaj} = time expenditure of travel and preparation for one visit, cmin (equation 45)
ct_{koka} = constant time of commencing work, cmin (here applied 1500 cmin).

Verification measurements are carried out in increments of 10 % of the total felled volume. For the purposes of this study, annual output by a logging machine was determined as 30 000 m^3, and so verification measurements were performed on 3000 m^3. Time expenditure for verification measurements by a team of two workers including travel time is then:

$$ct_{kokktm} = \frac{V_l}{v_{tmv}}\cdot\left[np\cdot ce_{ktm} + np\cdot(3904+83.4m_a+1500m_j)\right] \quad (65)$$

where
ct_{kokktm} = time expenditure of verification measurement of an all-round contracting stand, incl. travel, cmin
V_l = outturn of the stand, m^3
v_{tmv} = volume of the verification measurements, m^3 (here applied 3000 m^3)
np = number of persons (here applied 2 persons)
ce_{ktm} = time expenditure of verification measurements, cmin, (here applied 9000 cmin) (equation 61)
m_a = travel distance with car (round-trip), km
m_j = walking distance (round-trip), km
"int" is for applying only the integer part of the remainder of the division.

Computation of the results of measurements is included in the time expenditure because the results must be obtained immediately to be able to determine whether the logging machine's scaling instruments need to be calibrated.

Time expenditure for inspecting and closing a mechanically felled stand including travel times at a constant inspection time expenditure of 1500 cmin is as follows:

$$ct_{koklop} = ct_{kaj} + ct_{kokl} \quad (66)$$

where
ct_{koklop} = time expenditure of closing and planning long distance transport on an all-round contracting stand, incl. travel, cmin
ct_{kaj} = time expenditure of one travel and preparation visit, cmin (equation 45)
ct_{kokl} = constant time of closing the stand and planning of long distance transport, cmin (here applied 1500 cmin).

By summing up the time expended on the various operations, employee time expenditure in all-round contracting for stands scaled by the logging machine is obtained as:

$$CT_{kokim} = ct_{kokalk} + ct_{kokktm} + ct_{koklop} + c_{ttil} \quad (67)$$

where
CT_{kokim} = time expenditure of office employees by carrying out harvesting of an all-round contracting stand, cmin,
ct_{kokalk} = time expenditure for commencing work, cmin (equation 64)
ct_{kokktm} = time expenditure of verification measurement, cmin (equation 65)
ct_{koklop} = time expenditure of closing the stand and planning long distance, cmin (equation 66)
c_{ttil} = time expenditure of accounting, cmin (here applied 1000 cmin).

3.3.5.2 Cost Models for Other Administrative Activities

Time expended on planning, scaling and work supervision are, to some extent, determined by the volume of timber to be handled and the working conditions. The resources required for purchasing timber depend very little on the volume of wood being purchased. There are a number of other duties related to timber purchasing that are extremely difficult to relate to the volume of timber to be handled. The resource requirements for actions necessary for controlling timber procurement are determined by the corporate organization, traditions and a number of other such factors. Very little data is available on this subject outside the operative organizations, if even there. Organizations are undergoing profound changes aiming at reducing the number of levels within the organization (cf. Kanto 1990).

Of the total working hours of the district managers, procurement managers and forepersons of a certain company, 6 % was expended on making the deals, 12 % on harvesting and 13 % on long-distance haulage (Laine 1989). Only a third of their working hours was then expended on duties directly related to procurement. Most of their time was used on training, advising and management (47 %), part of which, of course, had to do with procurement. In 1985, district managers procured an average of 22 000 m³ of timber p.a. (Juntunen 1988). The important part played by the organization is illustrated by this example provided by Juntunen (1988): foreperson working for private companies had to have a total of 50 stands harvested to achieve the same volume as the Finnish Forest and Park Service could harvest from 2 stands. The difference is not only due to different modes of operation but mainly to the fact that the duties of the various individuals at private companies and the Finnish Forest and Park Service differ greatly.

The selected method of scaling has a marked impact on the size of the organization. In 1988, scaling of standing trees accounted for 27 % of the total in timber procurement by the industry (Elovainio & Halinen 1989) but this figure is constantly declining as a result of companies switching over to automatic scaling by logging machines.

Administrative measures required in addition to operations directly related to the implementation of cutting on the stand were included in the form of average costs.

3.4 Model Validation

Model validation refers to a process by which it is determined how accurately the model describes the actual state of affairs being modelled. Because a model is, by definition, a simplification of reality, it should not be expected to provide a perfect description of the behaviour of any system. However, if the model is appropriately designed and tested, the result it yields gives an adequate approximation of the actual situation (Hillier & Lieberman 1974).

The most common method of testing the validity of a model is to compare its performance against previous data available on the actual system. A model is valid if it, given identical input values, yields results identical to real values. However, the problem with this type of retrospective testing is that it is often necessary to use the same data on the basis of which the model was originally created. Nor can there be any certainty that any system will in the future perform in the same way as in the past (Hillier & Lieberman 1974, Taha 1985).

The timber procurement model was validated with regard to the equations for, and form of, harvesting method and short-distance haulage in a separate study (Alanne 1993) where target optimization was used to determine the manpower requirement for commercial cutting in 1990. This was done by creating a monthly model based on

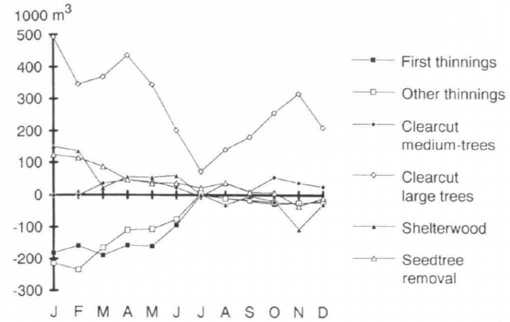


Fig. 16. Correspondence of annual outturn calculated with model to goals in year 1990 (Alanne 1993)(see text). On X-axis abbreviations of months.

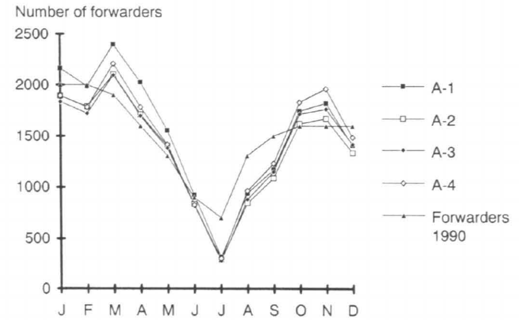


Fig. 17. Correspondence of annual number of forwarders calculated with model to those actually working in year 1990 (Alanne 1993). A-1 ... A-4 represent four different calculation scenarios (see text). On X-axis abbreviations of months.

goal optimization which was then used for computing manpower requirements for cutting, off-road haulage and work supervision. Goal optimization was selected as the method of mathematical programming because it makes it possible to take account of several goals simultaneously.

Monthly felled volumes necessary as input values for validation were obtained from the commercial cutting and labour statistics compiled by the Finnish Forest Research Institute (Markkinapuun ... 1990, 1991a and 1992a). Felled volumes in individual forestry board areas were taken from half-yearly statistics (Markkinapuun ...1991b and 1992b). Distributions by harvesting method and area were calculated from the relative areas of the cutting sites selected from the Yearbook of Forest Statistics (1992). The percentages of timber felled using the various harvesting systems were calculated by weighing the areas of local cutting sites by stand densities. The distribution by harvesting method for the areas was computed as a ratio of volumes by harvesting method to total felled volumes by harvesting method.

The target felled volumes were divided between cutting operations carried out by professionals on one hand and private woodlot owners on the other. The percentages of professional and private logging were calculated from the half-yearly statistics. To calculate the distribution by harvesting method according to operator, the distribution by harvesting method suggested by Toivanen et al. (1992) for delivery cuttings was used. Percentages of mechanized felling of professionally harvested timber were defined in accordance with the figures suggested by Laajalahti and Pennanen (1991) and Laajalahti and Säteri (1992 and 1993).

The model was validated using four different calculation scenarios (curves A–1 ... A–4 in the Fig. 17). The variables consisted of permitted variations in the volumes by timber assortment and harvesting method. The difference in felled volumes by timber assortment, as compared with real figures, was 1 to 9 % (Fig. 16). The volumes departed from the goals more with regard to harvesting method than to timber assortment. As far as internal differences between the various harvesting methods are concerned, the felled volumes exceeded the goals by a wide margin, while the volumes cut in thinnings fell short of the targets.

In terms of manpower requirements, the volumes matched the real figures fairly closely. However, the number of forest owners engaged in private cutting and haulage operations yielded by the model was clearly higher than that suggested by the reference data given by Mr Ilppo Greis (M.Sc.(Arg.For.), employer representative of Forest Centre Tapio). With regard to professionally operated harvesters, the numbers were in agreements with the statistics in the autumn and winter seasons. For summer, the model clearly exaggerated the number of logging and short-distance haulage machines. Fig. 17 presents the comparison of number of actually worked forwarders and number of forwarders calculated with model in four scenarios.

4 Procurement Model and Future Scenarios

4.1 Optimization Model

The goal function used in the timber procurement model devised for the purposes of the present study minimizes annual procurement costs within the limits imposed by the given resource and timber utilization data. The model includes 862 variables and 560 limiting factors. The variables, target function and equations used in the model are presented in Appendix 1. The input data for optimization were as follows:

- Timber recovery by timber assortment in the cutting area according stand type
- Bartering between the areas analyzed by timber assortment
- Volumes used by timber assortment and processing point
- Variation range for seasonal fluctuations in the percentages of private and industrial harvesting
- Variation range for seasonal fluctuations in private and industrial harvesting by stand type
- Seasonal fluctuations in mill reception (long-distance haulage)
- Productivity of cutting and off-road haulage according to stand type and season
- Productivity of long-distance haulage
- Time expenditure for work supervision and scaling
- Costs of man-hour and machine-hour according to season
- Unit costs of floating and railway transportation according to processing point
- Method-related and seasonal restrictions on harvesting
- Percentages of silvicultural operations in terms of the area of the cutting sites following completed felling
- Productivity of silvicultural operations
- Cost of silvicultural operations

In the 1990 model, the limiting factors were used fairly extensively to compel the outcome to match real conditions. A minimum area restriction for each stand type was given as 80 % of materialized cutting area. The maximum restriction for tree farmers own logging work was calculated from enquiry values given by Koistinen (1991). The lower limit of forest owners own transport work was given as 35 % of the volume cut by tree farmers. The floating volumes in East- and West-Finland were forced to follow the materialized volumes.

For the 2000 and 2010 models, the restrictions were made somewhat less strict. Two new logging methods was created. Semi professional tree farmer's productivity is 80 % of professional logger ("normal" tree farmer: 75 %) and he cuts 350 m^3/a (200 m^3/a). An all-round contractor owns 10-tonne one grip harvester and forwarder. Forepersons supervising work in this method is faster than in method where harvester and forwarder are owned separately. Tree farmers logging work was restricted to the maximum willingness in Koistinen's (1991) enquiry. There was no minimum volume restrictions for tree farmers own transport work in 2000 and 2010. First thinnings had a minimum area requirement in 2000, so that the changes would not be too big. Seed tree and shelter wood cutting had to be restricted in 2010 in East-Finland. Floating and railroad transportation had reasonable maximum limits in 2000 and 2010, but limits were not hit.

The model provides the following data:

- Total costs
- Unit costs of work supervision and scaling
- Unit costs of cutting and off-road haulage
- Unit costs of long-distance haulage
- Unit costs of silvicultural operations
- Required manpower and machine resources
- Breakdown of harvesting into delivery cuttings and stumpage sales
- Seasonal fluctuations in private and industrial-scale harvesting
- Timber volumes by stand type

- Timber volumes by harvesting system
- Timber volumes by season
- Volumes of bartered timber
- Shadow prices.

The various optional courses of future development were studied by computing the results at several input and variable values. The stability of individual solutions was analyzed by means of shadow prices.

4.2 Optional Courses of Development and Restrictions

4.2.1 Future Trends in Timber Usage and Supply

In the summer of 1992, scientists involved in the project "Effects of the Structural Changes in the Forest Industry on the Various Professional Categories" held a number brainstorming meetings where it was agreed that the calculation bases to be used for computation should be as uniform as possible. To this end, Seppälä (1993) prepared forecasts for timber usage by the industry and derived from them three accumulation alternatives (Fig. 18). On the basis of timber supply, Järveläinen and Torvelainen (1993) calculated

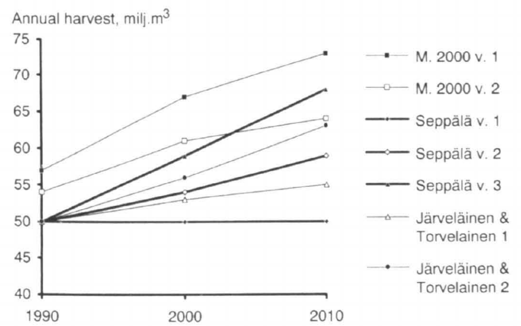


Fig. 18. Timber recovery alternatives for years 1990, 2000 ja 2010 by Järveläinen and Torvelainen (1993)(two alternatives), Forest 2000 Programme (Metsä 2000 ... 1992)(M. 2000 -curves, two alternatives) and Seppälä (1993)(three alternatives). In this study the optimization calculations are made for all three Seppälä's alternatives. Seppälä's alternative two is base for several cost-devepment alternative calculations.

two timber recovery alternatives (Fig. 18). The cutting plans drawn up by the Forest 2000 Programme (Metsä 2000...1992) suggest higher figures than the studies mentioned above (Fig. 18). A decision was made to compute procurement optimization for Seppälä's alternative no. 2 which falls in between the scenarios computed by Järveläinen and Torvelainen (1993). To determine the effect of felled volume, the employment and cost effects of procurement were also computed for Seppälä's alternatives 1 and 3 (Fig. 18).

The prediction of changes in the volume of timber to be used by the processing points is based on Seppälä's calculations (1993) concerning the production estimates for individual product groups and consumption of raw timber by the forest industry in 1990, 2000 and 2010 (Appendix 2). Growth in industrial capacity is expected to be more or less uniform within each processing point so that the number of processing points and mills contained in them has remained unchanged. The volumes of the various wood products used at the mills will change. According to Seppälä (1993), the use of spruce sawlogs for making groundwood pulp will increase. As a result of more stringent quality criteria for timber species and more versatile end-uses, the size limits for sawlogs and pulpwood were modified in Mr Waite's programme which is used for dividing the logs into timber assortments. In the 1990 calculations, the minimum dimensions of pulpwood irrespective of species are a length of 15 dm and top diameter of 6 cm. The minimum length of a sawlog is 37 dm and minimum top diameter 17 cm. In 2000 and 2010 the minimum dimensions of pulpwood will remain the same whereas the minimum length of pine and hardwood sawlogs will be 46 dm and top diameter 19 cm. The minimum dimensions of spruce sawlogs are 40 dm and 19 cm, respectively.

According to the production estimate given by the industry on the basis of the 68 million m3 timber recovery suggested by Seppälä (1993), sawmill production will drop by 0.7 % per year from 1990 to 2010. The production of plywood and other boards will remain more or less at the current level. Groundwood pulp production will grow by 2.1 % per year in the future. Total production of chemical pulp will increase by 1.1 %

per year, with hardwood sulphate growing faster than softwood sulphate. No other chemical pulp types will be produced. Paper production will increase faster than any other product, the growth rate being 2.9 % per year from 1990 to 2010. Newsprint production will fall, while the production of wood-containing printing and writing papers and special papers will increase. Cardboard production will grow by 1.2 % per year. On the basis of these figures on industrial production, Seppälä (1993) predicts that demand for pine and spruce logs will decline by 16 % from the current 18.1 million m³ during the period from 1990 to 2010. Demand for hardwood logs will remain constant. To increase production, 44 % more pulpwood will be required. The growth in demand will be greatest for spruce logs.

Appendix 2 provides an example of the timber usage volumes by the processing points in each area, the size of the procurement areas and the average haulage distances in 1990, 2000 and 2010 as used in the optimization calculations.

4.2.2 Future Trends in Stand Composition

The number of stems on a stand and their size distribution are determined by the history of the stand, mainly by planting density and the intensity of the cuttings completed to date. To predict the characteristics of stands in 2000 and 2010, the alternative programme IV drafted by the Thinning Commission of the Ministry of Agriculture and Forestry (Harvennushakkuiden... 1992). It represents an optimum thinning model computed by means of the MELA system aimed at maximizing the discounted current value of woodlots at an interest rate of 3 %. For the purposes of this study, Mr Mauno Pesonen, M.Sc.(Agr.For.), researcher in the Finnish Forest Research Institute, outputted area-specific cutting data forecasts from the computations he had made in the course of the study mentioned above. The optimization calculation takes account of the productivity and cost of harvesting. This degree of overlapping was found to be acceptable in the light of the fact that the input data used in the report by the Thinning Commission and in this study were based on the same surveys carried out by Metsäteho. Stand volumes will increase in the future, excluding removals of seed and shelter trees which will decline with time. The volume per hectare of the trees to be removed will increase in first thinnings but decrease in the removal of seed and shelter trees. Other types of stands will be characterized by alternating growth and decline with time. Timber species distributions will vary from area to area and stand to stand.

The composition of timber by stem type removed from the different types of stands was modified on the basis of "scaling of standing trees" -statistics data (Lassheikki 1989), usually by reducing the values. Thinnings and small stands are under-represented in the "scaling of standing trees" -statistics. Stem volume distribution was modified according to the forecasts prepared by Mr Pesonen and, particularly, Lilleberg and Raitanen (1989).

4.2.3 Future Trends in Costs

The costs of labour-intensive cutting are based on the forest work force number and income figures given by Mr. Erkki Eilavaara (M.Sc. (Agr.For.), representative of the Forest Employers Association), the Collective Agreement on Forest and Floating Work (Metsä- ja.... 1990), Rainio (1992), the Statistical Yearbooks of the Forest Employers (Tilastokatsaus 1989, 1990 and 1992) and the Yearbook of Forest Statistics (1989). The costs of cutting operations carried out with logging machines and harvesters are based on the data published by Hemmilä (1991) and Jaakkola (1990a and 1990b). Mr. Harri Rumpunen, (M.Sc.(Agr.For.), representative of the Transport User's Association of Forest Branch), gave cost calculation examples and hour-cost statistics for harvesters and forwarders. The costs of logging and haulage by private woodlot owners are taken from Valkonen's study (1990). General costs were estimated on the basis of the Yearbook of Forest Statistics (1989) and Metsäteho's SUSY system (Lindroos 1991). The costs of floating and railway transportation are determined by means of the cost-dependence equations at the 1990 price level. The costs and wages used as a basis for the 1990 calculations are shown in Table 2.

Table 2. Overhead cost, wages and subsidiary cost, costs per hour for machines and unit costs of rail transport and floating, which are applied in optimum calculations for the year 1990.

Cost component	Cost	Unit	Remarks
Cost of purchase			
Harvesting by company	12	FIM/m³	
Harvesting by forest owner	12	FIM/m³	
Overhead cost			
Procurement by company, mechanized cutting	3	FIM/m³	
Procurement by company, manual cutting	5	FIM/m³	
Harvesting by forest owner	2	FIM/m³	
Wage cost in person work hours			
Cutting by professional logger	39	FIM/h	Subsidiary cost 68 %
Logging by forest owner	35	FIM/h	Subsidiary cost 20 %
Scaling and supervision of work	40	FIM/h	Subsidiary cost 68 %
Cost per hour for machine work			
Track-mounted 4-tonne forwarder	208	FIM/h	
8-tonne forwarder	250	FIM/h	
10-tonne forwarder	293	FIM/h	
Farm tractor + hydraulic skidding grapple	205	FIM/h	
Farm tractor + trailer + hydraulic loader	230	FIM/h	
Light one-grip harvester	298	FIM/h	
One-grip harvester	373	FIM/h	
Two-grip harvester	418	FIM/h	
Truck and trailer	290	FIM/h	

The optimums for procurement costs in 2000 and 2010 were calculated for three alternative procurement volumes compatible with Seppälä's (1993) three scenarios (Fig. 18). In addition to the cost development scenario used in the comparison of procured volumes, cost development for the middle scenario was also calculated in respect of three other alternatives (Table 3). Apart from these, the optimum alternative for procurement costs was computed for the middle procurement volume alternative on the basis of the standard cost development, where each type of stand was burdened by silvicultural operations following the completion of cutting.

The costs used as a basis for the optimization calculations for 2000 and 2010 were computed by increasing the 1990 costs by a certain annual percentage. The percentage increase in the cost of the basic solutions in terms of procurement volumes are based on the nominal increase in costs from 1980 to 1990 (Table 4) (Yearbook of... 1989, Tilastokatsaus 1989 and 1990 and statistics given by Mr. Markku Maukonen, (Department manager of Finnish Truck Owners Association), and Mr. Harri Rumpunen. To test cost sensitivity, three optional scenarios were prepared for future cost development in addition to the basic concept, which will subsequently be referred to as follows in accordance with Table 4: basic, low-cost, high-cost and expensive machinery. The costs are nominal costs.

4.3.4 Future Trends in Working Methods and Conditions

The model was not allowed to compute the 1990 optimum freely: instead, calculations were governed by a number of restrictions based on the 1990 data. For example, the total area of first

Table 3. Annual procurement and cost trend alternatives which are applied in optimum calculations for 1990, 2000 and 2010. The names and abbreviations of optimization alternatives. Alternatives of annual procurement are based on Seppälä's (1993) three future scenarios (Figure 18).

Name of optimization alternative	Abbreviation	Annual procurement 1990, Mm³	Annual procurement 2000, Mm³	Annual procurement 2010, Mm³	Level of the increase of costs	Remarks
Procurement optimum	59 KO	50	54	59	Basic	Seppälä's scenario n:o 2
Silvicultural-optimum	59 MHO	50	54	59	Basic	Type stands burdened by silvicultural operations
High costs	59 +20%	50	54	59	Basic +20%	
Low costs	59 –20%	50	54	59	Basic –20%	
High machine cost	59 Mixed	50	54	59	Manual work Basic, machine work + 20%	
Small procurement	50 Mm³	50	50	50	Basic	Seppälä's scenario n:o 1
Large procurement	68 Mm³	50	59	68	Basic	Seppälä's scenario n:o 3

thinnings was based on the actual area in 1990. Of course, the optimization model scheduled all work for seasons when ground is bare because harvesting is more expensive in winter due to snow. The variation range for seasonal fluctuations in the 1990 calculations was determined in accordance with Korpilahti's (1990) study. For 2000 and 2010, seasonal fluctuations were slightly levelled out by adjusting the percentage of volumes felled in the summer season (July to September) from 12 % in 1990 to 19 to 20 % whereas the percentage of volumes felled in the winter season (January to March) was reduced from 34 % in 1990 to 30 % for the future.

The limiting factor used for forest owners own cutting and haulage work consisted of the working hours completed in 1990 as indicated by the statistics compiled by Koistinen (1991). For 2000 and 2010, the upper limit for individual work input was based on Koistinen's forecasts (1991 and 1992) for the maximum input available. Optimization suggests that forest owners cutting work is profitable with certain working methods to the extent that such work is available. Off-road haulage by a farm tractor is not equally profitable so that at least 35 % of the volume felled by private means was assumed to be transported by similar means. From the point of view of private householding, such haulage is often profitable at current tax rates, providing that the necessary machinery is available. The 1990 calculations did not take into account active tree farmers cutting method. Later on, it proved to be the only method of private felling that made sense financially.

A harvester / forwarder series in all-round contracting was not included until the calculations for 2000 and 2010. In sharp contrast to the actual situation, loose floating was not allowed for northern Finland at all. It was felt to be unnecessary to prepare cost and time expenditure models for loose floating because it has not been carried out since 1991. Floating in bundles will probably be restricted by increasing shoreline conservation and the desire to maintain timber quality and curb capital costs. Carriage by ships may replace floating in some instances.

As a rule, the productivity of work and working methods increases as the methods improve. On the other hand, more careful execution of the work or a decrease in the size of the pieces to be handled can reduce productivity. The productivity of the various working methods was expected to increase in accordance with Table 5.

Table 4. Yearly percential cost increases, which are applied with different cost development scenarios.

Cost component	Basic, %/a	Low-cost, %/a	High-cost, %/a	High machinery cost, %/a
Cost of purchase				
Harvesting by company	3	2.4	3.6	3
Harvesting by forest owner	3	2.4	3.6	3
Overhead cost				
Procurement by company, mechanized cutting	3	2.4	3.6	3
Procurement by company, manual cutting	3	2.4	3.6	3
Harvesting by forest owner	3	2.4	3.6	3
Wage cost in person work hours				
Cutting by logger	5	4	6	5
Cutting by forest owner	5	4	6	5
Scaling and supervision	6	4.8	7.2	5
Hourly machine cost				
Track-mounted 4-tonne forwarder	2.5	2	3	3.75
8-tonne forwarder	2.5	2	3	3.75
10-tonne forwarder	2.5	2	3	3.75
Farm tractor + hydraulic skidding grapple	2.5	2	3	3.75
Farm tractor + trailer + hydraulic loader	2.5	2	3	3.75
Light one-grip harvester	2.5	2	3	3.75
One-grip harvester	2.5	2	3	3.75
Two-grip harvester	2.5	2	3	3.75
Truck and trailer	4.5	3.6	5.4	5
Unit cost				
Rail transport	3.5	2.8	4.2	4.5
Floating	3.5	2.8	4.2	4.5

Table 5. Yearly increment of work productivity in various functions of forest operations which are applied in optimum calculations.

Working methods	Increment of work productivity, %/a
Manual logging	0.5
Mechanized logging	1
Terrain transportation	1
Work supervision	2
Truck transportation	0.5
Manual silvicutural works	0.5
Mechanized silvicultural works	1

4.2.5 Future Trends in Silvicultural Operations

At present, the labour force engaged in wood procurement is no longer separate from those involved in silviculture. Almost without exception, loggers felling trees in winter participate in silviculture in the spring and spend the better part of the summer clearing planted stands. As it is becoming increasingly difficult to hire students and seasonal workers for a short term, loggers have been employed in greater numbers than necessary for cutting operations in winter in order to ensure a sufficient supply of labour in summer. In silviculture, the input of human labour is more important than in felling because attempts to mechanize silviculture have not been very successful. Annual working hours expended on the various areas of silviculture can be confined to a couple of months a year by biological factors.

The sequence of actions employed in different conditions make it possible, to some extent, to predict the amount of silvicultural operations resulting from given cutting methods because part of the work is directly linked to the felling quantitatively and temporarily. A case in point is the cultivation of clear-cut areas within a couple of years of the completion of cutting. Thinning and clearing of sapling stands are examples of actions whose timing and or execution is not directly determined by the preceding felling. The locality, site preparation, method of planting, financial targets established for silvicultural action and the quality objectives set for the timber to be grown on the site are examples of factors that affect the amount of clearing work more than the method of the preceding harvesting.

The effect of silvicultural operations on the resource requirements and costs of timber procurement is studied by determining a series of silvicultural actions to be implemented on each type of stand after felling. The resources required by such a series of actions per hectare are priced at the 1990 cost level, which is then augmented by the percentage increases in the cost of labour-intensive work and productivity for 2000 and 2010. The costs arrived at in this way will be taken into account, in respect of each stand type, as additional costs when procurement costs are optimized.

The sequence of actions for stands marked for clear-cutting includes the clearing, site preparation, planting and thinning of the regeneration area. The action on stands marked for seed and shelter trees cutting consists of site preparation and clearing. No action is required on stands marked for thinning and removal of shelter trees. The stands cut for shelter tree position are already burdened by the cost of thinning/clearing following the removal of shelter trees.

The percentages of clearing, site preparation and cultivation in the regeneration area used in the calculations in the various parts of the country were modified on the basis of the areas in 1990 (Yearbook ... 1992). The resource requirements for disc trenching and ploughing are based on the study published by Hämäläinen and Kaila (1985); the resource requirements for mounding on Hämäläinen's research (1984 and 1988); resource requirements for planting, direct seeding and clearing of the planted stand on Keränen's and Ojala's studies (1992), and the resource requirements for mechanical cleaning of sapling stands on the studies completed by Hämäläinen and Kaila (1990) and Keränen and Ojala (1992) (example in Table 6). The costs of silvicultural operations are based on the data published in the Yearbook of Forest Statistics (1992) (Table 6). The annual increase in the cost of silvicultural operations was determined as 5 % for labour-intensive action, 2.5 % for mechanized action. Similarly, the projected increase in productivity was 0.5 % in labour-intensive and 1 % in mechanized work.

Table 6. An example of resource requirements and cost of silvicultural work chains, which are applied in optimum calculations. See the origin of numbers in chapter 4.2.5's text. Numbers of this example belong to the area East-Finland.

Stand type / Silvicultural operation	Percentage of total cutting area	Productivity, ha/h	Unit cost, FIM/ha	Hourly cost, FIM/ha
Clear-cut stands				
Clearing the stand	90	0.31	349	103
Disk trenching	70	0.52	736	383
Mounding	10	0.14	1352	189
Plowing	20	0.55	830	456
Planting	80	0.08	1690	135
Direct seeding	20	0.13	707	92
Clearing of planted stand, 2 two times/rotation	60	0.07	1512	106
Clearing of planted stand, once in rotation	40	0.16	756	121
Seed tree and shelter-wood cut stands				
Disc trenching	30	0.50	736	368
Clearing of planted stand, once in rotation	100	0.16	756	121

5 Resource Requirements for Optimum Scenarios with Various Optional Courses of Development

5.1 Future Trends in Procurement

In the optimum scenarios, future stand types will be selected with a view to low-cost harvesting systems and associated timber assortment distributions. In the 1990 concept, the minimum area limits for each type stand were 80 % of the actual area of the logging sites. The model selected so much pulpwood from first thinnings that limits had to be imposed on their maximum area. As a result, the characteristics of future stands were modified and the timber assortment distribution of stems were relaxed with regard to pulpwood. According to the optimum scenarios, the total area of first thinnings will decline up to year 2000 and then disappear completely (Fig. 19). The area of thinnings other than first thinnings will increase beginning in 1990 according to scenarios where procurement volumes will grow from 1990. At constant procurement volumes, the area of thinnings will decline in the future. According to shadow prices, the total cost of additional volumes felled in first thinnings are 5 to 10 % higher than the average procurement costs in the optimum scenario. Such additional costs will drop to 2 to 3 % by 2010.

From 1990 to 2000, the combined area of clear cuttings will grow and increasingly concentrate on stands containing small stems. The areas of cuttings associated with natural regeneration are smaller than today only in concepts that optimize procurement. In the optimum scenarios that take into account compulsory silvicultural operations after felling, the areas of cuttings for seed and shelter tree positions and removal of seed and shelter trees will be far greater than today (Fig. 19). Naturally, clear-cutting areas would remain low in these options. According to shadow prices,

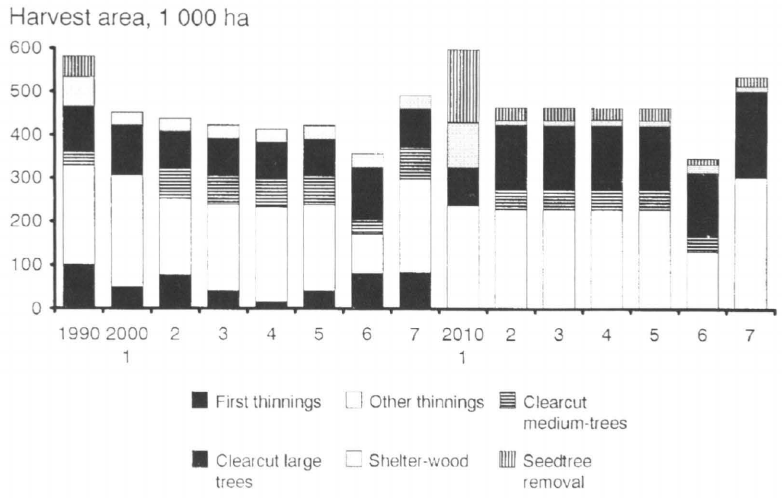


Fig. 19. Yearly cutting areas by stand types according to optimum calculations in different scenarios. Numbers describe names of scenario (see also table 3): 1 Silvicultural-optimum, 2 Procurement-optimum, 3 Low costs, 4 High costs, 5 High machine costs, 6 Small procurement, 7 Large procurement.

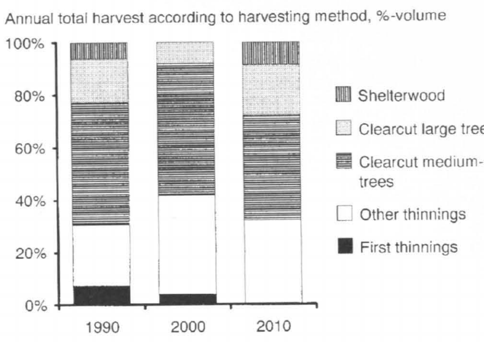


Fig. 20. Development scenario of stand type's volume shares. Values for 1990 from procurement-optimum and for 2000 and 2010 from silvicultural-optimum.

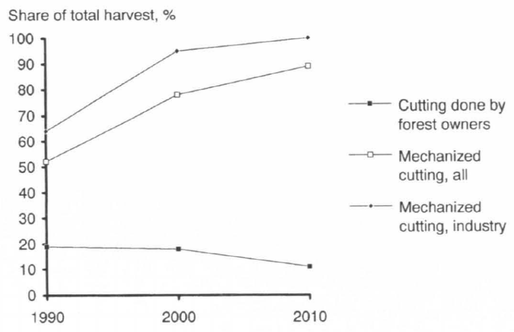


Fig. 21. Development of harvesting mechanization and private woodlot-owners own harvesting in silvicultural-optimum scenario.

the total costs of additional volumes obtained from the removal of seed and shelter trees will be 8 to 22 % higher in 2000 than those suggested by the optimum scenario. In 2010, such additional costs will only be 5 to 13 %. The optimum scenario could be improved by increased cutting of seed trees but this activity must be limited for biological reasons.

Variations in costs will only have a limited effect on the distribution of cutting areas (Fig. 19). Growth in the procurement volume clearly affects the area distribution, but the greatest impact is caused by the inclusion of silvicultural operations. The effects become more pronounced the further we go into the future.

The percentage of wood derived from first thinnings will decline (Fig. 20). Clear cutting will be the most important source of timber during the entire period under review. Wood procured from thinnings other than first thinnings will increase in volume. Timber to be obtained from cuttings for seed and shelter tree positions will vary a great deal in the future.

Mechanized harvesting will increase at all computed procurement volumes in all cost scenarios (Figs. 21 and 25, Appendix 4). Price development in the basic mechanized harvesting concept is more favourable than that in labour-intensive harvesting, but mechanization will also be greatly promoted by lower planning and work supervision needs. According to optimum scenarios, mechanized felling will be carried out solely by medium-size one-grip harvesters. The small-size har-

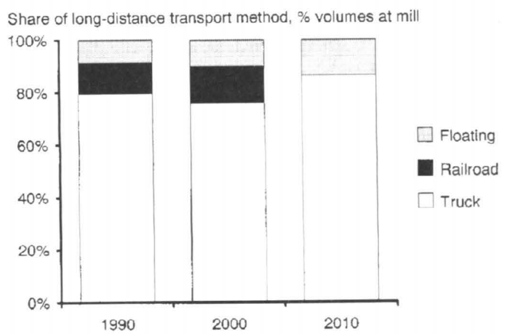


Fig. 22. Development scenario of long distance transport method's volume shares. Shares show volumes transported to mill. Values for 1990 from procurement-optimum and for 2000 and 2010 from silvicultural-optimum.

vester and two-grip harvester do not figure in any scenario. Fig. 21 compares the 1990 harvesting optimum with subsequent silvicultural optimums because the harvesting optimum primarily reflects the actual situation in 1990. Relatively speaking, work performed by a logger, which hardly fitted into the optimum scenario, is most economical in thinnings and in removal of seed trees. According to the shadow price analysis, replacing a medium-sized forwarder with a light forwarder will make up for the additional cost of 10 to 15 %.

Semi-professional forest owners own harvesting work is economical in first and other thinnings, the main reason being the low cost of work supervision. In all the other types of stand, small-

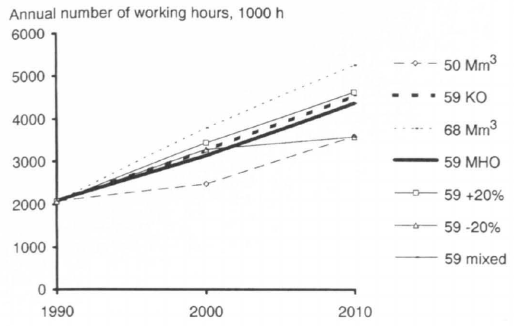


Fig. 23. Number of annual working hours for one-grip harvester in different scenarios. For explanation of the scenarios, see Table 3.

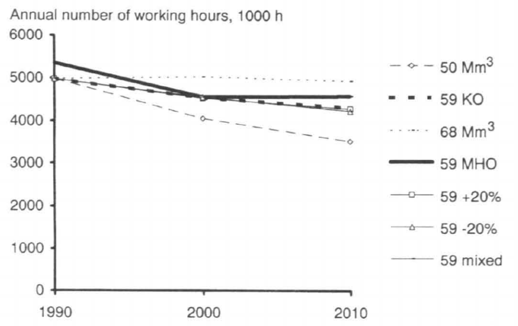


Fig. 24. Number of annual working hours for forwarder in different scenarios.

scale forest owners harvesting is very expensive. All the one-grip harvester sequences used in the optimum scenarios for 2000 and 2010 are based on all-round contracting. This clearly reflects the importance of work supervision costs because all-round contracting is the system where the need for supervision is lowest.

The role of truck haulage will continue to increase (Fig. 22). Transportation by rail will come to end by 2010 unless the current price trends change radically from the assumptions used for the calculations. Floating is slowly increasing. When the floating figures for 1990 are examined, it should be borne in mind that log driving in Lapland was not included. Fig. 22 compares the 1990 harvesting optimum with subsequent silvicultural optimums because the harvesting optimum primarily reflects the actual situation.

According to a shadow price analysis, the cost of additional volumes transported by floating are 10 to 15 % higher than the average procurement costs in the optimum scenario. Additional volumes transported by rail are 3 to 5 % more expensive.

5.2 Working Hours in the Various Scenarios

At the greatest procurement volume, work performed by harvesters will nearly triple from 1990 to 2010 (Fig. 23, Appendix 4). In the optimum scenarios for both harvesting and silvicultural operations, the number of harvester-hours doubled from 2000 hours to 4000 hours over a period of twenty years. If all costs increase 20 % less than assumed in the basic scenario, or if the increase in the price of machine-work exceeds the basic level by 20 % while the cost of work performed by the logger follows the general cost increase, the percentage of machine input will not increase after 2000. Instead, it will be replaced with small-scale felling carried out by private forest owners. Variations of ±20 % in costs will have less effect on the amount of machine work than ±15 % variations in the volumes felled. In 2010, the mixed scenario and low-cost scenario are clearly distinguished by the decline in mechanized harvesting to a level corresponding to a 15 % lower felled volume. Harvester inputs according to the harvesting optimum and silvicultural optimum are nearly identical, the silvicultural optimum being 4 % lower.

Work performed by forwarders will generally decrease over the next 20 years (Fig. 24, appendix 4). This will be due to improved working conditions. Working behind a harvester is more effective than behind a logger. First thinnings will come to an end. By 2010, the need for forwarders will decline by 20 % assuming that felled volumes remain unchanged. If the felled volume increases by 15 %, the amount of work will stay at the current level. Variations in costs will have little effect on the amount of work. The silvicultural optimum gives forwarders slightly more work than a pure harvesting optimum.

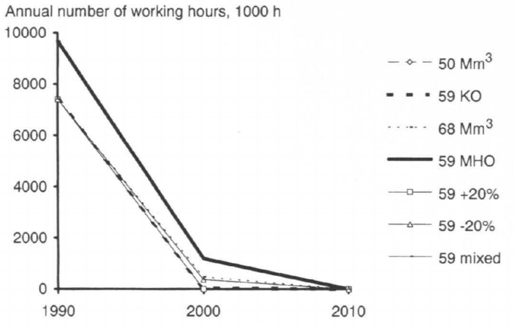


Fig. 25. Number of annual working hours for loggers in cutting work in different scenarios.

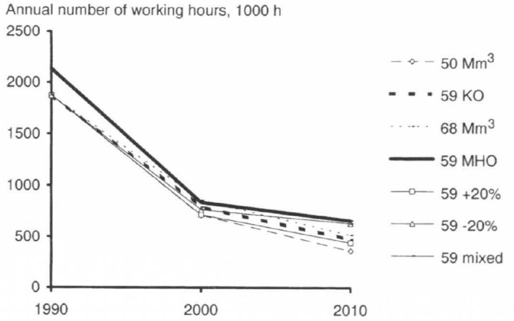


Fig. 26. Number of annual working hours for foreworker's work in stand design, scaling, payroll accounting and work supervision in different scenarios.

As a result of the increase in mechanized felling, the amount of work performed by loggers and forepersons has decreased (Figs. 25 and 26, Appendix 4). Work carried out by loggers only consists of logging. In the calculations, the work performed in summer is limited to 80 % of the input in winter because in summer they are assumed to be involved in silvicultural operations.

Cutting carried out by loggers will not be competitive on the average stands in 2010 studied here (Fig. 25). According to the optimum harvesting scenario for basic cost trends, loggers will not even be competitive in 2000 at current felled volumes, or in the event that the high-cost option materializes. If the costs increase sharply or mainly for machines, demand for loggers will decline to a tenth of present demand. According to the optimum silvicultural scenario, slightly more than one million man-hours of competitively sound logging work will be available in 2000.

The input by forepersons necessary for operations related to cutting will decline to less than half by 2000 and further to a third by 2010 (Fig. 26). Employment is best secured by the optimum silvicultural scenario. A slow growth in the cost of labour or a relatively rapid rise in the price of machine work will increase the need for work supervision at a quicker pace than the basic costs. Changes in felled volumes will have little effect on the amount of work available to foreperson. This decline will be due to new methods of scaling and the reduced need for supervision as a result of increased mechanization. Of all the work carried out by workmen, only stand design, scaling, payroll accounting and work supervision were included in the resource calculations. Other duties such as stand purchases and supervision of long-distance haulage are included in general costs but not in the determination of the work input.

Forest owners own small-scale haulage using the combination of a farm tractor, hydraulic loader and trailer will not be competitive in the future as compared to haulage by a forwarder, but it is nevertheless included because some forest owners will certainly continue to do it. Cutting by private woodlot owners is competitive but the maximum potential input calculated by Koistinen (1992) was assumed to establish the ceiling for the amount of work. Work performed by forest owners will decline below the present level (Figs. 27 and 28, Appendix 4). In the future, labour-intensive cutting will almost solely be carried out by active private woodlot owners. Any increase in the price of machine work or a slow growth in costs will increase the volume of small-scale haulage and slow down the decrease in logging by 2010.

The volume of small-scale cutting by woodlot owners will decline more slowly in the optimum scenario for silvicultural operations than in the optimum harvesting scenario. Working methods will develop and cutting and off-road haulage will only be carried out by active forest producers, who will have a higher productivity than today and who will do forest work outside their own farms as well.

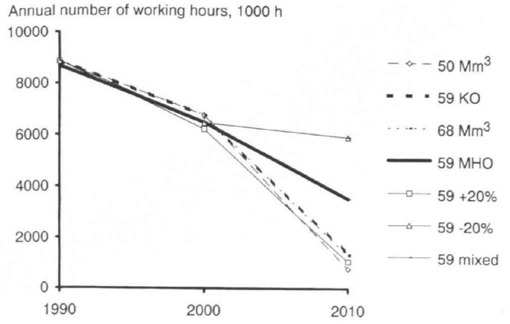


Fig. 27. Number of annual working hours for forest owners in cutting work in different scenarios.

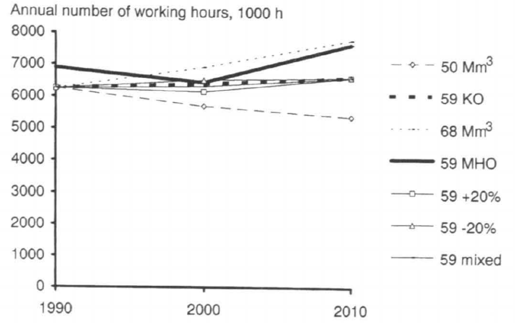


Fig. 29. Number of annual working hours for trucks in different scenarios.

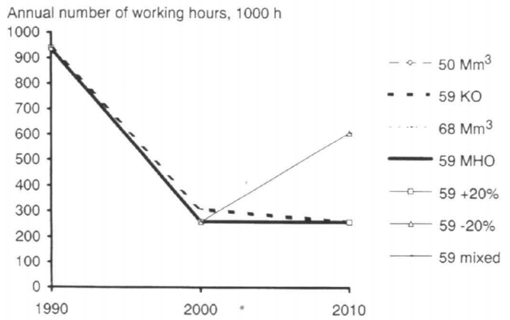


Fig. 28. Number of annual working hours for forest owners in off-road transport work in different scenarios.

Assessing the amount of work required for long-distance haulage is extremely difficult. Haulage by truck is the only area for which the dependence of the required work inputs on ton mileage can be calculated. For floating and transportation by rail, ton mileage can be indicated for a given number of personnel, but the actual ton mileage can be lower than that by any imaginable margin. Except for the cost of floatway maintenance underwritten by the government, a cost basis for work can be determined for floating. The government allocates large sums to track maintenance, but also to road and floatway maintenance. On the railways, the transportation rates are, to a great extent, determined by factors other than direct work cost considerations.

At the basic cost development trend, the number of working hours required for haulage by truck will remain more or less unchanged (Fig. 29, Appendix 4). The amount of work will decrease if the quantity delivered remains the same and increase if haulage volumes increase more than anticipated in the basic scenario. Any fluctuations in costs will have little, if any, effect on the amount of work associated with haulage by truck. According to the optimum scenario for silvicultural operations, the haulage distances will become longer because clear-cutting will account only for a very small percentage of the total. As a result, the amount of work required for truck haulage will also increase.

The amounts of work associated with silviculture were only calculated for the optimum silvicultural scenario. With this type of work, the season is always shorter than one year.

5.3 Timber Procurement Costs in Various Scenarios

The costs are subdivided into general, cutting, off-road haulage and long-distance haulage costs. Naturally, the increase in unit costs associated with each individual harvesting or haulage system is determined by the cost forecasts shown in Table 4. Generally, the unit cost trends for each type of work will be determined by the percentages of the various working conditions. In addition, total costs are affected by the quantity delivered. The total cost estimates are based on previous cost development and forecasts for productivity increase. All the costs discussed here are nominal costs.

Table 7. Yearly increment of unit costs by various operation functions in different development scenarios.

Development scenario	Increment of unit cost in wood procurement works, % per year: General cost	Cutting	Off-road transport	Long distance transport	Procurement total
59 MHO	2.5	2.6	0.9	4.9	3.1
59 KO	2.5	2.5	0.7	5.0	3.1
50 Mm³	2.5	2.1	0.5	4.7	2.8
68 Mm³	2.5	2.6	0.7	5.2	3.2
59 +20%	3.1	3.1	1.2	5.7	3.7
59 –20%	1.9	1.8	0.4	4.3	2.5
59 mixed	2.7	3.3	2.0	5.5	3.8

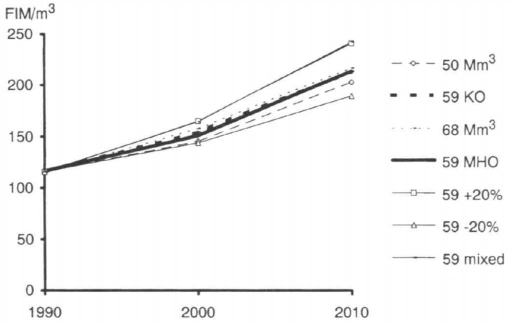


Fig. 30. Development of wood procurement's unit cost in different scenarios. For explanation of the scenarios, see Table 3.

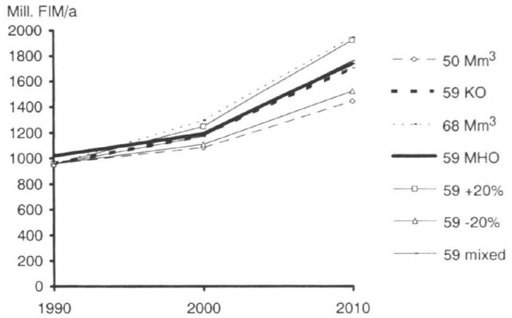


Fig. 31. Development of wood procurement's general cost in different scenarios.

In the basic scenario, the increase in procurement volume is 0.8 % per year, while the corresponding figure in the high-cost scenario is 1.5 % per year. According to the optimum scenario for silviculture and harvesting, the unit costs of procurement will increase by 3.1 % per year, or 2.8 % per year at a low procurement volume and 3.2 % at a high one (Fig. 30, Table 7 and Appendix 5). The greatest growth in costs is in scenarios caused by an increase in costs at a rate that is higher than that assumed in the basic scenario, or by a relative increase in machine costs, high costs and high machine costs. The increase then being 3.8 % per year. Fluctuations in procurement volumes and the inclusion of silvicultural operations as a limiting factor have little impact on future unit costs as compared with the basic scenario.

The units costs for general costs (Table 8) will increase at a slower pace than that suggested by the mere forecast for unit costs for the type of

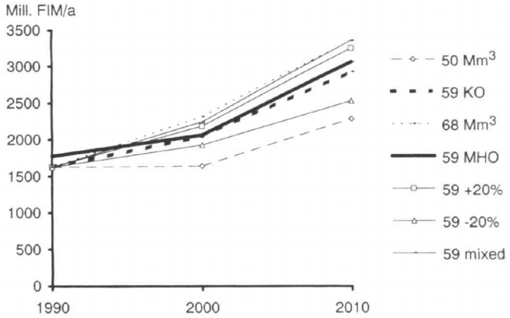


Fig. 32. Development of cutting costs in different scenarios.

work involved. The increase in the unit costs of cutting is more or less identical to the cost trends for mechanized cutting. The unit costs for off-road haulage will increase far less than general costs in this field. The unit costs for long-distance

Table 8. Yearly increment of total cost of procurement phases in different development scenarios.

Development scenario	Increment of wood procurement total cost, % per year: General cost	Cutting	Off-road transport	Long distance transport	Procurement total
59 MHO	2.7	2.8	1.1	5.6	3.3
59 KO	2.9	3.0	1.1	5.5	3.6
50 Mm³	2.1	1.7	0.1	4.3	2.5
68 Mm³	3.6	3.7	1.8	6.5	4.3
59 +20%	3.5	3.5	1.6	6.2	4.2
59 –20%	2.3	2.2	0.9	4.9	2.9
59 mixed	3.1	3.7	2.4	6.0	4.2

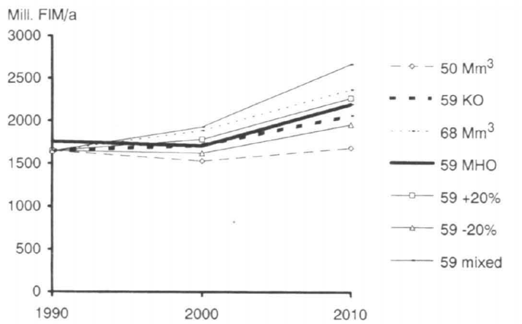


Fig. 33. Development of off-road transport cost in different scenarios.

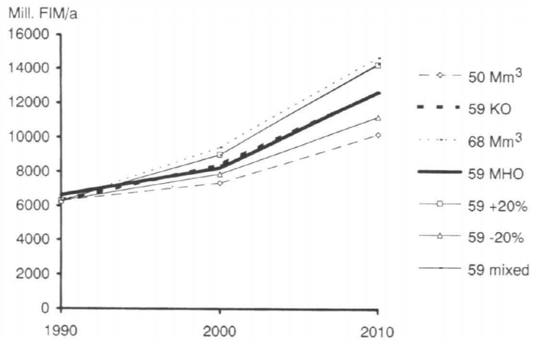


Fig. 35. Development of wood procurement's total cost in different scenarios. For explanation of the scenarios, see Table 3.

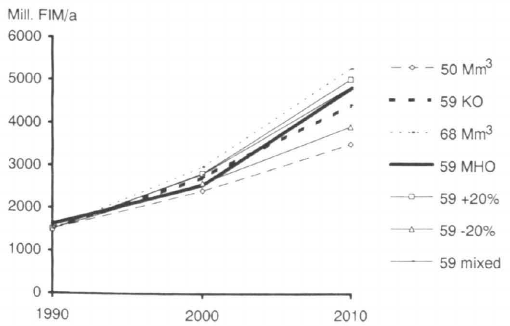


Fig. 34. Development of long-distance transport cost in different scenarios.

haulage will rise more rapidly than the unit costs predicted for the modes of transportation.

As well as the changes in unit costs, total future costs for wood procurement are, naturally, affected by the procurement volume. Apart from off-road haulage, this makes the scenario for maximum procurement volume the most expensive alternative in terms of total costs in all cost types (Figs. 31, 32, 33, 34 and 35, Appendix 5). Accordingly, the costs of the scenario for the current procurement volume are the lowest of all. The total costs suggested by the optimum scenarios for silviculture and harvesting are very close, the silvicultural optimum being slightly more expensive than the harvesting optimum. Of the cost trends for the basic procurement volume, the scenario for the slowest increase in costs is naturally the cheapest.

The scenarios for the fastest increase in costs and relative increase in machine work are equally expensive in terms of total costs, but costs vary by type of work. In cutting and off-road haulage, the scenario for the relative increase in machine work is more expensive than the alternative for the fastest rate of increase, the situation being reversed for general costs and long-distance haulage.

According to the basic assumptions made for the calculations, the costs increase at a constant rate per year, meaning that the increase will be increasingly sharp in future.

Cost trends suggested by the basic cost scenarios vary from 2.5 to 4.3 % per year according to procurement volume and calculation basis (Table 8). Apart from the scenario for current procurement volume, the increase in costs includes an annual increase of 0.8 % or 1.5 % in the procurement volume. According to the scenario for the lowest procurement volume, the cost of off-road haulage will not increase at all. The increase in costs is greatest for long-distance haulage. If the rate of increase in all costs or only in the costs of machine work accelerates by one fifth, the annual growth in total costs will nearly reach the same level as that attained when the maximum procurement volume is harvested in the basic cost trend scenario. By contrast, if the rate of increase in costs decelerates by one fifth, the cost increase does not drop to the level required for harvesting the current procurement volume. More often than not, the increase in costs suggested by the optimum silvicultural scenario is lower than that suggested by the harvesting optimum in spite of nearly equal total costs. This is due to the higher initial costs required by the optimum harvesting scenario.

6 Example of Allocation of Resources

6.1 Number of Forepersons and Loggers

The optimum scenarios yield the resources required by each working method in the three areas during the four seasons (Appendix 6). The sum total of the figures for the areas and seasons indicates the annual resource requirements for the whole country. The working hours presented in Chapter 5.2 can be roughly converted into the number of personnel by dividing the total working hours by the annual input by one individual. To qualify as a professional, a person must work at least 200 days per year as a logger according to the statistics of Forest Employers Association. Assuming an eight-hour working day, a logger then works a minimum of 1600 hours per year. With normal working hours and annual leaves, annual working hours amount to 1800 to 1900 hours. However, the hours may vary a great deal for a number of reasons. Particularly with machine operators, the working hours may vary considerably from one season to another. Work is also divided into long working days that are compensated for by long weekends.

As a example, the annual working hours entailed by the optimum silvicultural scenario are converted into man-hours and machine-hours (Appendix 6). For labour-intensive work, the required number of personnel is calculated by dividing the total work input, or resource requirement, by the working hours completed by one individual. When planning harvesting operations, supervising work, scaling and making payroll calculations, a foreperson was assumed to work 8.5 to 10 hours per day, inclusive of travel times, depending on the season. Fluctuations in the demand for labour was compensated for by regulating the number of daily working hours. The total working hours are 10.5 months, 21 days per month.

Forepersons have other duties as well that were not taken into account in the calculations. In summer, a major input by foreperson is required for silvicultural operations. The following figures provide examples of the required number of personnel for slow and busy seasons. In 1990, 20 % more forepersons are needed during the two winter seasons than during the two summer seasons (Fig. 36). In 2000, there will be one low season, whereas in 2010 the need for forepersons remains the same throughout the year.

In the example, a logger works 6.6 to 7.7 hours per day (Pajuoja 1986). Total working hours are equivalent to 11 months per year and 21 days per month. In 1990, the number of loggers needed for felling operations was 10 000 in the winter, 1800 in the spring, 4600 in the summer and 7700 in the autumn (Fig. 37). In the model, the amount of work in summer was restricted to 20 % of that in the winter to allow the workers to be active in silvicultural work. In 2000, the number of loggers required for cutting work will be 1100 in the autumn and winter season, 200 in the spring season and 600 in the summer season. The amount of work available in summer is restricted as much as in the 1990 scenario.

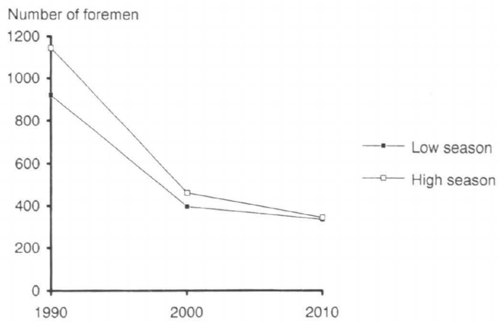


Fig. 36. An example of division of forepersons (stand design, work supervision, scaling and payroll accounting) total annual worktime into number of workers in silvicultural-optimum. Description of the basis of calculation and low and high season in text.

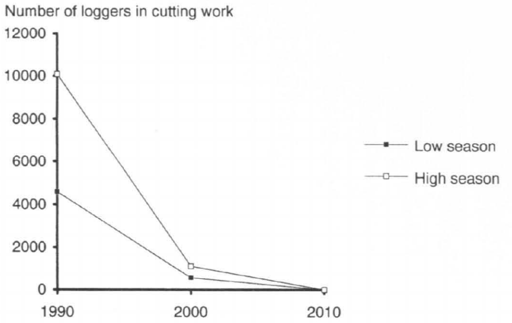


Fig. 37. An example of division of loggers (cutting work) total annual worktime into number of workers in silvicultural-optimum. Description of the basis of calculation and low and high season in text.

For biological reasons, silvicultural work can be carried out only at certain times of the year. In the calculation example, the number of daily working hours was assumed to be 6 for planting, sowing, sapling stand cleaning and clearing of regeneration areas. The length of the season is two 23-day months for planting, one 23-day month for sowing, three 22-day months for sapling stand cleaning and thinning and four 21-day months for the clearing of regeneration areas. The number of people involved in sowing and planting will have declined by one fifth by the end of the season.

6.2 Number of Private Woodlot Owners Engaged in Small-Scale Harvesting

The number of private woodlot owners involved in small-scale harvesting is determined by the volume of timber felled and transported by a single forest owner per year. In the example, the annual input by one forest owner involved in cutting was assumed to be 200 m³, which he is capable of felling when working 5 hours per day for 50 days at a rate of 4 m³ per day. The felled volume is one third higher than the size with contract sale in the study published by Koistinen (1991). According to the survey conducted by Uotila and Toivanen (1992), the average volume of a contract sale varies from 70 to 145 m³ according to the cutting method. In the same study, the volume of sales at delivered price carried out by

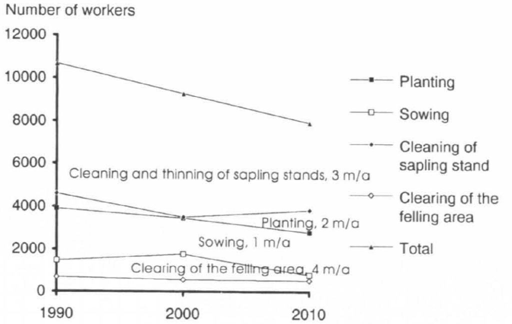


Fig. 38. An example of divison of loggers (silvicultural works) total annual work-time into number of workers in silvicultural-optimum. The season length (months / year) of each work operation is given in the figure.

outside personnel varied from 205 to 720 m³. The mean volume that is slightly higher than the average stand size suggested by the said studies and tax-free sales was arrived at mainly because the 1990 calculation takes no account of the role played by an active forest farmer, who carries out cutting operations outside his own farm as well. Moreover, a forest owner can conclude several deals during the same year. All in all, around 100 000 forest owners are involved in forest work at one time or another. In 1990, the number of forest owners who were actively involved in felling was 32 000 according to the statistics of Forest Centre Tapio given by Mr. Ilppo Greis. This number fits well the experience that one farmer is selling wood on about every second or third year.

The calculation example for 2000 and 2010 included the cutting methods employed by an active forest farm owner, where the farmer is assumed to carry out all the felling operations on his own farm and work for hire as well. His productivity was assumed to be 80 % of that of a professional logger, which is higher than in small-scale cutting carried out by private woodlot owners described above. On the basis of the work inputs evaluated by Koistinen (1992), the volume felled by one active forest farm owner was estimated to be 350 m3 per year. According to the calculation, the farmer is expected to cut 7 m³ per day for 50 days during a working day of six hours. Small-scale private cutting was not included in the optimum scenarios for 2000 and 2010.

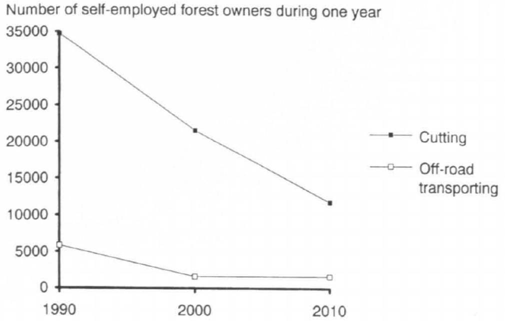


Fig. 39. Example of division of forest owners (cutting and off-road transport work) total annual work-time into number of workers in silvicultural-optimum. Yearly work amounts and other basis descriptions of the calculation are described in text.

The volume transported by a private woodlot owner using a farm tractor equipped with a hydraulic skidding grapple was assumed to be 200 m³ per year. This alternative was not included in the optimum scenario at any point. An active forest farmer working with a hydraulic loader and trailer is compelled to seek work outside his own farms because otherwise the capital costs of the equipment become too high. On the basis of the work inputs estimated by Koistinen (1992) the volume transported by one forest farmer was assumed to be 800 m³, the work being carried out in 32 days at a rate of 5 m³ per hour, 5 hours per day. The number of forest owners involved during one year in felling will decrease more rapidly than the number of those involved in haulage (Fig. 39).

6.3 Number of Machines and Timber Trucks and Their Drivers

6.3.1 Estimates of the Effects of Daily Working Hours on Productivity

It is not possible to determine the number of one-grip harvester and forwarder operators by dividing the volume of work by the annual input by an individual operator because the same machine can be operated by several people during one day. This makes sense from the point of view of reducing capital costs. Therefore the number of machine must be calculated independently of operators with due regard to reasonable operator hours. For example, if a machine is found to operate 12 hours per day, it cannot be assumed that one operator uses it for 8 hours and another operator for 4 hours.

The numbers of operators and machines were computed from the figures for required total resources (Appendix 6) so that the number of machines varies as little as possible from one season to another. The operators' working hours were adapted so that the length of the working day during any one season remains within the variation range of normal working hours. For these reasons, equalization of the number of machines and, particularly, the number of operators is effected between seasons; in other words, some workers can be working actively for only part of the year. The same applies to labour-intensive work as well.

Costs determined by time, such as wages and repayments on loans, are easy to calculate. When daily working hours exceed 8, operators must be paid extra for overtime and double shift. At the same time, any bonuses for dirty work and installation work at low temperatures increase as well. The current trend is that whenever operators are required to work more than one shift a day, extra will have to be paid for travel or accommodation on the site. As a result, the interest expenditure on the capital tied up in the machines decreases per effective working hour because the period of calendar time for repayment is shortened. On the other hand, the cost of repayments on the principal linked to calendar time increase because the principal must be repaid more quickly. Usually, general costs per hour decline because the administrative organization (often the contractor himself) is, with a little extra effort, able to handle the work required by several shifts.

No research data is available on any decline in productivity or increased need for repair and maintenance in relation to the number of day-light hours. Operator productivity decreases as a result of fatigue and long hours in the dark. The number of service and repair operations and their cost per hour are probably higher than in one-shift operation.

The effect of the number of daily working hours on the cost of work when using a one-grip harvester, forwarder and timber truck was calculated in accordance with the principles suggested by

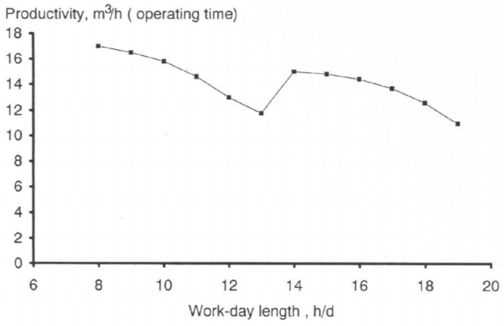


Fig. 40. Dependence of the gross effective time productivity of one-grip harvester on the length of work-day. Description of the basis of calculation in text.

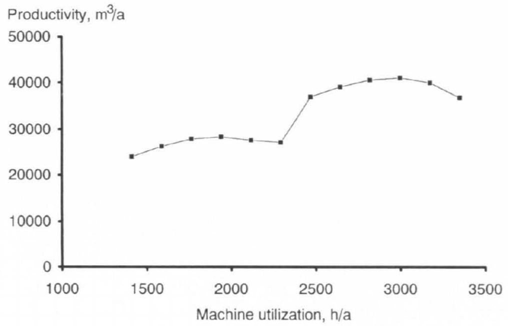


Fig. 41. Dependence of the annual output of one-grip harvester on the length of work-day calculated on the basis of figure 40 and mechanical availability. Description of the basis of calculation in text.

Jaakkola (1992) and Mr Markku Maukonen and Mr Harri Rumpunen, using the cost calculation program devised by Alanne and Rummukainen (1991) (example given in Appendix 7) by varying the number of daily working hours while the number of working days remained unchanged. From this it follows that the number of daily working hours determines the annual working hours according to the technical utilization rate. The product of output per effective hour and number of operating hours gives the annual machine output.

The dependence of output per operating hour on the number of daily working hours was estimated for a one-grip harvester, forwarder and timber truck (one-grip harvester in Fig. 40), and this value and operating time was then used for computing the dependence of output per operating hour on annual operating hours. Finally, this figure and the output per operating hour was used for computing the annual output by the machine (one-grip harvester in Fig. 41). In the calculations, the number of daily working hours in one shift varies from 8 to 14 and in two shifts from 14 to 19 hours, meaning that the number of working hours of individual employees varies from 7 to 14 hours.

The dependence of the productivity of a multi-function machine on the number of daily working hours was evaluated on the basis of the work study by Kuitto (1992) for determining piece rate. The productivity of work carried out by a one-grip harvester declines with the increasing number of hours as the operator gets tired. In winter, long working hours bring in its train the effects of darkness, snow and increasing need for thinning that slow down work. If daily hours exceed 14, work is carried out in two shifts, which increases productivity as a fresh operator takes over. Because of darkness and other limiting factors, productivity falls slightly short of the performance in one-shift operation. With longer working hours, the decline in productivity become sharper. The dependence of annual output on the number of working hours is computed directly by means of the technical utilization rate. With the calculation bases used here, the introduction of a second shift improves annual output considerably. An extension of both shifts begins to affect output negatively after 3000 hours.

With one-grip harvesters, fatigue and weather conditions have a greater impact on productivity that with forwarders which travel along an existing striproad picking up complete bunches. In Kuitto's study (1992) on piece rates, the decline in forwarder productivity with time was estimated to be less sharp than for a loader harvester. However, the introduction of a second shift increases annual output. The dependence of the productivity of silvicultural machines, mainly scarifying machines, on the number of working hours was assumed to be similar to that of forwarders.

The dependence of the productivity of timber haulage by truck on the number of working hours was estimated with the aid of Mr Pekka Mäkinen's, (Sc.D.(Agr.For.), senior researcher in Finnish Forest Research Institute), unpublished data

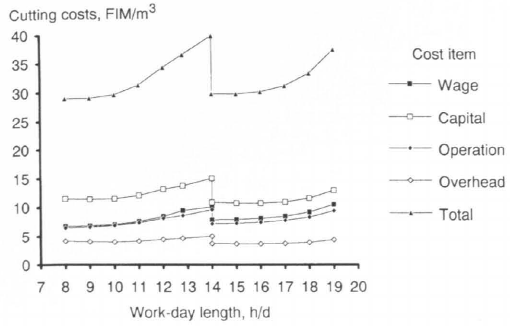


Fig. 42. An estimate how cutting costs by one-grip harvester depend on the length of work-day. Description of the basis of calculation in text.

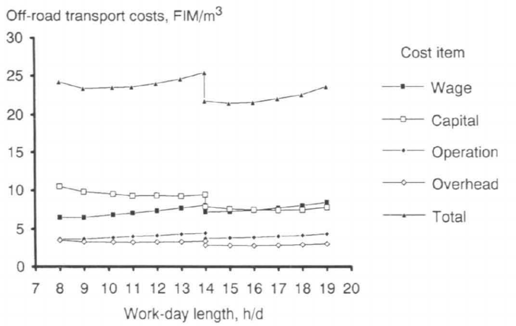


Fig. 43. An estimate how off-road transport costs by forwarder depend on the length of work-day. Description of the basis of calculation in text.

on the competitiveness of fleet operators and Mr Markku Maukonen's rate calculation basis. In the case of haulage by truck, the conditions are even more stabilized than in haulage by forwarders, and so the decline in productivity with the increasing number of working hours was assumed to be fairly low. The average haulage distance used in the calculations was 80 km. With trucks, the haulage of one load takes several hours so that the length of the day is preferably selected by considering how may round-trips can rationally be made. Also, daily working hours are affected by the timetables for mill yard operations observed by the mills. The technical utilization rate is higher for a vehicle combination than for tractors. With these calculation bases, annual output increases in a fairly straight line with increasing working hours.

6.3.2 Estimates of the Effects of Daily Working Hours on Unit Costs

The effect of the length of the working day on productivity was merged with calculations on the effects of the length of the day on the cost of operations produced by Alanne's and Rummukainen's (1991) computer application (Figs. 40, 41 and 42). At first, the cost per time unit declines slowly with the increase in the length of the day. As the operator tires, productivity decreases. Then the costs start increasing at an ever accelerating rate. The increase is sharpest with one-grip harvesters (Fig. 42). At the beginning of two-shift work, the unit costs decline because

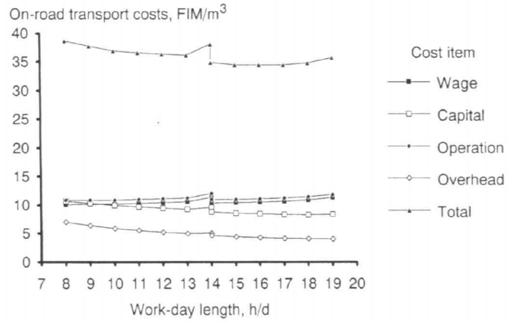


Fig. 44. An estimate how long-distance transport costs by truck depend on the length of work-day. Description of the basis of calculation in text.

productivity increases owing to a fresh operator. When a two-shift working gets longer, the costs begin to rise again. With forwarders and haulage by truck the increase is moderate (Figs. 43 and 44). At these input values, the best result for haulage by truck is given by the longest day. With a one-grip harvester, the difference in cost between the least expensive and most expensive length of working day is 25 %. The corresponding figure for forwarders is almost 15 %, 10 % for haulage by truck. The introduction of a second shift decreases capital costs most for loader harvesters and tractors. For truck transportation, the decrease in costs is fairly small. If productivity and cost vary as assumed in the calculations, the choice of the correct length of working day is of great importance to costs.

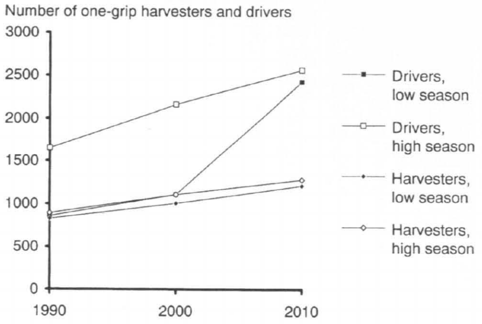


Fig. 45. An example of division of silvicultural-optimum's total annual worktime into number of one-grip harvesters and operators. Description of the basis of calculation and low and high season in text.

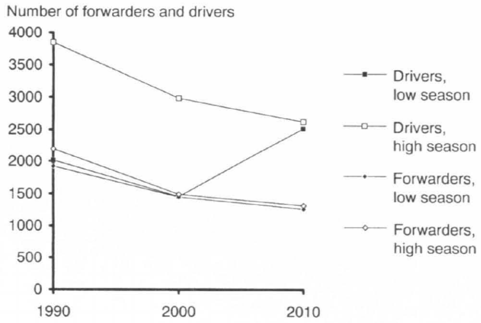


Fig. 46. An example of division of silvicultural-optimum's total annual work-time into number of forwarders and operators. Description of the basis of calculation and low and high season in text.

6.3.3 Number of Machines and Operators

In the calculation example, the annual input is divided into machine-hours and man-hours by adjusting the number and working hours of the operators so that the number of machines remains as constant as possible throughout the year. The operators' working time is very similar to normal daily working hours with a narrow margin for overtime. Another factor that determines the operators' working hours and, subsequently, their number is costs that vary according to the length of the working day. Working hours must be selected so that the unit costs that depend on the length of working day are low (Figs. 42, 43 and 44). The cost-dependence of forwarders was applied to scarifying machines a well.

According to the calculation example prepared on the basis of the optimum silvicultural scenario, the number of one-grip harvesters will increase at a fairly uniform rate from 900 to 1300 by the year 2010 (Fig. 45). The number of operators will increase more quickly, reaching up to 2600 in 2010. The 1990 example included only individual loader harvesters where later all the machines were part of an all-round contracting system working in collaboration with forwarders. In the 1990 example, the harvesters operate for one season in two shifts 16 hours a day. During other seasons, the length of the working day varies from 9 to 11 hours. In 2000, the one-grip harvester will operate three seasons working 14 hours a day in two shifts and one season working 10.5 hours a day in one shift. In 2010 work will be carried out in two shifts during all seasons. By 2010 all the harvester operators can be permanently employed year-round.

The number of forwarders will decrease in the future (Fig. 46). The number of operators will decline much more slowly than that of the machines. In the 1990 calculation example, individual forwarders worked 16 hours a day in two shifts during one season. During the three other seasons, the machines work long hours from 10.2 to 11 hours in one shift. In 2000 both the individual forwarders and forwarders operating as part of a all-round contracting system will operate in two shifts doing 14 to 16 hours per day for three seasons and 11 hours per day in one shift for one season. The number of independent forwarders will be less than a third of the total.

Forwarders will be involved in all-round contracting work in two shifts around the year doing 16 to 17 hours per day. Similarly, independent forwarders will also operate in two shifts, although the length of the day will be shorter, namely 13 hours during three seasons and 19 hours during one season. By 2010 the number of independent forwarders will decline to fewer than one fifth of all forwarders, which will drop to 1300 from the 2200 in 1990.

According to the calculation example, the number of vehicle combinations will decline from

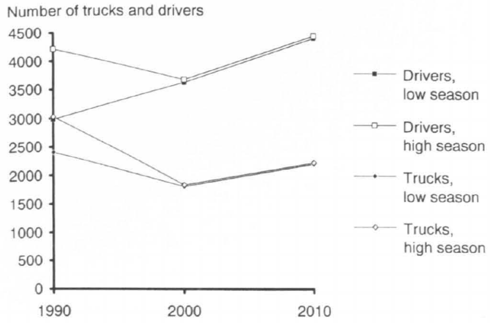


Fig. 47. An example of division of silvicultural-optimum's total annual work-time into number of articulated trucks and operators. Description of the basis of calculation and low and high season in text.

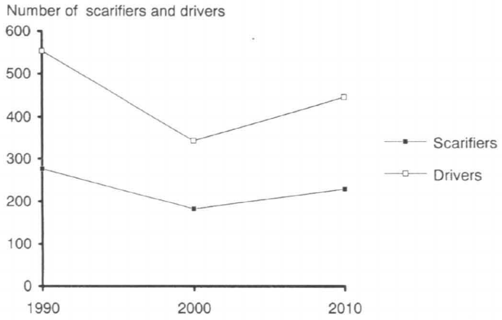


Fig. 48. An example of division of silvicultural-optimum's total annual work-time into number of scarifiers and operators. Description of the basis of calculation and the length of season in text.

3000 in 1990 to 2200 in 2010 (Fig. 47). However, demand for drivers will even increase during the same period. In 1990, the vehicles operated 10 hours a day in one shift for three seasons and 14 hours a day in two shifts for one season. In 2000 the trucks will operate in two shifts round the year, the length of the day being 15 to 18 hours according to season. By 2010 the number of vehicles and drivers will grow. Work will be carried out in two shifts all the time for 14 to 17 hours per day.

The need for scarifying machines varies considerably in the calculation example. This is due to the changes in the relative percentages of the various harvesting methods. The working seasons for all machines is 4 months per year. Harrows and mounding machines operate 15 hours per day in two shifts and ploughs 10 hours a day in one shift. In 1990, harrows will account for two-thirds of all site preparation machines, mounding machines for one third, the rest being ploughs. By 2000, the number of harrows and mounding machines will decrease and that of ploughs increase. Ploughs will be replaced by some other site preparation method. By 2010, the number of ploughs will decline to almost zero while the number of mounding machines will increase sharply.

7 Discussion of the Results

7.1 Validity of the Model

The soundness of a study refers to all the factors that contribute to the final results. Here, the question is whether future trends will materialize as predicted. This section will deal with the technical aspects. The following section (7.2) will discuss the bases and significance of the trends and selections associated with the forecasts. The validity of the model means how well it reflects reality. Here, the question is whether the authors have selected the correct procurement methods, described their operations correctly and whether the data on working conditions that affect performance are correct and whether a linear model is suitable for selecting the right combination of measures.

Methods, conditions and their combinations associated with timber procurement are in practice innumerable. Therefore an attempt has been made to create a model for each work operation, inclusive of the dependencies that have the greatest impact on the final result. For the purposes of the present study, it did not make sense to investigate the productivity and cost dependencies of the working methods separately, and so the studies used as basis for drawing up the model vary in terms of age, quality and scope. In many cases, it was necessary to combine the results of several studies. Results presented in the form of diagrams and tables have usually to be converted into a mathematical form. Where possible, the validity of the mathematical models has been proven by statistical parameters. Often, the dependence between the model and some variable in the basic data has been illustrated by means of curves (e.g. Equations 14, 15, and Fig. 7).

The highest number of studies was available for the description of cutting and off-road haulage. Unfortunately, many of the work-difficulty factors in the sources were only given as mean percentages that either increase or decrease the total. In addition, the mathematical models are not general models based on the various work operations which could be used for predicting new conditions by simply modifying the factors. The productivity models for chainsaw cutting had to be computed indirectly using wage tables. This approach may include errors because wages are not paid for individual work operations on the basis of the time required for their performance or the difficulty of the work, but on the basis of the collective agreement. Also, the sources used for compiling data on the methods of scaling and work supervision were numerous and possibly outdated. The dependence of work on the amount of work performed is not as clear as in cutting and haulage. No productivity models could be prepared for floating and transportation by rail. Instead, the authors had to resort to existing cost models that do not necessarily convey any information on factors that have an essential effect on productivity or costs. A number of activities had to be described by a single value. They included general administrative costs and the productivity of timber reception at the mills.

For the description of working conditions, the country was divided into three areas in order to achieve a degree of variation. The differences in the values between the areas are 30 to 50 %. Minor variations in conditions between most areas could not have been established reliably. Problems were encountered when trying to define the characteristics of various stand types. Data on stand size specified according to the method of cutting is only available from Scaling of standing trees -statistics (Lassheikki 1989) which are misleading, particularly with regard to thinnings. The data provided in Scaling of standing trees -statistics on the structure of the growing stock was arbitrarily modified by the authors to a fairly great extent. Future growing stock was analyzed by Mr Mauno Pesonen. The fact that only six stand types were included in the study simplified the conditions to such an extent that the working methods required for special conditions were left out. For example, clear-cutting stands featuring large stems suitable for two-grip harvesters and small-scale thinnings jobs for loggers should be found in Southern Finland where these cutting methods are more favourable than those suggested by the optimum scenarios. Aside from the exclusion of special conditions, the potential for error is even greater in the stem size distribution on the stands because the stem size affects productivity considerably in all cutting methods. The impact on productivity is greatest with stem sizes of less than 300 dm^3.

Alanne (1993) tested the validity of most important productivity and stand type models with target optimisation (chapter 3.4). It showed that the main parts of model follow quite accurately real life's monthly fluctuations. This validation emphasizes the correctness of input data. Stand type distribution, harvested volumes per stand type, productivity of harvesting method and distribution of harvesting methods used on different stand types are especially critical input parameters in the model. The validation of total model is not possible because appropriate real life statistic does not exist.

The factors affecting the competition in the procurement areas and the form of the areas were all selected by the authors. However, distortions in the proportions of the various timber assortments with regard to individual processing points are uniformly distributed between all the 20 points. Breakdown of stems into timber assortments on one hand and the prediction of their future use at various mills on the other is complicated, involving questions such as the consumption of spruce logs for pulp production, etc. Consumption plays a role in determining what type of stand cutting will be focused on because the aim is to avoid species that are not required.

A linear model is fairly reliable in predicting timber procurement as a whole because the whole is assumed to be a sum total of its component parts. Where necessary, non-linearities of conventional form can be rectified by mathematical conversions which will then be reconverted to a non-linear form when the results are interpreted. By contrast, the logical non-continuity of a factor poses problems for the conventional formulation of the linear model that must be resolved arbitrarily. In its basic form, the linear model yields decimal values that must be rounded up to the nearest integer if the decimal value is of no actual relevance in practice. In this study, the problem was by-passed by selecting working hours as the variable, the result then being converted into integers, for example by using annual working hours. As such, the results yielded by the LP model do not contain probabilities for the various alternatives but are deterministic.

Numerical validity refers to correct calculation. In a study containing thousands of calculations, it is not possible to repeat them all in order to verify their validity, meaning the errors due to human factors may be involved. The errors found in the course of calculations were usually detected as a result of the illogical behaviour of the results. Many sub-models had to be extrapolated beyond the input data, and so there is reason to assume that the extrapolation is broadly indicative but individual values may be erroneous. The individual calculated values can include errors but the overall trends and orders of magnitude appear correct from a logical point of view.

7.2 Reliability of the Results

The main result provided by this study was the relations between the working methods calculated on the basis of operating hours. The cost figures, computed as nominal values, should be understood as indicators for relations. Individual values cannot be regarded as reliable even in the near future. The relations between cost curves remain more stable than individual costs. Estimates of the numbers of personnel and machines are mainly indicative because the working hours of machines and operators can easily be varied and very much even within one year. The comparison of long-distance haulage systems was analyzed on a much shakier basis than cutting and off-road haulage because very little data is available on the cost and productivity dependencies of the former. Silvicultural work is included only in order to support the selection of harvesting methods and therefore the forecasts for costs and volumes of work in silviculture are only indicative.

The cost of work when employing the various methods was selected as the point of reference for this study. Therefore the results can be easily used for a neutral evaluation of the methods because the most important government subsidies for individual methods that obscure the differences in costs were left out. Particularly in the case of private woodlot owners, the actual choice made in reality may lead to action that departs from the results suggested by this study for reasons such as tax reliefs, differences in the valuation of capital costs or unrealistic wage claims. Probably, it makes sense for the forest owner to work more than indicated by the cost comparison. It may be profitable for companies to hire forest owners to carry out highly priced work if government subsidies are available or if the forest owner is willing to compromise over his own income.

Although the calculations presented in this study are not based on a income forecast for a forest farm, which is very difficult to predict for tax reasons and other such factors, the results agree with the predictions made by Koistinen (1992) concerning the work input by forest owners involved in forest work. These calculations are based on the forecasts for the number of farms and forest owners willing to engage in such work. Work performed by forest owners figured in nearly all optimum scenarios up to the allowed maximum in the linear model.

The technological development in machines seems to have reached a point of maturity, where changes mainly consist of fine-tuning. The significant foreseeable modifications are related to the improvement of transmission and loader control systems. Scaling, data transmission and automation is also undergoing rapid development. Introduction of completely new types of machines will not be feasible until towards the end of the forecast period because the existing machines have a useful service life of 5 to 10 years. Developing new machines to the point that they are operational takes easily 5 to 15 years, as e.g. the experience with one-grip harvesters has shown. With one-grip harvester, an important new technology is mass processing in felling and cutting. Experience indicates that it is most economical on stands with small-sized stems marked for thinning. Time expenditure on small stems will be reduced by 10 to 40 % but the overall gain will be less than that because mass processing is not suitable for all stems (Brunberg 1989 and Lilleberg 1991). The benefits offered by mass processing can be eclipsed by the productivity increases taken into account in the calculations.

The benefits of technological advance are modified by the fact that, with increasing mechanization, the machines will have to operate in less favourable conditions. The structure of forests changes only slowly. With the normal felling cycle, the same site is visited every 20 to 40 years. Extension of the thinning intervals increases the volume of timber removed at any one time but reduces stem size. Growth in productivity is slowed down by the demands for improved quality of work and conservation. As far as southern Finland is concerned, an additional factor is action against butt rot, other fungi and pesticides which does not necessarily slow down work but increases costs (Keränen 1992 and Korpilahti 1991). Increasing natural regeneration and preservation of various protection zones will reduce the volumes of timber harvested from stands per unit of area, with a consequent adverse effect on productivity (Galland & Pätilä 1993). Potential benefits offered by technological advance seem to be tempered by new demands for quality work.

Introduction of methods other than the timber assortment method was not taken into account in the calculations because they will not be competitive unless major changes take place in price ratios, which is not in view. Increased use of wood for energy production may bring about new harvesting methods. This will entail changes in energy prices or government subsidies (Hakkila 1992), which are possible during the forecast period.

Measures related to work organization, administration and the closing of deals will become simpler. Many work methods will disappear because of the high general cost associated with them. As the results indicate, all-round contracting based on joint management of the cutting and off-road haulage machines is superior to all other systems in terms of economy. Small-scale felling performed by private woodlot owners is more economical than work carried out by loggers hired by the procurement company. The effects of all-round contracting with regard to long-distance haulage are not evident in this study. Similarly, the types of purchases were not investigated here.

The long distance hauling will be intensified because companies are developing map based strategical planning and tactical leading systems. It means also more combinatorial transports: truck – train, truck – ship etc.

Significant factors that are undergoing rapid transformation are changes in decision-making in society affecting taxation, business practices, forest ownership, economic recession and boom, price of oil, mechanisms for determining the price of timber, government subsidies, road service licences, maximum vehicle weights, conservation zones and social security taxes on labour. These are examples of elements that are extremely difficult to predict. Future trends in railway transportation rates is a good example of external influence. A forecast based on current rates and their predicted trends foresees a decline in volumes transported by rail. However, since timber and wood products are the most important cargo for the Finnish State Railways, the rate will most probably be reduced to secure further traffic. At the same time, European integration creates pressures towards reducing the maximum weights of vehicles. In addition, emissions and speed limits and pollution taxes may be imposed on road traffic, which will probably increase the cost of haulage and move haulage's to rails or ships.

Silvicultural work was included in only one optimum scenario, and even then in terms of its restraining effect on the stand type. A series of silvicultural measures very similar to current practice was defined for each stand type. The relative percentages of these operations were not adjusted in respect of time. However, changes in the relative percentages of the various cutting methods affected silvicultural work to such an extent that fellings aimed at natural regeneration were included. Unlike cutting and haulage, silvicultural work provides the possibility of the introduction of new types of machines. For the time being, the competitiveness of the machines used for planting and clearing of sapling stands, as compared to human labour, is poor (Kääriäinen et al. 1992 and Rummukainen 1993). The forecast for the amount of silvicultural work is also uncertain because the values relating to the need for silvicultural works can change. Silvicultural work may be neglected or its frequency and intensity modified for financial reasons. The use of fertilizers and pesticides on conventional sites will decrease but may also increase in the form of restorative fertilization. The number of workers predicted in the forecast can be regarded as a maximum number.

From the point of view of timber procurement, the forestry industry is in a position to face the challenges presented by the future. Domestic timber is available in sufficient quantity to allow expansion of operations by the industry, with the possible exception of certain individual timber species. Results show that it is economical to increase cuttings on later thinnings, clear cuttings and seed tree- and shelter wood cuttings on cost of first thinnings. To skip first thinnings is made in practise by making pre-commercial thinnings late and strong so that the harvesting conditions will be more favourable than today. First thinnings add extra 2...10 % cost for harvesting. Cost and procurement level variations effect quite little on the stand type structure of cutting areas. The burdening cutting types by silvicultural measures increases clearly the share of seed tree- and shelter wood cuttings on cost of clear cuttings.

Amount of manual work is decreasing in logging from 45 % in 1990 to less than 15 % in 2010. Forest owners own work will replace even this little amount of work of company loggers. Cost increment and procurement level alternatives effect very little on profitability of manual work. The further we go into the future, the fewer are the number of harvesting methods selected by the model. Harvesting is done most economical by 10-tonne one grip harvester and forwarder chain. Besides manual logging no other harvesting method is competitive to 10-tonne mechanized chain according to scenarios.

The use of general-purpose machines and methods makes sense in terms of easier organization and reduced need for transfers between stands. The organizing of light and heavy harvesting chains with good productivities on extreme conditions will be more expensive than to use only one medium heavy chain on same area with lower productivity on extreme conditions but ability to work on all stands. It is not excluded that on more extreme conditions than on this study's six stand types special machines could be profitable. General-purpose machines are useful especially in Finland, where the wood lots are small and processing takes place on a relatively small scale.

According to the calculations based on the silvicultural minimum scenario, the work hours of harvesters need to be doubled till 2010, while the level of procurement increases 20 %. The increase of work is possible to handle by increasing the number of harvesters only by 40 %. The need for drivers in the high season is double the number of harvesters. In 1990 the number of drivers in low season is the same as number of harvesters, but in 2010 all harvesters should have two drivers even in the low season. One doubt is that, if summer time harvesting is greatly increased, it may on sensitive soils cause severe injuries to the stand.

The demand for labour will decrease for most types of work, except for mechanized harvesting and haulage by truck, where there will be a slight increase. According to a study on the general interest in the field, enough labour is seeking work in this sector (Elovirta 1993). Forest workers who are currently working or in training are interested in further education and job diversification. Two-thirds of the trainees are interested in mechanized work, the percentage of which will increase in the future (Onttinen & Vanhanen 1992). Problems in terms of the availability of labour may be encountered in silvicultural work for which enough labour will not be found in the future, at least not from among those involved in cutting operations.

The unit cost of wood procurement will double till 2010. The yearly increment varies 2.5 ... 3.8 %/a depending on the scenario. The total wood procurement cost per year will also double till 2010. The increment is 2.5 ... 4.3 %/a. The increment or decrease of procurement level by 15 % has about the same cost effect than increment of harvesting cost that is 20 % faster or slower than the materialized increment of ten last years. Taking the silvicultural measures in account compared to the pure harvesting optimum does not effect on total procurement cost. Increased mechanization will give added flexibility to handle larger procurement volumes.

However, there is no reason to look back: the organizations, employees and machines will have to respond to ever increasing demands concerning the landscape and the quality of supplied timber. To ensure an adequate supply of labour, the duties related to procurement must be responsible, versatile and productive. The main pressures for changes in this field of activity come from outside the industry. Unfortunately, the powers of prediction of the industry with regard to such pressures has been lamentably poor.

7.3 Comparison with Other Forecasts

At the beginning of the research project, Vantaala (1990) mailed an inquiry to those responsible for timber procurement in the procurement areas of Finnish Forest Industry Association's Research Organization – Metsäteho's member companies and the Finnish Forest and Park Service. The respondents were asked to answer questions concerning anticipated changes in procurement volumes, demand for labour as well as harvesting and scaling methods during the period from 1989 to 1995. According to the replies, the procurement volume was expected to increase from 47 million m^3 in 1989 to 56 million m^3 in 1995. Over the same period, the volumes felled as part of thinnings and natural regeneration was expected to increase. Clear-cutting volumes were estimated to decline by a fifth.

The results obtained by Vantaala (1990) showed that the timber assortment method will retain its position as the principal harvesting system. Of the total volume, the part-tree method was expected to account for 3.1 % and chipwood for 0.1 %. The degree of mechanization in the harvesting of standing trees was assumed to rise from 41 % in 1989 to 65 % in 1995. If so, a total of 80 % of regeneration cuttings and 47 % of thinnings would be carried out mechanically. According to the survey, the one-grip harvester will be the most common machine in cutting and a medium-sized forwarder in haulage. The use of scaling at the road-side and scaling of standing trees was expected to decline, whereas automatic scaling by logging machines, scaling by loggers and mill scaling was assumed to increase. However, only 28 % of the total volume of stumpage sales was expected to be scaled by logging machines.

The survey by Vantaala (1990) was conducted in 1989 when there was a shortage of labour, the price of timber was high and the economy was booming. As far as the surveys and its predictions that failed to materialize in mid-term is concerned, it could be said that man always expects minor changes and is deeply influenced by the notions

prevailing at any given time.

This study predicts that mechanization will be far more rapid that assumed in Vantaala's survey. Actual development since the completion of the survey and reference year in the model, including the downswing in economy, shows that economic considerations and other factors external to the forest industry have a deep impact on timber procurement. Since 1990, the cost of timber procurement has decline by approx. 20 % in terms of nominal prices. The cost of machine work has decreased faster than that of human labour. As revenues have declined, a number of non-viable contractors have gone bankrupt. These events affect the forecasts by lowering cost level curves, at least in the short term. The competitiveness of labour-intensive cutting will decline more rapidly than predicted. However, the forecasts for the number of operators are not much affected by these changes in costs, considering the changes in felled volumes.

Man's belief in only marginal changes and his tendency, and that of the nature, to undergo major ones are contradictory elements whose interplay will finally determine the validity of these forecasts over the next 10 years.

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Total of 114 references

Appendix 1(1)

Variables, objective function and equations of wood procurement model.

WOOD PROCUREMENT MODEL

VARIABLES

Harvesting quantity variables (m^3) 1 - 7

KOKOPUU	Total harvest quantity
EHKOK	First thinnings
MHKOK	Other thinnings
KAKOK	Clearcuts, medium trees
TAKOK	Clearcuts, large trees
SPKOK	Cutting for seed and shelter tree position
YPKOK	Seed and shelter tree removals

Import of timber assortments from outside of the procurement area (m^3) 8 - 14

ALIJ_MÄT	Import pine sawlogs
ALIJ_KUT	Import spruce sawlogs
ALIJ_KOT	Import birch sawlogs
ALIJ_MÄK	Import pine pulpwood
ALIJ_KUK	Import spruce pulpwood
ALIJ_KOK	Import birch pulpwood
ALIJ_SUM	Import altogether

Export of timber assortments to outside of the procurement area (m^3) 15 -21

YLIJ_MÄT	Export pine sawlogs
YLIJ_KUT	Export spruce sawlogs
YLIJ_KOT	Export birch sawlogs
YLIJ_MÄK	Export pine pulpwood
YLIJ_KUK	Export spruce pulpwood
YLIJ_KOK	Export birch pulpwood
YLIJ_SUM	Export altogether

Total amounts by timber assortment (m^3) 22 - 27

M3_S_MÄT	Pine sawlogs, altogether
M3_S_KUT	Spruce sawlogs, altogether
M3_S_KOK	Birch sawlogs, altogether
M3_S_MÄK	Pine pulpwood, altogether
M3_S_KUK	Spruce pulpwood, altogether
M3_S_KOK	Birch pulpwood, altogether

Cuttings altogether 28- 29

YHTIÖH	Cuttings from stumpage sales
OMAH	Cuttings from delivery sales

Appendix 1(2)

Cuttings by stand type

$_s$_YHTIÖ	First thinnings, stumpage sale
$_s$_OMA	First thinnings, delivery sale
$_s$_H_Y_K$_k$	First thinnings, stumpage sale at season k, seasons 1..4
$_s$_H_0_K$_k$	First thinnings, delivery sale at season k, seasons 1..4

k = season, k = 1..4
s = stand type, s = EH, MH, KA, TA, SP, YP

EH =	First thinnings	30 - 39
MH =	Other thinnings	40 - 49
KA =	Clearcuts, mediumwood	50 - 59
TA =	Clearcuts, bigwood	60 - 69
SP =	Cutting for seed and shelter tree position	70 - 79
YP =	Seed and shelter tree removals	80 - 89

Timber quantities according to sale type and harvesting method (m^3) 90 - 94

OSTO_Y	Purchace of timber, stumpage sale
OSTO_O	Purchace of timber, delivery sale
H_Y_MOTO	Stumpage sales harvested mechanically
H_Y_MANU	Stumpage sales harvested manually
H_OMAT	Delivery sales

Man- and machine work-hour variables (h)

SMITJ$_k$	Scaling- and work supervision	95 - 98
SMANU$_k$	Manual cutting, stumpage sale	99 -102
SOTMA$_k$	Manual cutting, delivery sale	103 - 106
SOTSP$_k$	Manual cutting, delivery sale	107 - 110
SPHAR$_k$	Small-sized harvester	111 - 114
SKHAR$_k$	One-grip harvester	115 - 118
S2OTE$_k$	Two-grip harvester	119 - 122
SKOHA$_k$	One-grip harvester in all-round contracting	123 - 126
STELA$_k$	Track-mounted 4 ton forwarder	127 - 130
S08KT$_k$	Forwarder, 8 ton	131 - 134
S10KT$_k$	Forwarder, 10 ton	135 - 138
SMTJK$_k$	Farm tractor with skidding grapple	139 - 142
SMTHY$_k$	Farm tractor with hydraulic loader and trailer	143 - 146
SKOAJ$_k$	Forwarder, 10 ton in all-round contracting	147 - 150

k = season, k = 1..4

Harvesting method variables (m^3)

${}_sM_mK_k$

m = harvesting method, m = 1..25, depending on stand type 12 - 19
k = season, k = 1..4
s = stand type, s = EH, MH, KA, TA, SP, YP

First thinnings	151 - 222
Other thinnings	223 - 298
Clearcuts, medium trees	299 - 354
Clearcuts, large trees	355 - 406
Cutting for seed and shelter tree position	407 - 458
Seed and shelter tree removals	459 - 506

Timber consumption by processing points (m^3)

KP_nKS	Total consumption per processing point	507 - 526
KP_n_O	Procurement area	527 - 546
KP_n_A	Import	547- 566

n = processing point, n = 1 - 20

Truck transport hours

AUTOTUNT	Truck transport hours altogether	567
$AUTOK_k$	Truck hours in season k	568 - 571
$AUTOK_k$T	Truck hours in season k in transport to mill	572 -575
$AUTOK_k$U	Truck hours in season k in transport to floating	576 - 579
$AUTOK_k$J	Truck hours in season k in transport to rail	580 - 583

k = season , k = 1..4

Transport method variables (m^3)

$KP_nA_aK_k$ 584 - 823

n = processing point, n = 1 - 20
a = transport method, a = T, U, J
T = truck transport to mill
U = truck transport to floating
J = truck transport to rail
k = season , k = 1 - 4

Transport of exported timber 824 - 835

$VA\_A_aK_k$

a = transport method, a = T, U, J
T = truck transport to mill
U = truck transport to floating
J = truck transport to rail
k = season , k = 1 - 4

Total transport quantities of timber arriving in mill (m^3)

AUTOLLA	Total quantity arriving by truck	836
UITTAEN	Total quantity arriving by floating	837
JUNALLA	Total quantity arriving by rail	838

Areas of renewal cuttings (ha)

KA_AVO	Clearcuts, medium trees	839
TA_AVO	Clearcuts, large trees	840
AVO_PA	Clearcuts altogether	841
SP_PA	Cutting for seed and shelter tree position	842

Silvicultural work areas (ha)

A_UUD_PA	Clearing of regeration areas in clearcut stands	843
A_ÄES_PA	Harrowing in clearcut stands	844
A_MÄT_PA	Mounding in clearcut stands	845
A_AUR_PA	Ploughing in clearcut stands	846
A_IST_PA	Planting in clearcut stands	847
A_KYL_PA	Sowing in clearcut stands	848
A_TA1_PA	Sapling stand cleaning (2 times) in clearcut stands	849
A_TA2_PA	Sapling stand cleaning (1 time) in clearcut stands	850
SPÄES_PA	Harrowing in cuttings for seed and shelter tree position	851
SPTA1_PA	Sapling stand cleaning in cuttings for seed and shelter tree position	852

Silvicultural worktime variables (h)

A_UUD_H	Clearing of regeration areas in clearcut stands	853
A_ÄES_H	Harrowing in clearcut stands	854
A_MÄT_H	Mounding in clearcut stands	855
A_AUR_H	Ploughing in clearcut stands	856
A_IST_H	Planting in clearcut stands	857
A_KYL_H	Sowing in clearcut stands	858
A_TA1_H	Sapling stand cleaning (2 times) in clearcut stands	859
A_TA2_H	Sapling stand cleaning (1 time) in clearcut stands	860
SPÄES_H	Harrowing in cuttings for seed and shelter tree position	861
SPTA1_H	Sapling stand cleaning in cuttings for seed and shelter tree position	862

SYMBOLS

- C = objective function coefficients, C = 1..22
- d = silvicultural work, d = UUD, ÄES, MÄT, AUR, IST, KYL, TA1, TA2
- d_t = productivity of silvicultural work, ha/h
- d_o = share of certain silvicultural work, % whole area / 100
- e_a = lowest allowable level of delivery cuttings, % stand type cutting volume / 100
- e_y = highest allowable lovel of delivery cuttings, % stand type cutting volume / 100
- f_a = lowest allowable level of stumpage cuttings at season k, % stand type cutting volume / 100
- f_y = highest allowable level of stumpage cuttings at season k, % stand type cutting volume / 100
- g_a = lowest allowable level of delivery cuttings at season k, % stand type cutting volume / 100
- g_y = highest allowable level of delivery cuttings at season k, % stand type cutting volume / 100
- h_a = lowest allowable level of delivery cuttings, % total cutting volume / 100
- h_y = highest allowable level of delivery cuttings, % total cutting volume / 100
- k = season , k = 1..4
- l = lower limit off-road transport done by forest owners, % total cutting volume
- m = harvesting method, m = 1..25
- n = processing point, n = 1..20
- o_a = stand type's lower limit's share, % total cutting volume / 100
- o_y = stand type's upper limit's share, % total cutting volume / 100
- p_s = timber assortment's share, % total stand volume , according to stand type
- r = resource, r = MANU, OTMA, OTSP, PHAR, KHAR, 2OTE, KOHA, TELA, 08KT, 10KT, MTJK, MTHY, KOAJ
- r_a = lower limit in resource use compared to season k-1
- r_y = upper limit in resource use compared to season k-1
- s = stand type, l = EH, MH, KA, TA, SP, YP
- t = productivity (m^3/h)
- u_l = timber volume at stand, m^3/ha
- v_k = share of season k, % total timber use of processing point n / 100
- w_k = share of season k, % total export / 100

OBJECTIVE FUNCTION

$$\text{Min } Z = \sum_{k=1}^{4}\sum_{n=1}^{20} SMITJ_k\, C1_k + SMANU_k\, C2_k + SOTMA_k\, C3_k + SOTSP_k\, C4_k + SPHAR_k\, C5_k + SKHA_k\, C6_k +$$
$$S2OTE_k\, C7_k + SKOHA_k\, C8_k + STELA_k\, C9_k + S08KT_k\, C10_k + S10KT_k\, C11_k + SMTJK_k\, C12_k + SMTHY_k\, C13_k +$$
$$SKOAJ_k\, C14_k + AUTOTUNT_k\, C15_k + KP_nAUK_k\, C16_{k,n} + KP_nAJK_k\, C17_{k,n} + OSTO\_Y\, C18 + OSTO\_O\, C19 +$$
$$H\_Y\_MOTO\, C20 + H\_Y\_MANU\, C21 + H\_OMAT\, C22$$

Variables

$SMITJ_k$	=	work supervision hours, h/season
$SMANU_k$	=	working hours of logger, h/season
$SOTMA_k$	=	working hours in delivery cuttings, h/season
$SOTSP_k$	=	working hours in delivery cuttings, active farmer, h/season
$SPHAR_k$	=	working hours of small-sized harvester, h/season
$SKHAR_k$	=	working hours of one-grip harvester, h/season
$S2OTE_k$	=	working hours of two-grip harvester, h/season
$SKOHA_k$	=	working hours of one-grip harvester in all-round contracting, h/season
$STELA_k$	=	working hours of 4 ton tracked forwarder, h/season
$S08KT_k$	=	working hours of 8 ton forwarder, h/season
$S10KT_k$	=	working hours of 10 ton forwarder, h/season
$SMTJK_k$	=	working hours of farm tractor with skiddding grapple, h/season
$SMTHY_k$	=	working hours of farm tractor with hydraulic loader and trailer, h/season
$SKOAJ_k$	=	working hours of 10 ton forwarder in all-round contracting, h/season
$AUTOTUNT_k$	=	working hours of articulated truck, h/season
KP_nAUK_k	=	timber floated, m^3/processing point/season
KP_nAJK_k	=	timber transported by rail, m^3/processing point/season
OSTO_Y	=	purchace of timber, stumpage sale, m^3
OSTO_O	=	purchace of timber, delivery sale, m^3
H_Y_MOTO	=	stumpage sales harvested mechanically, m^3
H_Y_MANU	=	stumpage sales harvested manually, m^3
H_OMAT	=	delivery sales, m^3

Where k = season, k = 1..4
n = processing point, n = 1..20

Appendix 1 (7)

Coefficients

$C1_k$	=	wage cost of foremen, FIM/h
$C2_k$	=	wage cost of loggers, FIM/h
$C3_k$	=	wage cost of logger in delivery cuttings, FIM/h
$C4_k$	=	wage cost of logger in delivery cuttings, active farmer, FIM/h
$C5_k$	=	hour cost of small-sized harvester, FIM/h
$C6_k$	=	hour cost of one-grip harvester, FIM/h
$C7_k$	=	hour cost of two-grip harvester, FIM/h
$C8_k$	=	hour cost of one-grip harvester in all-round contracting, FIM/h
$C9_k$	=	hour cost of 4 ton tracked forwarder, FIM/h
$C10_k$	=	hour cost of 8 ton forwarder, FIM/h
$C11_k$	=	hour cost of 10 ton forwarder, FIM/h
$C12_k$	=	hour cost of farm tractor with skiddding grapple, FIM/h
$C13_k$	=	hour cost of farm tractor with hydraulic loader and trailer, FIM/h
$C14_k$	=	hour cost of 10 ton forwarder in all-round contracting, FIM/h
$C15_k$	=	hour cost of articulated truck, FIM/h
$C16_{k,n}$	=	unit cost of floating, FIM/m^3
$C17_{k,n}$	=	unit cost of transport by rail, FIM/m^3
C18	=	general cost of stumpage sale, FIM/m^3
C19	=	general cost of delivery sale, FIM/m^3
C20	=	general cost of mechanized cutting in stumpage sale, FIM/m^3
C21	=	general cost of manual cutting in stumpage sale, FIM/m^3
C22	=	general cost of manual cutting in delivery sale, FIM/m^3

Where k = season, k = 1..4
n = processing point, n = 1..20

Appendix 1 (8)

EQUATIONS

Total timber quantities 1 - 3

KOKOPUU = EHKOK + MHKOK + KAKOK + TAKOK + SPKOK + YPKOK

ALIJ_SUM = ALIJ_MÄT + ALIJ_KUT + ALIJ_KOT + ALIJ_MÄK + ALIJ_KUK + ALIJ_KOK

YLIJ_SUM = YLIJ_MÄT + YLIJ_KUT + YLIJ_KOT + YLIJ_MÄK + YLIJ_KUK + YLIJ_KOK

Timber assortment balance 4 - 9

Timber quantities consumed and export equals quantities cut and import. Example equation for pine sawlogs, corresponding equations for other timber assortments.

$$M3\_S\_MÄT + YLIJ\_MÄT = \sum_{s=1}^{6} {}_sKOK * p_s + ALIJ\_MÄT$$

Where p_s = timber assortment's share, % total stand volume, according to stand type
s = stand type, s = EH, MH, KA, TA, SP, YP

Total cutting volume 10

total cutting volume = cuttings from stumpage sales + cuttings from delivery sales

KOKOPUU = YHTIÖH + OMAH

Lower and upper limits of delivery sales 11 - 12

$KOKOPUU * h_a + OMAH > 0$
$KOKOPUU * -h_y + OMAH < 0$

Where h_a = lower limit of delivery sales, % total cutting volume/100
h_y = upper limit of delivery sales, % total cutting volume/100

Appendix 1 (9)

Cuttings by stand type

$${}_sKOK = {}_{s-}YHTIÖ + {}_{s-}OMA$$

$${}_{s-}YHTIÖ = \sum_{k=1}^{4} {}_{s-}Y\_K_k$$

$${}_{s-}OMA = \sum_{k=1}^{4} {}_{s-}O\_K_k$$

Where k = season, k = 1..4
s = stand type, s = EH, MH, KA, TA, SP, YP

EH	First thinnings	13 - 15
MH	Other thinnings	16 - 18
KA	Clearcuts, medium trees	19 - 21
TA	Clearcuts, large trees	22 - 24
SP	Cutting for seed and shelter tree position	25 - 27
YP	Seed and shelter tree removals	28 - 30

Equations for stumpage sales 31 - 54

$${}_{s-}Y\_K_k = \sum_{m=1}^{25} {}_sM_mK_k \quad ;\text{for all k, s}$$

Where k = season, k = 1..4
s = stand type, s = EH, MH, KA, TA, SP, YP
m = harvesting method, m = 1..25

Equations for delivery sales 55 - 78

$${}_{s-}O\_K_k = \sum_{m=1}^{25} {}_sM_mK_k \quad ;\text{for all k, s}$$

Where k = season, k = 1..4
s = stand type, s = EH, MH, KA, TA, SP, YP
m = harvesting method, m = 1..25

Appendix 1 (10)

Man- and machine work-hour equations 79 - 130

$$S_rK_k = \sum_{m=1}^{25}\sum_{s=1}^{6} {}_sM_mK_k * 1/t_{smk} \quad ;\text{for all k, r}$$

Where m = harvesting method, m = 1..25, depending on stand type 12 - 19
s = stand type, s = EH, MH, KA, TA, SP, YP
t = productivity (m^3/h)
k = season, k = 1..4
r = resource, r = MANU, OTMA, OTSP, PHAR, KHAR, 2OTE, KOHA, TELA, 08KT, 10KT, MTJK, MTHY, KOAJ

MANU	Manual cutting, stumpage sale
OTMA	Manual cutting, delivery sale
OTSP	Manual cutting, delivery sale
PHAR	Small-sized harvester
KHAR	One-grip harvester
2OTE	Two-grip harvester
KOHA	One-grip harvester in all-round contracting
TELA	Track-mounted 4 ton forwarder
08KT	Forwarder, 8 ton
10KT	Forwarder, 10 ton
MTJK	Farm tractor with skidding grapple
MTHY	Farm tractor with hydraulic loader and trailer
KOAJ	Forwarder, 10 ton in all-round contracting

Scaling- and work supervision work-hour equations 131 - 134

$$SMITJK_k = \sum_{m=1}^{25}\sum_{s=1}^{6} {}_sM_mK_k * 1/t_{smk} \quad ;\text{for all k}$$

Where m = harvesting method, m = 1..25,
s = stand type, s = EH, MH, KA, TA, SP, YP
t = productivity (m^3/h)
k = season, k = 1..4

Purchase from stumpage sales 135

$$OSTO\_Y = \sum_{m=1}^{25}\sum_{s=1}^{6}\sum_{k=1}^{4} {}_sM_mK_k$$

Where m = harvesting method, m = 1..25,
s = stand type, s = EH, MH, KA, TA, SP, YP
k = season, k = 1..4

Appendix 1(11)

Purchase from delivery sales

$$OSTO\_O = \sum_{m=1}^{25}\sum_{s=1}^{6}\sum_{k=1}^{4} {}_sM_mK_k$$

Where m = harvesting method, m = 1..25,
s = stand type, s = EH, MH, KA, TA, SP, YP
k = season, k = 1..4

Mechanized cutting from stumpage sales 137

$$H\_Y\_MOTO = \sum_{m=1}^{25}\sum_{s=1}^{6}\sum_{k=1}^{4} {}_sM_mK_k$$

Where m = harvesting method, m = 1..25,
s = stand type, s = EH, MH, KA, TA, SP, YP
k = season, k = 1..4

Manual cutting from stumpage sales 138

$$H\_Y\_MANU = \sum_{m=1}^{25}\sum_{s=1}^{6}\sum_{k=1}^{4} {}_sM_mK_k$$

Where m = harvesting method, m = 1..25,
s = stand type, s = EH, MH, KA, TA, SP, YP
k = season, k = 1..4

Cutting from stumpage sales 139

$$H\_OMAT = \sum_{m=1}^{25}\sum_{s=1}^{6}\sum_{k=1}^{4} {}_sM_mK_k$$

Where m = harvesting method, m = 1..25,
s = stand type, s = EH, MH, KA, TA, SP, YP
k = season, k = 1..4

Lower limit for forest owners own off-road transport 140

$$OMAH * \cdot l + \sum_{m=1}^{25}\sum_{s=1}^{6}\sum_{k=1}^{4} {}_sM_mK_k > 0$$

Where m = harvesting method, m = 1..25,
s = stand type, s = EH, MH, KA, TA, SP, YP
k = season, k = 1..4
l = lower limit for forest owners own off-road transport, % total cutting volume / 100

Appendix 1(12)

Equations for truck transport

Truck transport work-hours altogether 141

$$AUTOTUNT = \sum_{k=1}^{4} AUTOK_k$$

Where k = season, k = 1..4

Truck transport work-hours by season 142 - 145

$$AUTOK_k = \sum_{k=1}^{4} AUTOK_kT + AUTOK_kU + AUTOK_kJ$$

Where k = season, k = 1..4

Truck transport work-hours to processing points by season 146 - 149

$$AUTOK_kT = \sum_{n=1}^{20} KP_nATK_k \qquad ;\text{for all } k$$

Where n = processing point, n = 1..20
k = season, k = 1..4

Truck transport work-hours to floating by season 150 - 153

$$AUTOK_kU = \sum_{n=1}^{20} KP_nAUK_k \qquad ;\text{for all } k$$

Where n = processing point, n = 1..20
k = season, k = 1..4

Truck transport work-hours to rail by season 154 - 157

$$AUTOK_kJ = \sum_{n=1}^{20} KP_nAJK_k \qquad ;\text{for all } k$$

Where n = processing point, n = 1..20
k = season, k = 1..4

Equations for total wood consumption by processing point 158 - 177

$$KP_nKS = KP_n\_O + KP_n\_A \qquad ;\text{for all } n$$

Where n = processing point, n = 1..20

Appendix 1(13)

Equations for import to processing point from outside of the procurement area 178 - 197

$$KP_nA = ALIJ\_SUM * KP_nKS / \cdot \sum_{n=1}^{20} KP_nKS \qquad ;\text{for all } n$$

Where n = processing point, n = 1..20

Equations for wood consumption by processing point and season 198 - 277

$$KP_n\_O * \cdot v_k = KP_nATK_k + KP_nAUK_k + KP_nAJK_k \quad ;\text{for all } n, k$$

Where n = processing point, n = 1..20
k = season, k = 1..4
v_k = season's k share % total use by processing point n / 100

Equations for export to outside of the procurement area 278 - 281

$$YLIJ\_SUM * \cdot w_k = VA\_ATK_k + VA\_AUK_k + VA\_AJK_k \qquad ;\text{for all } k$$

Where k = season, k = 1..4
w_k = season's k share % total export / 100

Equations for lower limit of cutting from delivery sales 282 - 287

$${}_{s}\_OMA + {}_sKOK * e_a > 0 \qquad ;\text{for all } s$$

Where s = stand type, s = EH, MH, KA, TA, SP, YP
e_a = lower limit of cutting from delivery sales, % cutting of stand type/ 100

Equations for upper limit of cutting from delivery sales 288 - 293

$${}_{s}\_OMA + {}_sKOK * e_y < 0 \qquad ;\text{for all } s$$

Where s = stand type, l = EH, MH, KA, TA, SP, YP
e_y = upper limit of cutting from delivery sales, % cutting of stand type/ 100

Equations for lower limit of cutting from stumpage sales by season 294 - 317

$${}_{s}\_Y\_K_k + {}_{s}\_YHTIÖ * f_a > 0 \qquad ;\text{for all } s, f_a, k$$

Where s = stand type, s = EH, MH, KA, TA, SP, YP
f_a = lower limit of cutting from stumpage sales at season k, % stand type volume/ 100
k = season, k = 1..4

Appendix 1(14)

Equations for upper limit of cutting from stumpage sales by season 318 - 341

$${}_{s}\_Y\_K_k + {}_{s}\_YHTIÖ * f_y < 0 \qquad ;\text{for all } s, f_y, k$$

Where s = stand type, s = EH, MH, KA, TA, SP, YP
f_y = upper limit of cutting from stumpage sales at season k, % stand type volume/ 100
k = season, k = 1..4

Equations for lower limit of cutting from delivery sales by season 342 - 365

$${}_{s}\_O\_K_k + {}_{s}\_OMA * g_a > 0 \qquad ;\text{for all } s, g_a, k$$

Where s = stand type, s = EH, MH, KA, TA, SP, YP
g_a = lower limit of cutting from delivery sales at season k, % stand type volume/ 100
k = season, k = 1..4

Equations for upper limit of cutting from delivery sales by season 366 - 389

$${}_{s}\_O\_K_k + {}_{s}\_OMA * gy < 0 \qquad ;\text{for all } s, g_y, k$$

Where s = stand type, s = EH, MH, KA, TA, SP, YP
g_y = upper limit of cutting from delivery sales at season k, % stand type volume/ 100
k = season, k = 1..4

Equation for total cutting from stumpage sales 390

$$YHTIÖH = \sum_{s=1}^{6}\sum_{k=1}^{4} {}_{s}\_Y\_K_k$$

Where s = stand type, s = EH, MH, KA, TA, SP, YP
k = season, k = 1..4

Equation for total cutting from delivery sales 391

$$OMAH = \sum_{s=1}^{6}\sum_{k=1}^{4} {}_{s}\_O\_K_k$$

Where s = stand type, s = EH, MH, KA, TA, SP, YP
k = season, k = 1..4

Appendix 1(15)

Lower limits for resource use variation by season 392 - 443

$$S_rK_k - r_a * S_rK_{k+1} > 0$$

Where r_a = lower limit for resource employment compared to season k-1
k = season, k = 1..4
r = resource, r = MANU, OTMA, OTSP, PHAR, KHAR, 2OTE, KOHA, TELA, 08KT, 10KT, MTJK, MTHY, KOAJ

Upper limits for resource use variation by season 444 - 495

$$S_rK_k - r_y * S_rK_{k+1} < 0$$

Where r_y = upper limit for resource employment compared to season k-1
k = season, k = 1..4
r = resource, r = MANU, OTMA, OTSP, PHAR, KHAR, 2OTE, KOHA, TELA, 08KT, 10KT, MTJK, MTHY, KOAJ

Equations for stand type's lower limits of total cutting volume 496 -501

$$KOKOPUU * o_a - {}_sKOK < 0$$

Where s = stand type, s = EH, MH, KA, TA, SP, YP
o_a = stand type's lower limit % total cutting volume/ 100

Equations for stand type's upper limits of total cutting volume 502 -507

$$KOKOPUU * o_y - {}_sKOK > 0$$

Where s = stand type, s = EH, MH, KA, TA, SP, YP
o_y = stand type's upper limit % total cutting volume/ 100

Long-distance transport equations 508 - 510

$$AUTOLLA = \sum_{n=1}^{20} \sum_{k=1}^{4} KP_nATK_k$$

$$UITTAEN = \sum_{n=1}^{20} \sum_{k=1}^{4} KP_nAUK_k$$

$$JUNALLA = \sum_{n=1}^{20} \sum_{k=1}^{4} KP_nAJK_k$$

Where n = processing point, n = 1..20
k = season, k = 1..4

Appendix 1(16)

Equations for regeneration areas 511 - 513

$${}_{s\_}AVOPA * u_s = {}_{s\_}AVO$$

Where s = stand type, s = KA, TA, SP
u_s = timber volume at stand type m^3/ha

Equation for total clear-cut area 514

AVO_PA = KA_AVO + TA_AVO

Silvicultural treatment areas following clear-cut stands 515 - 522

$$A_{\_d\_}PA = AVO\_PA * d_o$$

Where d = silvicultural treatment, d = UUD, ÄES, MÄT, AUR, IST, KYL, TA1, TA2
d_o = silvicultural treatment % total area / 100

Silvicultural treatment areas following stands cut for seed and shelter tree position 523 - 524

$$SP_{d\_}PA = AVO\_PA * d_o$$

Where d = silvicultural treatment, d = ÄES, TA1
d_o = silvicultural treatment % total area / 100

Work-hours of silvicultural work following clear-cut stands 525 - 532

$$A_{\_d\_}H * d_t = A_{\_d\_}PA$$

Where d = silvicultural treatment, d = UUD, ÄES, MÄT, AUR, IST, KYL, TA1, TA2
d_t = productivity of silvicultural work ha/h

Work-hours of silvicultural work following stands cut for seed and shelter tree position 533 - 534

$$SP_{d\_}H * d_t = SP_{d\_}PA$$

Where d = silvicultural treatment, d = ÄES, TA1
d_t = productivity of silvicultural work ha/h

Appendix 1(17)

RHS of following equations is fixed, it's taken from wood calculation procedure by processing point

Total consumption of pine sawlogs 535

$$M3\_S\_MÄT = \sum_{n=1}^{20} MÄT_n$$

Total consumption of spruce sawlogs 536

$$M3\_S\_KUT = \sum_{n=1}^{20} KUT_n$$

Total consumption of birch sawlogs 537

$$M3\_S\_KOT = \sum_{n=1}^{20} KOT_n$$

Total consumption of pine pulpwood 538

$$M3\_S\_MÄK = \sum_{n=1}^{20} MÄK_n$$

Total consumption of spruce pulpwood 539

$$M3\_S\_KUK = \sum_{n=1}^{20} KUK_n$$

Total consumption of birch pulpwood 540

$$M3\_S\_KOK = \sum_{n=1}^{20} KOK_n$$

Where n = processing point, n = 1..20

Total wood consumption by processing point

$$KP_nKS = KP_nMÄT + KP_nKUT + KP_nKOT + KP_nMÄK + KP_nKUK + KP_nKOK;$$ for all n 541 - 560

Where n = processing point, n = 1..20

Appendix 2(1)

An example of the description of processing points with their wood consumption figures and properties of procurement areas.
East-Finland. Total wood procurement 50 Mm³ in 1990 and 59 Mm³ in 2010. For more accurate explanation see chapters 3.1 and 4.2.1.

East-Finland 1990 / 50 Mm³

No.	Type of processing point	Capacity, 1 000 m³ or tn	No. of mills, pcs	Co.'s share of total proc., %	Sector of operation, °	Bending coefficient (m), transport distance by truck (a) and by train or watertransport (j)	Truck	Train	Water	Volume of the consumption of wood assortment (k), size of the wood procurement area (h) and the average transport distance (e). Pi = Pine, Sp = Spruce, Bl = Broadleaved; lo = logs, pu = pulpwood	Pi-lo	Sp-lo	Bl-lo	Pi-pu	Sp-pu	Bl-pu	Total
6	Saw mill	50-90	5	30	360	m	1.33	1.51	1.76	k, 1 000 m³	0	629	20	0	30	3	682
						a, km	41	0	0	h, 1 000 ha	0	602	71	0	32	5	
						j, km	-	0	0	e, km	0	41	15	0	11	6	
7	Saw mill	10-49	11	10	360	m	1.33	1.51	1.76	k, 1 000 m³	214	169	14	7	8	2	413
						a, km	31	0	0	h, 1 000 ha	334	220	65	14	12	5	
						j, km	-	0	0	e, km	31	25	14	8	7	6	
8	Saw mill	1-9	6	7	360	m	1.33	1.51	1.76	k, 1 000 m³	30	24	0	1	1	0	56
						a, km	19	0	0	h, 1 000 ha	123	81	0	5	4	0	
						j, km	-	0	0	e, km	19	16	0	6	6	0	
9	Saw mill	<1	6	2	360	m	1.33	1.51	1.76	k, 1 000 m³	2	2	0	0	0	0	4
						a, km	10	0	0	h, 1 000 ha	30	20	0	1	1	0	
						j, km	-	0	0	e, km	10	9	0	5	5	0	
10	Veneer mill	35-70	5	35	280	m	1.33	1.51	1.76	k, 1 000 m³	0	287	475	37	37	89	887
						a, km	72	20	0	h, 1 000 ha	0	236	1428	0	33	154	
						j, km	-	62	0	e, km	0	30	72	0	12	24	
11	Veneer mill	<35	2	35	280	m	1.33	1.51	1.76	k, 1 000 m³	9	39	65	0	5	12	130
						a, km	42	20	0	h, 1 000 ha	21	80	487	0	11	53	
						j, km	-	28	0	e, km	10	18	42	0	8	15	
12	Mech. pulp mill	400-600	1	30	90	m	1.33	1.51	1.76	k, 1 000 m³	0	66	0	0	565	1	631
						a, km	184	20	38	h, 1 000 ha	0	314	0	0	3010	6	
						j, km	-	189	206	e, km	0	60	0	0	184	10	
13	Mech. pulp mill	300-390	1	30	100	m	1.33	1.51	1.76	k, 1 000 m³	0	52	0	0	449	1	502
						a, km	156	20	38	h, 1 000 ha	0	250	0	0	2394	5	
						j, km	-	157	168	e, km	0	51	0	0	156	9	
16	Sulphate pulp mill	400-550	2	35	90	m	1.33	1.51	1.76	k, 1 000 m³	0	0	0	1651	294	1058	3003
						a, km	245	20	38	h, 1 000 ha	0	0	0	5317	671	4609	
						j, km	-	258	286	e, km	0	0	0	245	87	228	
17	Sulphate pulp mill	200-390	4	35	90	m	1.33	1.51	1.76	k, 1 000 m³	35	21	12	1728	308	1107	3211
						a, km	177	20	38	h, 1 000 ha	43	22	46	2782	351	2412	
						j, km	-	181	196	e, km	22	16	23	177	63	165	

Appendix 2(2)

East-Finland 2010 / 59 Mm³

No.	Type of processing point	Capacity, 1 000 m³ or tn	No. of mills, pcs	Co.'s share of total proc., %	Sector of operation, °	Bending coefficient (m), transport distance by truck (a) and by train or watertransport (j)	Truck	Train	Water	Volume of the consumption of wood assortment (k), size of the wood procurement area (h) and the average transport distance (e). Pi = Pine, Sp = Spruce, Bl = Broadleaved; lo = logs, pu = pulpwood	Pi-lo	Sp-lo	Bl-lo	Pi-pu	Sp-pu	Bl-pu	Total
6	Saw mill	50-90	5	30	360	m	1.33	1.51	1.76	k, 1 000 m³	0	562	19	0	14	2	597
						a, km	32	0	0	h, 1 000 ha	0	346	94	0	18	3	
						j, km	-	0	0	e, km	0	32	17	0	9	5	
7	Saw mill	10-49	11	10	360	m	1.33	1.51	1.76	k, 1 000 m³	189	151	12	5	4	1	362
						a, km	28	0	0	h, 1 000 ha	277	126	85	11	7	2	
						j, km	-	0	0	e, km	28	19	16	7	6	5	
8	Saw mill	1-9	6	7	360	m	1.33	1.51	1.76	k, 1 000 m³	27	21	0	1	1	0	49
						a, km	18	0	0	h, 1 000 ha	102	47	0	4	1	0	
						j, km	-	0	0	e, km	18	12	0	6	5	0	
9	Saw mill	<1	6	2	360	m	1.33	1.51	1.76	k, 1 000 m³	2	2	0	0	0	0	3
						a, km	10	0	0	h, 1 000 ha	25	11	0	1	1	0	
						j, km	-	0	0	e, km	10	7	0	5	5	0	
10	Veneer mill	35-70	5	35	280	m	1.33	1.51	1.76	k, 1 000 m³	0	290	450	0	37	84	860
						a, km	84	20	0	h, 1 000 ha	0	153	1944	0	39	113	
						j, km	-	75	0	e, km	0	24	84	0	13	21	
11	Veneer mill	<35	2	35	280	m	1.33	1.51	1.76	k, 1 000 m³	9	40	61	0	5	11	126
						a, km	49	20	0	h, 1 000 ha	20	52	663	0	13	38	
						j, km	-	36	0	e, km	10	15	49	0	8	13	
12	Mech. pulp mill	400-600	1	30	90	m	1.33	1.51	1.76	k, 1 000 m³	0	124	0	0	760	0	884
						a, km	230	20	38	h, 1 000 ha	0	380	0	0	4713	0	
						j, km	-	242	267	e, km	0	66	0	0	230	0	
13	Mech. pulp mill	300-390	1	30	100	m	1.33	1.51	1.76	k, 1 000 m³	0	98	0	0	605	0	703
						a, km	195	20	38	h, 1 000 ha	0	302	0	0	3749	0	
						j, km	-	201	220	e, km	0	56	0	0	195	0	
16	Sulphate pulp mill	400-550	2	35	90	m	1.33	1.51	1.76	k, 1 000 m³	0	0	0	2030	387	1513	3930
						a, km	291	20	38	h, 1 000 ha	0	0	0	7511	1029	5085	
						j, km	-	310	347	e, km	0	0	0	291	108	239	
17	Sulphate pulp mill	200-390	4	35	90	m	1.33	1.51	1.76	k, 1 000 m³	136	34	32	2125	405	1583	4314
						a, km	210	20	38	h, 1 000 ha	156	22	173	3930	538	2661	
						j, km	-	219	240	e, km	42	16	44	210	78	173	

Appendix 3 (1)

Development series of typical stands: outturn, area, density and proportions of tree species. Data is modified mostly on the basis of data from Lassheikki (1989). See also chapters 3.2 and 4.2.2. (* St. & sw. = seed tree and shelter wood.)

West-Finland 1990

Variable	I-thinning	Other thinnings	Clear-cutting, medium trees	Clear-cutting, large trees	*St. & sw. - cuttings	Removals of *st. & sw.
Outturn, m3	170	290	567	936	690	510
Area, ha	4.3	5.2	4	4.1	4.6	6
Density, m3/ha	40	56	142	228	151	85
Pine-%	31.5	33.2	13.4	34.4	34.2	45.4
Spruce-%	41.7	56.6	77.5	55.7	58.8	43.7
Broadl.-%	26.8	10.2	21.7	9.9	1.5	10.9

West-Finland 2000

Variable	I-thinning	Other thinnings	Clear-cutting, medium trees	Clear-cutting, large trees	*St. & sw. - cuttings	Removals of *st. & sw.
Outturn, m3	212	498	563	1117	695	196
Area, ha	4.5	5.3	4.2	4.2	4.6	5.8
Density, m3/ha	47	94	134	266	151	34
Pine-%	23	25	20	39	40	50
Spruce-%	40	45	64	49	56	38
Broadl.-%	37	30	16	12	4	12

West-Finland 2010

Variable	I-thinning	Other thinnings	Clear-cutting, medium trees	Clear-cutting, large trees	*St. & sw. - cuttings	Removals of *st. & sw.
Outturn, m3	226	510	568	1148	700	168
Area, ha	4.7	5.6	4.3	4.4	5	5.6
Density, m3/ha	48	91	132	261	140	30
Pine-%	27	30	22	33	40	89
Spruce-%	35	39	60	53	50	2
Broadl.-%	36	31	18	14	10	9

East-Finland 1990

Variable	I-thinning	Other thinnings	Clear-cutting, medium trees	Clear-cutting, large trees	*St. & sw. - cuttings	Removals of *st. & sw.
Outturn, m3	210	330	800	991	900	750
Area, ha	5	5.5	5.3	4.7	6.1	8.6
Density, m3/ha	42	60	152	213	148	87
Pine-%	42	29	25	35	65	67
Spruce-%	32	46	61	52	26	15
Broadl.-%	26	25	14	13	9	18

East-Finland 2000

Variable	I-thinning	Other thinnings	Clear-cutting, medium trees	Clear-cutting, large trees	*St. & sw. - cuttings	Removals of *st. & sw.
Outturn, m3	250	524	847	1318	912	349
Area, ha	5	5.4	5.1	4.9	6	8
Density, m3/ha	50	97	166	269	152	44
Pine-%	37	27	41	42	55	45
Spruce-%	34	44	42	45	37	44
Broadl.-%	29	29	17	13	8	11

Appendix 3 (2)

East-Finland 2010

Variable	I-thinning	Other thinnings	Clear-cutting, medium trees	Clear-cutting, large trees	*St. & sw. - cuttings	Removals of *st. & sw.
Outturn, m3	250	522	779	1516	940	236
Area, ha	5.2	5.8	4.9	5.3	5.8	7
Density, m3/ha	48	90	159	286	162	34
Pine-%	43	33	29	30	57	33
Spruce-%	25	38	54	56	35	9
Broadl.-%	32	29	17	14	8	58

North-Finland 1990

Variable	I-thinning	Other thinnings	Clear-cutting, medium trees	Clear-cutting, large trees	*St. & sw. - cuttings	Removals of *st. & sw.
Outturn, m3	105	340	315	347	271	205
Area, ha	3.4	6.5	2.6	2.2	2.5	4.1
Density, m3/ha	31	52	119	157	109	50
Pine-%	68	71	40	44	44	75
Spruce-%	17	9	47	46	38	17
Broadl.-%	15	20	13	10	18	8

North-Finland 2000

Variable	I-thinning	Other thinnings	Clear-cutting, medium trees	Clear-cutting, large trees	*St. & sw. - cuttings	Removals of *st. & sw.
Outturn, m3	109	330	374	430	297	59
Area, ha	3.5	6.6	2.9	2.5	2.7	4
Density, m3/ha	31	50	129	172	110	15
Pine-%	27	37	61	62	59	77
Spruce-%	23	20	27	28	24	16
Broadl.-%	50	43	12	10	17	7

North-Finland 2010

Variable	I-thinning	Other thinnings	Clear-cutting, medium trees	Clear-cutting, large trees	*St. & sw. - cuttings	Removals of *st. & sw.
Outturn, m3	126	356	343	331	218	50
Area, ha	3.6	6.6	3.4	2.9	2.2	3.6
Density, m3/ha	35	54	101	114	99	14
Pine-%	30	41	59	63	59	76
Spruce-%	18	12	28	27	23	12
Broadl.-%	52	47	13	10	18	12

Appendix 4 (1)

Yearly numbers of working hours by operation in all cost scenarios.
The abbreviations of cost scenarios are explained in table 3.

Annual number of working hours in technical harvest planning,work supervision and timber scaling, h/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	2131711	1870394	1870394	1870394	1870394	1870394	1870394
2000	837077	793187	765572	716269	765572	711152	858747
2010	661266	476148	633533	443530	633533	364737	519476

Annual number of working hours in manual logging work, h/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	9656088	7408991	7408991	7408991	7408991	7408991	7408991
2000	1186428	314390	371491	0	371491	0	471157
2010	0	0	0	0	0	0	0

Annual number of working hours in logging work of small woodlot owners, h/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	8671586	8852716	8852716	8852716	8852716	8852716	8852716
2000	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0

Annual number of working hours in logging work of active forest farm owners, h/a

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	0	0	0	0	0	0	0
2000	6468685	6722798	6444315	6209861	6444315	6745897	6765556
2010	3554563	1371676	5932884	1065283	5932884	785432	1303435

Total of all forest owners logging work, h/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	8671586	8852716	8852716	8852716	8852716	8852716	8852716
2000	6468685	6722798	6444315	6209861	6444315	6745897	6765556
2010	3554563	1371676	5932884	1065283	5932884	785432	1303435

Appendix 4 (2)

Annual number of working hours in off-road transport work with farm tractor and hydraulic skidding grapple by forest owner, h/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	0	0	0	0	0	0	0
2000	0	0	0	0	0	0	0
2010	0	0	0	0	0	0	0

Annual number of working hours in off-road transport work with farm tractor, trailer and hydraulic loader by forest owner, h/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	226062	938226	938226	938226	938226	938226	938226
2000	257731	306463	257731	257731	257731	257731	257731
2010	257731	257731	606714	257731	606714	257731	257731

Total of all off-road transport work by forest owner, h/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	226062	938226	938226	938226	938226	938226	938226
2000	257731	306463	257731	257731	257731	257731	257731
2010	257731	257731	606714	257731	606714	257731	257731

Annual number of working hours of separate one-grip harvesters, h/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	2091461	2070382	2070382	2070382	2070382	2070382	2070382
2000	0	0	0	0	0	0	0
2010	47794	0	633533	16873	0	0	0

Annual number of working hours of one-grip harvesters in all-round contracting, h/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	0	0	0	0	0	0	0
2000	3127723	3258360	3277027	3432274	3277027	2475478	3783864
2010	4321193	4537076	3582795	4604568	3582795	3596648	5260065

Total of all harvesting work by one-grip harvesters, h/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	2091461	2070382	2070382	2070382	2070382	2070382	2070382
2000	3127723	3258360	3277027	3432274	3277027	2475478	3783864
2010	4368987	4537076	4216328	4621441	3582795	3596648	5260065

Appendix 4 (3)

Annual number of working hours of separate 10-tonne forwarders, h/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	5354998	4979330	4979330	4979330	4979330	4979330	4979330
2000	1372009	1235809	1234810	1119101	1234810	1170277	1313572
2010	796202	335787	898015	229940	898015	186281	307474

Annual number of working hours of 10-tonne frowarders in all-round contracting, h/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	3183292	0	0	0	0	0	0
2000	3183292	3301443	3316182	3406754	3316182	2888285	3716265
2010	3780573	3972132	3335012	4055405	3335012	3335329	4630442

Total of all off-road transport work by 10-tonne forwarders, h/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	8538290	4979330	4979330	4979330	4979330	4979330	4979330
2000	4555301	4537252	4550992	4525855	4550992	4058562	5029837
2010	4576775	4307919	4233027	4285345	4233027	3521610	4937916

Annual number of working hours of trucks, h/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	6893241	6255023	6255023	6255023	6255023	6255023	6255023
2000	1372009	6399093	1448365	6154085	6323684	5699902	6917465
2010	2165433	6612777	6612777	6608159	6608159	5376344	7778346

Appendix 5 (1)

Yearly total- and unit costs of wood procurement in all cost scenarios.
The abbreviations of cost scenarios are explained in table 3.

Total overhead cost (incl. work supervision) of wood procurement, million FIM/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	1020	957	957	957	957	957	957
2000	1193	1184	1112	1252	1176	1088	1297
2010	1738	1705	1522	1921	1761	1443	1945

Total cost of logging, million FIM/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	1777	1630	1630	1630	1630	1630	1630
2000	2063	2049	1927	2188	2247	1644	2320
2010	3067	2926	2532	3257	3362	2286	3360

Total cost of off-road transport, million FIM/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	1760	1651	1651	1651	1651	1651	1651
2000	1709	1716	1626	1782	1927	1528	1887
2010	2197	2068	1962	2268	2672	1691	2371

Total cost of long distance transport, million FIM/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	1622	1503	1503	1503	1503	1503	1503
2000	2541	2730	2590	2818	2801	2409	2979
2010	4797	4422	3921	5018	4840	3511	15982

Total cost of wood procurement, million FIM/a.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	6630	6289	6289	6289	6289	6289	6289
2000	8245	8431	7884	9034	9003	7341	9445
2010	12671	12656	11228	14287	14350	10229	14705

Appendix 5 (2)

Average overhead cost per unit, FIM/m³.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	17,9	17,6	17,6	17,6	17,6	17,6	17,6
2000	21,9	21,7	20,3	22,9	21,5	21,6	21,7
2010	29,3	28,7	25,7	32,4	29,7	28,6	28,7

Average unit cost of logging, FIM/m³.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	31,2	29,9	29,9	29,9	29,9	29,9	29,9
2000	37,8	37,6	35,2	40	41,1	32,6	38,8
2010	51,7	49,3	42,7	54,9	56,7	45,3	49,5

Average unit cost of off-road transport, FIM/m³.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	30,9	30,3	30,3	30,3	30,3	30,3	30,3
2000	31,3	31,5	29,7	32,6	35,2	30,3	31,6
2010	37	34,9	33,1	38,2	45	33,5	34,9

Average unit cost of truck transport, FIM/m³.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	35,1	33,3	33,3	33,3	33,3	33,3	33,3
2000	53,3	52,8	49,2	55,2	54,6	51	52,2
2010	90	78	65,6	92,5	87,5	74,5	80,2

Average unit cost of long distance transport, FIM/m³.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	36,4	37,8	37,8	37,8	37,8	37,8	37,8
2000	60,1	63,7	58,9	69,6	66,7	61,2	66
2010	95,6	100,4	87,8	115,3	110,5	95,3	103,7

Average unit cost of wood procurement (excl. timber price), FIM/m³.

	59MHO	59KO	59-20%	59+20%	59Mixed	50Mm3	68Mm3
1990	116,4	115,6	115,6	115,6	115,6	115,6	115,6
2000	151,1	154,5	144,1	165,1	164,5	145,7	158,1
2010	213,6	213,3	189,3	240,8	241,9	202,7	216,8

Appendix 6(1)

Yearly work hours by area and season in the silvicultural-optimum calculation of timber procurement.

Yearly outturn is 50 Mm^3 in 1990, 54 Mm^3 in 2000 and 59 Mm^3 in 2010.

Annual number of working hours in technical harvest planning, work supervision and timber scaling, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	360779	164823	194358	**719960**
Season 2	264572	104212	124855	**493639**
Season 3	141436	48383	78789	**268608**
Season 4	342891	125423	181190	**649504**
Total	**1109678**	**442841**	**579192**	**2131711**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	100267	57670	96336	**254273**
Season 2	89927	44292	65973	**200192**
Season 3	43763	32601	44309	**120673**
Season 4	100267	57670	104002	**261939**
Total	**334224**	**192233**	**310620**	**837077**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	77617	49766	66110	**193493**
Season 2	69167	44467	60766	**174400**
Season 3	41657	21888	27381	**90926**
Season 4	86572	49766	66110	**202448**
Total	**275013**	**165887**	**220367**	**661267**

Annual number of working hours in manual logging work, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	1927952	292059	1944697	**4164708**
Season 2	385590	58412	388939	**832941**
Season 3	652780	100707	728744	**1482231**
Season 4	1398813	215801	1561593	**3176207**
Total	**4365135**	**666979**	**4623973**	**9656087**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	456319	**456319**
Season 2	0	0	91264	**91264**
Season 3	0	0	182527	**182527**
Season 4	0	0	456319	**456319**
Total	**0**	**0**	**1186429**	**1186429**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	0	0	0	**0**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**0**	**0**	**0**	**0**

Annual number of working hours in logging work of small woodlot owners, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	2346176	1211081	738258	**4295515**
Season 2	1072448	544285	336869	**1953602**
Season 3	257388	130629	80849	**468866**
Season 4	1072448	544285	336869	**1953602**
Total	**4748460**	**2430280**	**1492845**	**8671585**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	0	0	0	**0**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**0**	**0**	**0**	**0**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	0	0	0	**0**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**0**	**0**	**0**	**0**

Annual number of working hours in logging work of active forest farm owners, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	0	0	0	**0**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**0**	**0**	**0**	**0**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	1267002	597470	409176	**2273648**
Season 2	887877	400115	286555	**1574547**
Season 3	440795	240069	141752	**822616**
Season 4	996504	480139	321230	**1797873**
Total	**3592178**	**1717793**	**1158713**	**6468684**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	568946	326386	371080	**1266412**
Season 2	380857	236402	247930	**865189**
Season 3	228514	112807	148758	**490079**
Season 4	457028	178340	297516	**932884**
Total	**1635345**	**853935**	**1065284**	**3554564**

Total of all forest owners logging work, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	2346176	1211081	738258	**4295515**
Season 2	1072448	544285	336869	**1953602**
Season 3	257388	130629	80849	**468866**
Season 4	1072448	544285	336869	**1953602**
Total	**4748460**	**2430280**	**1492845**	**8671585**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	1267002	597470	409176	**2273648**
Season 2	887877	400115	286555	**1574547**
Season 3	440795	240069	141752	**822616**
Season 4	996504	480139	321230	**1797873**
Total	**3592178**	**1717793**	**1158713**	**6468684**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	568946	326386	371080	**1266412**
Season 2	380857	236402	247930	**865189**
Season 3	228514	112807	148758	**490079**
Season 4	457028	178340	297516	**932884**
Total	**1635345**	**853935**	**1065284**	**3554564**

Appendix 6(2)

Annual number of working hours in off-road transport work with farm tractor and hydraulic skidding grapple by forest owner, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	0	0	0	**0**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**0**	**0**	**0**	**0**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	0	0	0	**0**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**0**	**0**	**0**	**0**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	0	0	0	**0**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**0**	**0**	**0**	**0**

Annual number of working hours in off-road transport work with farm tractor, trailer and hydraulic loader by forest owner, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	51641	72846	139597	**264084**
Season 3	77461	29655	42557	**149673**
Season 4	322754	123562	75577	**521893**
Total	**451856**	**226063**	**257731**	**935650**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	0	0	139597	**139597**
Season 3	0	0	42557	**42557**
Season 4	0	0	75577	**75577**
Total	**0**	**0**	**257731**	**257731**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	0	0	139597	**139597**
Season 3	0	0	42557	**42557**
Season 4	0	0	75577	**75577**
Total	**0**	**0**	**257731**	**257731**

Total of all off-road transport work by forest owner, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	51641	72846	139597	**264084**
Season 3	77461	29655	42557	**149673**
Season 4	322754	123562	75577	**521893**
Total	**451856**	**226063**	**257731**	**935650**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	0	0	139597	**139597**
Season 3	0	0	42557	**42557**
Season 4	0	0	75577	**75577**
Total	**0**	**0**	**257731**	**257731**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	0	0	139597	**139597**
Season 3	0	0	42557	**42557**
Season 4	0	0	75577	**75577**
Total	**0**	**0**	**257731**	**257731**

Annual number of working hours of separate one-grip harvesters, h/a

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	262265	255660	29226	**547151**
Season 2	386802	221913	223449	**832164**
Season 3	114741	111851	0	**226592**
Season 4	245873	239681	0	**485554**
Total	**1009681**	**829105**	**252675**	**2091461**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	0	0	0	**0**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**0**	**0**	**0**	**0**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	0	0	0	**0**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**0**	**0**	**0**	**0**

Annual number of working hours of one-grip harvesters in all-round contracting, h/a

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	0
Season 2	0	0	0	0
Season 3	0	0	0	0
Season 4	0	0	0	0
Total	**0**	**0**	**0**	**0**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	385089	343550	197914	**926553**
Season 2	325574	243963	236747	**806284**
Season 3	187877	214104	94977	**496958**
Season 4	385089	343550	169289	**897928**
Total	**1283629**	**1145167**	**698927**	3127723

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	527874	384427	398395	**1310696**
Season 2	446533	320279	370156	**1136968**
Season 3	281196	192290	161038	**634524**
Season 4	456183	384427	398395	**1239005**
Total	**1711786**	**1281423**	**1327984**	**4321193**

Appendix 6(3)

Total of all harvesting work by one-grip harvesters, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	262265	255660	29226	**547151**
Season 2	386802	221913	223449	**832164**
Season 3	114741	111851	0	**226592**
Season 4	245873	239681	0	**485554**
Total	**1009681**	**829105**	**252675**	**2091461**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	385089	343550	197914	**926553**
Season 2	325574	243963	236747	**806284**
Season 3	187877	214104	94977	**496958**
Season 4	385089	343550	169289	**897928**
Total	**1283629**	**1145167**	**698927**	3127723

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	527874	384427	398395	**1310696**
Season 2	446533	320279	370156	**1136968**
Season 3	281196	192290	161038	**634524**
Season 4	456183	384427	398395	**1239005**
Total	**1711786**	**1281423**	**1327984**	**4321193**

Annual number of working hours of separate 10-tonne forwarders, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	994764	523608	458239	**1976611**
Season 2	671169	333155	278635	**1282959**
Season 3	312238	170232	177211	**659681**
Season 4	669081	377574	389092	**1435747**
Total	**2647252**	**1404569**	**1303177**	**5354998**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	173959	88463	135943	**398365**
Season 2	166791	79622	75741	**322154**
Season 3	83113	47773	69840	**200726**
Season 4	187427	95547	167790	**450764**
Total	**611290**	**311405**	**449314**	**1372009**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	77987	63583	60004	**201574**
Season 2	70184	63262	53094	**186540**
Season 3	42110	27604	31856	**101570**
Season 4	174654	68150	63713	**306517**
Total	**364935**	**222599**	**208667**	**796201**

Annual number of working hours of 10-tonne forwarders in all-round contracting, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	0	0	0	**0**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**0**	**0**	**0**	**0**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	427503	340766	156673	**924942**
Season 2	398343	251731	185515	**835589**
Season 3	188807	222016	71553	**482376**
Season 4	1455015	355310	144713	**1955038**
Total	**2469668**	**1169823**	**558454**	**4197945**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	529513	352836	243507	**1125856**
Season 2	500429	317700	240034	**1058163**
Season 3	284001	168417	103293	**555711**
Season 4	418761	364588	257495	**1040844**
Total	**1732704**	**1203541**	**844329**	**3780574**

Total of all off-road transport by 10-tonne forwarders, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	994764	523608	458239	**1976611**
Season 2	671169	333155	278635	**1282959**
Season 3	312238	170232	177211	**659681**
Season 4	669081	377574	389092	**1435747**
Total	**2647252**	**1404569**	**1303177**	**5354998**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	601462	429229	292616	**1323307**
Season 2	565134	331353	261256	**1157743**
Season 3	271920	269789	141393	**683102**
Season 4	1642442	450857	312503	**2405802**
Total	**3080958**	**1481228**	**1007768**	**5569954**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	607500	416419	303511	**1327430**
Season 2	570613	380962	293128	**1244703**
Season 3	326111	196021	135149	**657281**
Season 4	593415	432738	321208	**1347361**
Total	**2097639**	**1426140**	**1052996**	**4576775**

Annual number of working hours of trucks, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	993495	623728	533334	**2150557**
Season 2	899402	495610	527162	**1922174**
Season 3	623593	336278	333093	**1292964**
Season 4	747297	380081	400167	**1527545**
Total	**3263787**	**1835697**	**1793756**	**6893240**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	872681	506731	495171	**1874583**
Season 2	753671	502835	490071	**1746577**
Season 3	658020	394520	333634	**1386174**
Season 4	631948	411533	400536	**1444017**
Total	**2916320**	**1815619**	**1719412**	**6451351**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	1034858	761802	594668	**2391328**
Season 2	841256	544825	588390	**1974471**
Season 3	700157	412801	401021	**1513979**
Season 4	830140	446004	481341	**1757485**
Total	**3406411**	**2165432**	**2065420**	**7637263**

Appendix 6(4)

Annual number of working hours in planting work, h/a

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	334745	417889	323678	**1076312**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**334745**	**417889**	**323678**	**1076312**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	471269	271809	208875	**951953**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**471269**	**271809**	**208875**	**951953**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	451472	315147	0	**766619**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**451472**	**315147**	**0**	**766619**

Annual number of working hours in direct seeding work, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	44304	64290	96036	**204630**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**44304**	**64290**	**96036**	**204630**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	139827	41817	61974	**243618**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**139827**	**41817**	**61974**	**243618**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	59754	48484	0	**108238**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**59754**	**48484**	**0**	**108238**

Annual number of working hours in clearing and thinning of sapling stands, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	625086	612573	584697	**1822356**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**625086**	**612573**	**584697**	**1822356**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	622149	379217	383681	**1385047**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**622149**	**379217**	**383681**	**1385047**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	567660	418634	529159	**1515453**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**567660**	**418634**	**529159**	**1515453**

Annual number of working hours in clearing the felling area, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	126584	121322	95121	**343027**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**126584**	**121322**	**95121**	**343027**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	138495	78912	61384	**278791**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**138495**	**78912**	**61384**	**278791**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	170725	91494	0	**262219**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**170725**	**91494**	**0**	**262219**

Annual number of working hours in scarifying, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	70722	70645	61197	**202564**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**70722**	**70645**	**61197**	**202564**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	53387	41970	22283	**117640**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**53387**	**41970**	**22283**	**117640**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	62432	44476	68999	**175907**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**62432**	**44476**	**68999**	**175907**

Appendix 6(5)

Annual number of working hours in mounding, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	63292	29849	0	**93141**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**63292**	**29849**	**0**	**93141**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	0	18475	0	**18475**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**0**	**18475**	**0**	**18475**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	77297	20383	0	**97680**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**77297**	**20383**	**0**	**97680**

Annual number of working hours in plowing, h/a.

1990/50	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	0	15195	37832	**53027**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**0**	**15195**	**37832**	**53027**

2000/54	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	52416	9405	23232	**85053**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**52416**	**9405**	**23232**	**85053**

2010/59	W-Finland	E-Finland	N-Finland	Total
Season 1	0	0	0	**0**
Season 2	0	10377	0	**10377**
Season 3	0	0	0	**0**
Season 4	0	0	0	**0**
Total	**0**	**10377**	**0**	**10377**

Appendix 7. 3(1)

WOOD PROCUREMENT 2000 -project
Alanne & Rummukainen 14.6.1991
According Mäkelä (1986) Cost calculation of forest machines.

CALCULATION OF MACHINE COST
Identification data

Recorder	**Arto Rummukainen**
Date	**25.2.1993**
Base machine	**10-tonne one-grip harvester**
Make and model	**Work time 1.5 shifts, 12.8 h/d.**
Equipment 1	
Make and model	
Equipment 2	
Make and model	

Base machine: purchase price, amortization prices and -times

-base machine		1500000 FIM		
-accessories		85000 FIM		
Machine price		1585000 FIM		
Machine life, hours	11500 h	11500 h		
Machine life, years		5.2 a		
Depreciation	27 %/a	Scrap value	19.37 %	
Scrap value			307057 FIM	
Amortized value			1277943 FIM	
Average bound capital		907547.91 FIM		
Installment of base machine		245038 FIM/a		
Interest of installment	14 %	127057 FIM/a		

Working time and amount

Number of w.shifts/day	1 shift	1.5 shifts	2 shifts	Total	Workdays	
months	4.1			6.0	10.1	345 days/a
hours/shift	8.0			8.0		
Work place time (wpt)	21.4 days/montl			2756 h/a		
Gross effective time (% wpt)	80 %			2205 h/a		
Service and rep. time (% wpt)	13 %					
Moving time (% wpt)	7 %					
Percentace of delays shorter than 15 min					m3/a	m3/h
%-of gross effective time	10 %		Productivity		27057	12.3

Fuel consumption	10 dm3/h
Oil consumption	1.9 dm3/h
Hydraulic oil consumption	0.9 dm3/h

Wages and compensations	FIM/h	h/a	
Piece work wage	49.68	2205	109547 FIM/a
Hourly wage	39.75	428	17026 FIM/a
Shift work extras	2.7	811	2190 FIM/a
Cold service extras	1,9	319	606 FIM/a
Dirty work extras	1.7	491	834 FIM/a
Wage extras total			3630 FIM/a
Frince benefits	67.92 %		88434 FIM/a
Travelling distance	24118 km/a		70 FIM/d
-compensation	1.28 FIM/km		30871 FIM/a
Field work time	17 d/a		
-compensation	435 FIM/d		7395 FIM/a

Appendix 7. 3(2)

Base machine: Fuel, oil and maintenance costs

Fuel costs	1.7 FIM/dm3	37486 FIM/a	
Oil costs	9.2 FIM/dm3	38544 FIM/a	
Hydraulic oil costs	6.4 FIM/dm3	12701 FIM/a	
Repair and service cost			
either	% of purchase price		
or	144403 FIM/a	144403 FIM/a	
Oil costs total		88731 FIM/a	
Repair and service costs total		144403 FIM/a	
Insurance, tax and overhead costs			
Fire insurance		11250 FIM/a	
Traffic insurance		2300 FIM/a	
Accidents and damages ins.		450 FIM/a	
Insurance total		14000 FIM/a	
Average working capital	52000 FIM/a		
interest of work.capital	14 %		
Interest of working capital		7280 FIM/a	
Business driving distance	3608 km/a		
-compensation	1.4 FIM/km	5051 FIM/a	
Overhead costs		20000 FIM/a	
Profit fot the enterprise	5 %	45423 FIM/a	
Moving cost of the machine			
Basic compensation	227 FIM/turn	600 m3 average size of a stand	
Tracks removing compens.	115 FIM/turn		
Moving distance	30 km, of whic	37 km compensated.	
Moving time	3 h		
Mov. compensation	9.15 FIM/km		
Mov. compensation	18.42 FIM/km	184.15 FIM/h	
Moving compensation total			35530 FIM/a

Appendix 7. 3(3)

TABLE OF RESULTS	25.2.1993	Arto Rummukainen	
Machine	**10-tonne one-grip harvester**		
Equipment 1			
Equipment 2			
Year production	27507 m3	Gr. effective time	2205 h
WAGE COSTS	FIM/a	FIM/h	FIM/m3
Piece rate wage	109547	49.68	4.05
Hourly wage	17206	7.72	0.63
Extras	3630	1.65	0.13
Fringe benefits	88434	40.10	3.27
Travelling compensation	30871	14.00	1.14
Fieldwork compensation	7395	3.35	0.27
TOTAL	256903 FIM/a	116.51 FIM/h	9.49 FIM/m3
	26.0 %		
CAPITAL COSTS OF MACHINE			
Base machine	FIM/a	FIM/h	FIM/m3
Installment	245038	111.13	9.06
Interest costs	127057	57.62	4.70
TOTAL	372095	168.75	13.75
Equipment 1			
Installment			
Interest costs			
TOTAL			
Equipment 2			
Installment			
Interest costs			
TOTAL			
GRAND TOTAL	372095 FIM/a	168,75 FIM/h	13.75 FIM/m3
	37.6 %		
FUEL AND MAINTENANCE COSTS			
Base machine	FIM/a	FIM/h	FIM/m3
Fuel and oil costs	88731	40.24	3.28
Repair and service costs	144403	65.49	5.34
TOTAL	233134	105.73	8.62
Equipment 1			
Fuel and oil costs			
Repair and service costs			
TOTAL			
Equipment 2			
Fuel and oil costs			
Repair and service costs			
TOTAL			
GRAND TOTAL	233134 FIM/a	105.73 FIM/h	8.62 FIM/m3
	23.6 %		
OVERHEAD COSTS	FIM/a	FIM/h	FIM/m3
Insurance	14000	6,35	0.52
Overhead costs	20000	9.07	0.74
Business driving costs	5051	2.29	0.19
Working capital costs	7280	3.30	0.27
Profit	45423	20.60	1.68
Moving costs	35530	16.11	1.31
TOTAL	127285 FIM/a	57.72 FIM/h	4.70 FIM/m3
	12.9 %		
GRAND TOTAL	989416 FIM/a	448.70 FIM/h	36.57 FIM/m3
	100 %		

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