TIMBER SALE AND LOGGING PLANNING: USING A GEOGRAPHICAL INFORMATION SYSTEM BASED METHODOLOGY

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ABSTRACT

There is increasing pressure to integrate the economics of timber sale and logging planning with environmental considerations and strategic sustainability. Some forestry organisations are hoping to replace pre-harvesting inventory with a database designed for periodical inventory and long-term timber production planning to facilitate continuous (rolling) planning. The aim of this study is to analyse the possibilities of integrating different forest planning levels with each other and a Geographical Information System (GIS), and replacing the pre-harvesting inventory with a GIS.

An integrated GIS and planning system is implemented. Firstly, the production system is analysed to define the system requirements in detail. Then the data model and processes together with system architecture are designed. A new concept of treatment stand is adopted for modelling site-specific restrictions into the calculation units of a Finnish forest simulator, MELA. Thereafter corresponding databases are defined and implemented. System interfaces are developed to provide data flow between subsystems. Additional modules for economic analyses are developed to sit on top of the linear programming (LP) package.

A case study is undertaken to test the functionality of the integrated planning system. In the case study, forest inventory data and GIS-analyses are used for modelling both site-specific restrictions and harvesting conditions. New LP-formulations are defined and implemented using a Finnish LP-package, JLP. The 'production possibility frontiers' (extremes of possible production) are used to estimate the value of GIS in taking into account the effects of site-specific constraints. The results from a combinatorial model are compared with the results of a standard model to measure the benefits of GIS in timber sale and logging planning.

The implemented tools can be used to study the effect of changes in available timber resources, environmental constraints, and market conditions for timber sale. The combinatorial model is applicable for studies concerning the effect of synchronisation of treatments on costs and returns. In the future, more attention should be paid to the design of inventory databases, for example, in terms of terrain modelling. The methods for recording the location and rules of site-specific restrictions - such as management prescriptions for habitats of rare species - should be standardised. The next generation of an integrated planning system should rely on a modern client-server architecture to provide more advanced communication mechanisms between a GIS, simulation models and an LP-algorithm.

In conclusion, it can be said that the system is a step towards continuous and holistic planning where the operational plans are made whenever there are changes in the forest or its environment.

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I extend my sincere thanks to all concerned.

Edinburgh February 1996

Declaration

I declare that this thesis has been composed by myself and that the work it describes is my own.

Tuula Anita Nuutinen

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The aim of this chapter is to outline the framework of the study. First, the problems related to timber sale and logging planning are introduced. Current practices of forest planning are then described. Thereafter the possibilities and limitations of GIS are introduced and, finally, the aims and tasks of the study are presented.

1.1 Background

The aim of this section is to introduce the problems related to timber sale and logging planning. First, the relationship between medium-term (tactical) forest planning and short-term (operational) timber sale and logging planning is described. Then the site-specific issues are discussed and the resulting new requirements for timber sale and logging planning presented.

The goal of forest management is to maximise the utility the forest yields to the decision maker. The task of planning is to provide relevant information on production possibilities for the decision maker (Kilkki 1987, Leuschner 1990).

The decisions can be classified into three categories: strategic decisions on the resources that the enterprise will have available, tactical decisions to make the most effective use of the resources, and operational decisions on detailed scheduling - including timber sale and logging planning (Covington et al. 1988, Davis & Martell 1993, Nelson & Brodie 1990, USDA Forest Service 1987, Weintraub & Cholaky 1991).

In Finland, tactical forest planning includes the model of sustainability (**sustained yield**), the decisions on standwise operations during the management period and the estimation of the volume of harvests from each stand. Planning is based on the corporate timber inventory databases and **cutting budget** methods. The model of sustainability usually covers the **planning horizon** of 10-100 years and the result is referred to as the **allowable cut**. The actual management plan (including treatment proposals based on **prescriptions** prepared in the field) covers 10-15 years. (Poso 1990).

Traditionally, a separate model is applied for annual **timber sale** and **logging** planning (Peltonen & Väisänen 1972, Eskelinen & Peltonen 1982). A timber sale and logging plan should at the same time reflect the market (i.e. short-term production possibilities) and the medium- and long-term resource constraints or production targets such as allowable cut (fig. 1). The problems arise when the given constraints and targets become infeasible due to errors or changes in the value of planning parameters of aggregate models used in long- and medium-term planning.

The road-side value of timber depends on the use-value at the mill and on the on-road transportation costs. The stumpage value is the difference between road-side value and logging costs. The costs per m3 for alternative logging methods and sub-operations (such as felling, conversion and extraction) are presented in cost tables as a function of factors affecting the costs, and the total logging costs are usually calculated by summing up the costs of the chosen **logging** system (i.e. the combination of sub-operations) in particular logging conditions.

In practice, economies of scale affect the costs of logging and on-road transportation. The direct costs of **felling** and **extraction** per m3 are reduced as well as certain indirect costs of road maintenance, tree marking and supervision due to the increased and spatially concentrated volume of timber per treatment (Peltonen & Vesikallio 1979). Therefore, there are usually several **cutting stands** (grouped into a felling area) marked at the same time and sold as a **timber parcel** or a **timber lot**.

Because the synchronisation of operations in time and space reduces the costs both via decreasing the average extraction distance and increasing the amount of timber extracted (the size of timber parcel), a task of planning is to consider the synchronisation i.e. the spatial arrangement of logging operations and the savings due to more effective arrangement of working areas. The deviation from the long-term guidelines due to the synchronisation of operations may, however, lead to losses within the total planning period. Therefore it is also important to estimate the long-term implications simultaneously with the short-term production potential.

It is also possible that timber markets may have changed after the management plan has been prepared. Therefore the marketing and long-term timber production possibilities should be checked and adjusted during short-term timber sale and logging planning.

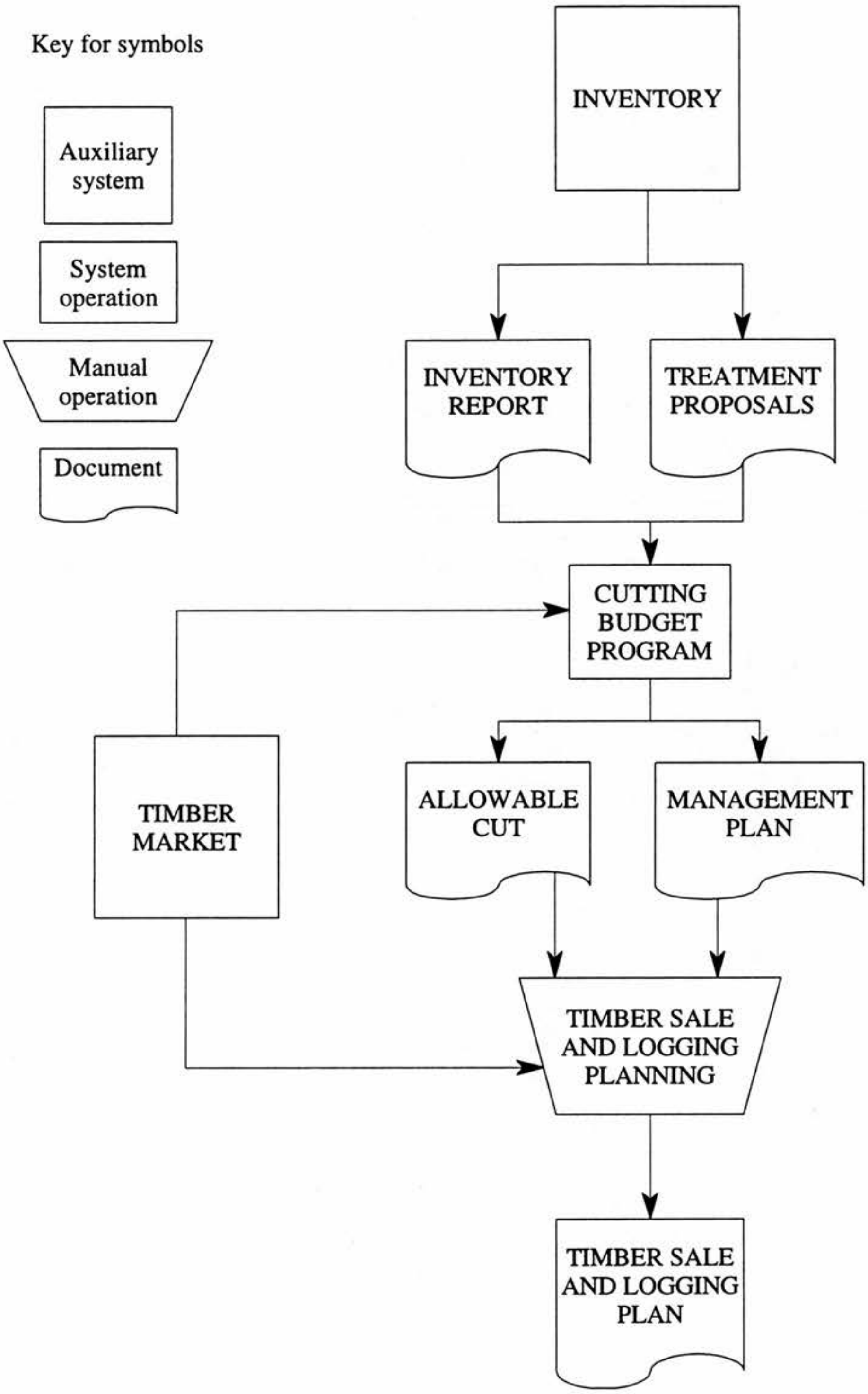

Figure 1. The stages of tactical forest planning (cutting budget) and timber sale and logging planning.

In addition to the economies of scale the site-specific restrictions are usually ignored in aggregate models. Site-specific restrictions decrease the area in timber production or result in special measures including, for example, manual harvesting techniques or longer extraction routes to avoid sites of specific interest, where the use of mechanised harvesting techniques is forbidden. For example, a decrease in the sustained yield, increased costs both on the work site and on surrounding areas due to special measures should all be taken into account.

Usually there is a separate pre-harvesting inventory to collect, for example, information on terrain and site-specific restrictions needed in timber sale and logging planning (Hämäläinen et al. 1990, Lemmetty 1991, Mäkelä 1990, Sunabacka 1985, Uusitalo & Kivinen 1995). As a result of organisational changes (where private contractors are responsible for both planning and logging operations) and the resulting decrease in the number of foremen, there is a growing tendency to dispense with detailed pre-harvesting inventory. Some forestry organisations are hoping to replace pre-harvesting inventory with a database designed for periodical inventory and long-term timber production planning to facilitate continuous (rolling) planning. Unfortunately, the data **accuracy** requirement is higher for timber sale and logging planning than for long-term planning and more information should be collected in traditional compartmentwise inventory. However, it would be very expensive to collect all the necessary data at the most accurate level. There is a trade-off between the increase in accuracy and the cost of data collection and management.

It may be possible to utilise existing forest inventory data and maps in timber sale and logging planning. For example, Geographic Information Systems (GIS) offer tools for spatial data management and analysis needed to take into account terrain and other site-specific conditions. The suitability of existing forest inventory and map data for timber sale and logging planning should be analysed before giving up the current practice.

Clearly, the principles of spatial feasibility and long-term sustainability should be simultaneously taken into consideration in timber sale and logging planning. In principle, operational (short-term), tactical (medium-term) and even strategic (long-term) planning should be operationally integrated into one system, so that the decision maker would be able to adjust either short-term objectives or strategic goals - or both - to ensure that site-specific plans are consistent with longer term strategies. However, there is a lack of methods for the integration of short-term timber sale and logging planning with tactical models (e.g. cutting budgets), and the integration of environmental and economic objectives into the same planning process.

1.2 Forest planning

The aim of this section is to describe current practices of forest planning. First, the concepts and principles of forest planning are presented. Thereafter an implementation of a computerised method for determining cutting budget is presented.

In traditional forest planning a **treatment stand** is usually a **forest stand** described by its area, site variables, and by forest stand characteristics. In principle, a treatment stand should be homogeneous with respect to forest stand characteristics, suitable as a management unit and suitable for updating purposes (Poso 1983).

A **treatment schedule** describes the development of a forest stand under the assumptions made about future silviculture and cuttings for the planning period. A management plan is prepared simultaneously for a number of treatment stands which all have one or more possible treatment schedules. The purpose of planning is to select a combination of schedules for the whole forest area that fulfils the goal of the decision maker (Siitonen 1993). The decision maker is interested in the aggregated variables, i.e. in the sums of variables over the treatment schedules (Lappi 1992). The costs and returns of treatments are usually calculated as independent of the acreage for which they are applied.

On the one hand, forest plans must be disaggregated into site-specific plans in a way that achieves the targets established using a non-spatial, forest-level model (Church & Barber 1992, Jamnick & Walters 1993). However, the overall plan cannot always be disaggregated into site-specific plans without losing its integrity because some treatment stands (such as wilderness areas or other specific habitats that require protection) have not been explicitly recognised in forest-level plans (USDA Forest Service 1987). The lack of a consistent procedure for the downward allocation of output targets leads to under-achievement in terms of total output.

On the other hand, forest-wide plans can be aggregated upward from site-specific plans (Hokans 1983, Davis & Martell 1993). Site-specific planning will consider multiple-use requirements more explicitly than forest-level planning and, thus, facilitate trade-off analysis between timber and multiple-use services. Unfortunately, due to individual (bottom-up) models, interactions between forest subdivisions are not recognised.

A possible solution is a continuous, adaptive and hierarchical planning process where the models provide only broad guidance in the long-term, leaving detailed decisions to be made when more accurate information is available (Nelson et al. 1991, Gong 1994). In hierarchical planning each model involved is usually aimed at a specific level of management (Weintraub & Cholaky 1991). Before the implementation of lower-level plans, the upper-level models will be re-run with updated information. Only the first period solution is implemented and all parameters of the models are updated and the optimal solution re-calculated before proceeding to the next period. The decisions taken at one level act as constraints on the lower level decisions and the information from the lower levels of the process feedback information to the upper level decision processes.

Since the 1960's, mathematical programming (MP) techniques have been increasingly used for solving forest management planning problems (Dykstra 1984, Johnson & Scheurman 1977). MP makes it possible to evaluate several decision variables at the same time. In Finland, Kilkki (1968) started developing a computerised cutting budget approach based on mathematical programming methods. An implementation of the methods is the MELA software (Siitonen 1983, 1993, 1994).

MELA is a data processing system consisting of a general forest simulator based on individual trees and standard linear programming (LP) with an automated matrix generator. MELA was initially developed for long-term forest planning at the national level. The national and regional analyses are based on the sample plot and sample tree data of the Finnish National Forest Inventory (Tomppo et al. 1993). Early in the development of MELA the analyses were strata-based and the sample plots (or stands) were grouped into land or timber classes (**calculation units**). Increasing computing capacity and a more efficient LP-algorithm (Lappi 1992, Lappi et al. 1995) have now made area-based (site-specific) analysis possible. Individual stands are defined as calculation units and thus LP-solutions are directly linked to stands. There is no need for disaggregation algorithms.

In recent years MELA has been (or is being) installed by a limited number of clients in state, company and private forestry to be the forest management planning module of their own forest (stand level) information systems (Siitonen 1993, 1994). Nuutinen (1989, 1990, 1992) has implemented the system for short-term planning.

Unit costs and prices in MELA are calculated as a function of the quality and size of the harvested trees (Siitonen 1994). Neither the simulation process nor the LP-formulation takes the spatial interaction of treatments into account (Ojansuu et al. 1991, Siitonen 1994). If there is nonlinearity of relationships between inputs and outputs and treatment units are not independent, the assumptions of linearity and additivity are violated and LP cannot be regarded as suitable for timber sale and logging planning.

1.3 Geographical Information Systems (GIS) in forest planning

The aim of this section is to introduce the possibilities and limitations of Geographical Information Systems (GIS). First, the need for site-specific information is explained. An overview of the development of GIS is then presented. Thereafter the ability and benefits of GIS are summarised. In addition some GIS-applications used in forest planning are introduced.

Short-term planning requires detailed site-specific, up-to-date descriptions of the forest and its environment. However, the inventory database rarely contains information on harvesting conditions that affect the choice of timber sale and harvesting methods (for example landuse, multiple-use and environmental protection, and terrain conditions).

The development of remote sensing technology for the purposes of inventory, updating and monitoring has generated the requirement for an integrated system to combine data from different sources (Campbell 1987). At the same time digital mapping has advanced due to the development of computer aided design (CAD), computer graphics and **Data Base Management Systems (DBMS)**. Computer-assisted systems for capture, storage, analysis and display of spatial data called **Geographical Information Systems (GIS)** have become readily available tools to forest managers (Aronoff 1989). A GIS is more than a cartographic system, a CAD or a DBMS (Cowen 1988): it can also be used to manage, analyse and output the data in a more efficient and meaningful way than manual techniques, spatial relationships being as valuable as the character of the site itself.

Since the 1960's both the conceptual methods for spatial analysis and the computer software for quantitative thematic mapping and spatial analysis have increased (Burrough 1986). An advanced GIS should also be capable of spatial analysis and modelling (Berry 1986, Tomlin 1990). The development of **digital elevation models (DEM)** or **digital terrain models (DTM)** and 3-D graphics has provided more advanced tools for both terrain analysis and visualisation (Burrough 1986, Raper 1989).

GIS provides planning with more current data, the ability to process large quantities of data, the ability to integrate multiple data sets efficiently, and the ability to generate planning scenarios rapidly. The benefits of a GIS are (Aronoff 1989):

- better storage and updating of data
- more efficient retrieval of information
- more efficient production of information products
- rapid analysis of alternatives, and
- the value of better decisions.

A GIS integrated with simulation tools could be used to generate management alternatives (scenarios) quickly for the evaluation of the consequences of different decisions or to refine plans progressively based on current information. However, the analytical capabilities of a GIS are not effectively utilised in forest management. Most GIS still treat the database as a static model of the landscape even if there are many situations where the landscape changes over time. A few studies, however, exist where GIS is used to identify management zones for scenarios to evaluate the economic loss due to environmental constraints (Nalli et al. 1996) or to model landscape or recreation value (Nuutinen & Pukkala 1992, Pukkala et al. 1995).

GIS together with some analyses and modelling tools have been integrated into **Management Information Systems** (MIS) or **Decision Support Systems** (DSS) (Bobbe 1987, Bulger & Hunt 1991, Chambers 1986, Leggat & Buckley 1991). In these applications, a corporate GIS is designed to serve various applications which may have different requirements in terms of the type and quality of data.

The quality of information is an important element of decision making. Therefore the applicability of data and models incorporated into decision support systems should be analysed.

1.4 Aims of the study

This section outlines the aims of the study. First, the possibility of using a GIS-based forest planning system to integrate environmental considerations with economics of timber sale is identified. The resulting need to analyse the possibilities of integrating different forest planning levels with each other and a GIS and replacing the pre-harvesting inventory with a GIS is expressed. Thereafter the information system needed for the analysis is defined and the tasks needed to accomplish both the implementation of the system and the analysis described.

On the one hand there is increasing pressure to integrate the economics of timber sale and logging planning with environmental considerations and strategic sustainability. The integration of site-specific data with planning methods and different planning levels with each other has become necessary. On the other hand the resources available for pre-harvesting inventory have become scarce. A GIS based forest planning system relying on already existing forest inventory data is regarded as a solution. The aim of this study is to analyse the possibilities of integrating different forest planning levels with each other and a GIS and thus replacing the pre-harvesting inventory with GIS.

For the analysis an integrated GIS and planning system for timber sale and planning has to be implemented. The system should deal with

- site-specific constraints to provide for nature conservation
- the effect of synchronisation of treatments on harvesting costs and returns, and
- the implications of short-term plans on long-term targets (such as sustainability) and vice versa.

For modelling the effect of site-specific constraints the system should be able to incorporate spatial data into economic analyses. For synchronisation the system should be able to deal with combinatorial problems. In this study combinatorial refers to the interdependence of activities: the result of the combined activities may be different from the result when activities are treated independently. To adjust short-term planning models to long-term targets, and vice versa, the non-spatial forest level and site-specific, spatially explicit planning models should be combined as a hierarchical planning system.

The study is divided into six main tasks.

First, the applicability of mathematical programming is analysed to select appropriate methods for solving combinatorial and hierarchical problems.

Second, the possibilities of integrating GIS with forest planning models are analysed.

Third, the principles of software engineering for the implementation of an integrated information system are described and the criteria for evaluating software listed. In addition, the methods for measuring the value of spatial information are studied.

Fourth, an integrated system based on standard tools such as a relational database management system (RDBMS), a GIS, a forest simulator (MELA) and a linear programming package (JLP) is implemented for the Finnish Forest Research Institute (METLA). METLA was chosen for the study because they had both the data and the necessary subsystems available (Saarenmaa et al. 1990). The aim of this study fit well with their aims to develop a forest inventory and planning system based on a GIS. It was agreed that this study would serve as a pilot study to define the system requirements and to test the applicability of the chosen approach. An additional benefit was that METLA had already purchased both an RDBMS (Ingres) and a GIS (ARC/INFO). Both the simulator and optimisation package were developed at METLA. Therefore, there were no purchasing costs and a formal cost-benefit analysis was left outside this study.

Implementation of the system is decomposed into subtasks. Both the organisation and production system are analysed to define the system requirements in detail. The data model and processes together with system architecture are designed. Corresponding databases are defined and implemented. System interfaces are developed to provide data flow between subsystems. Additional modules for economic analyses are developed to sit on top of the LP-package. In analysis the variables of the production processes are described as a non-linear and combinatorial function of the logging conditions.

Fifth, a case study is performed to test the functionality of the integrated planning system and to collect material for the analysis of possibilities of replacing pre-harvesting inventory with a GIS. In the case study, forest inventory data are used for modelling both site-specific restrictions and harvesting conditions. Harvesting conditions includes the layout of strip roads, and the estimation of extraction distance and terrain class as a function of slope, ground conditions, and surface barriers. The LP-model is used to analyse the production possibilities and to test the effects of combinatorics. The production possibility boundaries are used to estimate the value of GIS in the estimation of the effects of site-specific constraints. The results from the combinatorial model are compared with the results of the standard model to measure the benefits of GIS in the estimation of the effects of synchronisation.

Sixth, the results are used to evaluate the approach and to suggest the future development needs.

2. FOREST PLANNING

The aim of this chapter is to outline the optimisation approach adopted in the study. First, different approaches to developing a forest plan from standwise proposals to computerised cutting budgets are described and problems related to nature conservation issues introduced. The principles, assumptions and applicability of mathematical programming - especially linear programming (LP) - in forest planning are then presented. Thereafter harvest scheduling models are introduced. Finally timber sale and logging planning and pre-harvesting inventory are described in more detail.

2.1 Tactical forest planning

The aim of this section is to describe different approaches to developing a forest plan from standwise proposals to forest regulation methods such as computerised cutting budgets. In addition problems related to nature conservation issues are introduced.

Tactical forest planning is divided into three parts: long-term planning to determine sustainability, medium-term planning to derive in-site treatment proposals that meet the production targets within the existing monetary, labour and other resources given in a strategic plan, and short-term timber sale and logging planning. The long-term part sets production targets for each management period and the medium-term part defines the means to achieve the targets (i.e. the treatment proposals).

Traditionally, the purpose of forest planning has been to develop a timber production program to predict sustainable future timber supply (allowable cut) and provide guidelines for operational activities in the form of a cutting budget (Kilkki 1987, Leuschner 1990). A common practice has been to establish a cutting budget for the periods of five to ten years, usually coinciding with or being multiples of the strategic planning period for which the allowable cut is determined (e.g. Kuusela & Nyyssönen 1962). Within the cutting budget a specific timber sale and logging plan has been prepared for at least a year in advance (Peltonen & Väisänen 1972, Eskelinen & Peltonen 1982).

The forest plan has been made every 10-20 years based on forest inventory (Poso 1990). Forest inventory has consisted of data collection such as remote sensing (fig. 2) and field work (fig. 3) and calculation of inventory results. The basic inventory unit has been a stand i.e. a homogeneous forest area in terms of site and growing stock characteristics (Poso 1983). The inventory results have been presented as forest maps, stand lists and summary tables. During the years between inventories, neither the inventory results nor the planning documents have been updated.

Figure 2. Forest stands are delineated on aerial photographs.

The methods based on standwise proposals consider each stand independent (Valsta 1993). For practical purposes some rules to assist in the preparation of proposals have been given in the form of yield tables and silvicultural guides. The rules are usually based on the assumption that the utility to a forest owner from an individual stand equals the net present value of the future revenues. For example, the Faustmann formula defines the value of forest land as the present value of net revenues of the current and all the future generations (Kilkki 1987). The formula yields the rotation for the maximum land rent. At stand level regeneration decisions can then be formulated as a rotation problem: a stand is clear-cut when it achieves the optimal rotation age. It is possible to develop a complete forest management plan from standwise treatment proposals.

Figure 3. Forest stand characteristics are measured in the field.

According to the principle of sustained yield the forest resource should be managed in such a way that the current generation gets as much benefit as possible without decreasing what future generations can get from it. Two concepts, "normal forest" and "fully regulated forest", give the framework for sustainability. The "fully regulated forest" is an idealistic model of a multi-stand forest which consists of even-aged stands and in which the age-class distribution is even. From "fully regulated forest" the same amount of products can be harvested in the current and all the future periods and the maximum sustained-yield is achieved by adopting rotation age and the desired forest structure (Kilkki 1987).

Cutting budget methods are techniques for the incorporation of the "fully regulated forest" model into single-stand management based on silvicultural or economic rules. Cutting budgets based on standwise proposals are usually employed to check the feasibility of proposals for the whole forest area. The production program with the related input and output variables for the forest area are calculated as a sum of these proposals and compared with the management objectives. If the results fail to meet the given criteria (e.g. the future forest does not resemble the "fully regulated forest"), the plan has to be adjusted i.e. the proposals for one or more stands are modified. Thus, the optimal proposal for a particular stand is not necessarily the same as the standwise optimum. The benefits of this approach are its simplicity and the consistency of the total cut and the standwise proposals.

However, an individual stand is rarely a planning unit: the harvest decisions of stands at forest level are both temporally and spatially interrelated. The management decisions for interrelated stands should be made simultaneously. A forest management unit consists usually of hundreds of stands where each stand may have more than ten management options. Therefore, it is very difficult - if not impossible - to manually search for such a combination of treatment proposals which would satisfy all the objectives. An efficient planning method should produce such a set of treatment proposals which would ensure the achievement of the objectives. The methods can be implemented as computerised cutting budgets (Kilkki 1968) or harvesting scheduling models (Gong 1991, Brodie & Sessions 1991).

A traditional decision problem is to maximise the net present value of future income under some sustainability requirements. The net present value is usually the discounted net revenue from timber harvests over the planning period. Sometimes the discounted value of the inventory left at the end of the planning horizon is included (Johnson & Scheurman 1977). Sustainability can be expressed as allowable cut (the level of annual or periodical timber drains from the forestry unit over the planning horizon to maintain a continuous supply of raw material), non-declining net income (to maintain even cash flow) during the following periods, the growing stock volume in the final year or the net present value of future income at the end of the planning period. In the case of a fully regulated forest, maximal net present value is consistent with an even flow of resources and net income. When forests are not in a "regulated" state, non-declining yield constraints may cause substantial reductions in net present value. If the objective is to convert a non-regulated forest into a regulated one, a suitable approach is to formulate the model so that the minimum harvest during any one time period is maximised (Hof et al. 1986).

The rational decision maker aims at maximising his or her utility. It may, however, be impossible to condense the whole utility of the decision maker into one objective function or one variable as simple as the net present value of timber production. Usually there are several forest level objectives and constraints which should be met at the same time.

Timber production has been the main use of forests in Finland but the importance of multiple-use services is increasing. The timber management objective is increasingly being supplemented, replaced or restrained by multiple-use objectives concerning landscape, recreation or nature conservation (Nuutinen & Karjalainen 1994).

Nature conservation can be divided into two main categories. In the first category, sites and species are protected where conservation objectives will take priority over all other land-use objectives. Other uses are allowed only if they do not interfere with the primary use. A list of restrictions on actions that may conflict with nature conservation interests may be given externally by the authorities or internally by the land owner. Restrictions concern mainly non-timber landuse classes such as conservation areas established under the control of the nature conservation authorities. In Finland these include national parks, park forests, strict nature reserves, and national programmes for the protection of shorelines and ridges. Other sites of specific interest include national scenic areas (fig. 4), habitats of endangered species such as late-successional or old-growth forests (fig. 5), and specific transition zones around waterbodies and watercourses (fig. 6), for example.

In the second category, habitats are managed by increasing the variety of wildlife. This can be referred to as positive conservation: on a small scale, improvement of habitats (enhancing sustainability and biodiversity) is achieved by adopting simple changes in conventional silviculture to favour the diversity of species within a stand, or on a larger scale, certain woodland types or age-class structures have to be maintained or developed.

Figure 4. A national scenic area in Eastern Finland.

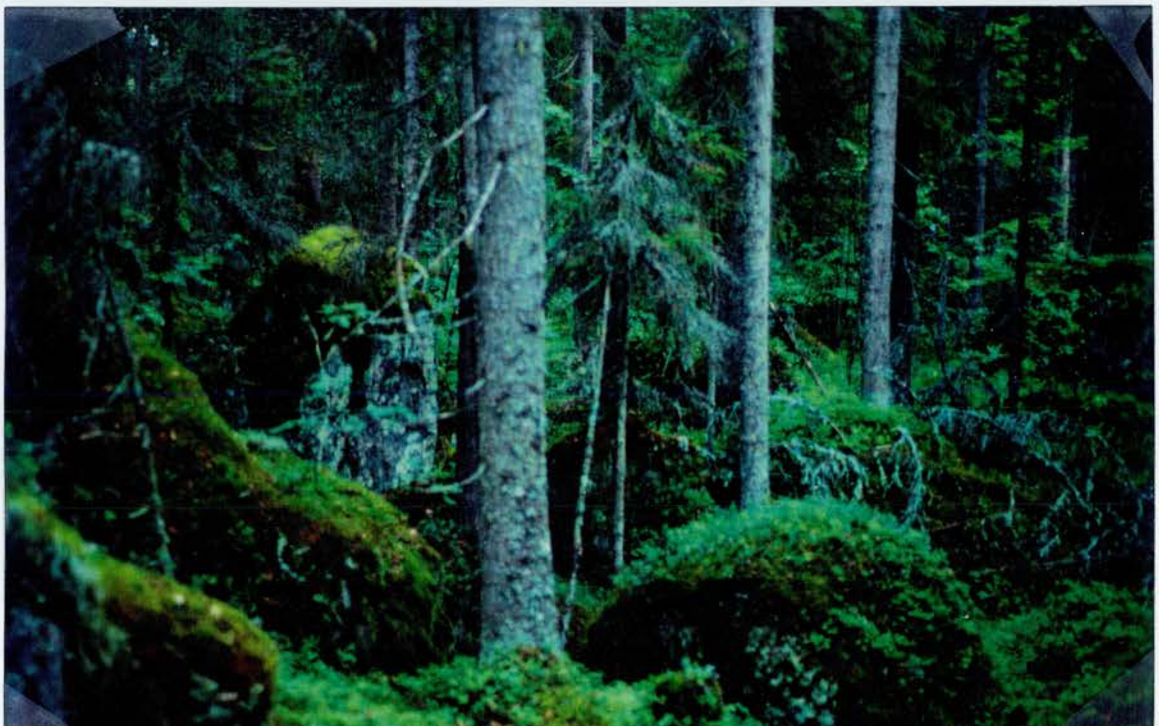

Figure 5. Late-successional spruce forests offer habitats for some endangered species.

Figure 6. Transition zones are needed around waterbodies and watercourses.

Both site-specific conservation and positive conservation may cause additional costs for timber production (Chong & Beck 1991). For example, the conservation or recreational use of a forest area may restrict the choice of logging system or season or even prohibit the use of mechanised methods. If the logging system has to comply with environmental regulation and the costs associated with compliance are significant, these should be identified.

There are two main approaches to allocate forest resources between timber production and other uses. In the first, the forest as a whole is managed for multiple use while the forest area is divided into zones each allocated for a single primary use

(Nalli et al. 1996). In the second, every hectare of forest should be managed for the combination of products and services which would maximise the forest owner's utility (Nuutinen & Pukkala 1992, Pukkala et al. 1995). Complete integration of uses may be difficult to manage but it is likely to provide greater overall benefit (Helliwell 1987).

In addition, there are rules referred to as temporal non-adjacency or spatial constraints (Clements et al. 1990, Dahlin & Sallnäs 1993, Torres-Rojo & Brodie 1990). An adjacency constraint defines that a unit cannot be harvested if an adjacent unit has been harvested in either the same period or in one or more preceding periods (O'Hara et al. 1989). Other constraints may define the maximum size of clear cutting area. For example, Nelson and Finn (1991) have studied the effect of cut-block size and adjacency rules on harvesting levels.

2.2 Mathematical programming in forest planning

The aim of this section is to present the principles, assumptions and applicability of mathematical programming - especially linear programming (LP) - in forest planning.

A typical decision problem arises in forest planning when we have a number of treatment stands (calculation units) each of which has a number of simulated treatment schedules. Each schedule is associated with a vector of production variables i.e. inputs and outputs.

In the decision-making process we are only interested in the aggregated variables, i.e., the sums of variables over the treatment schedules (Lappi 1992). The different schedules are tied together by decision constraints (e.g. forestwide net income requirements) and every calculation unit has its area constraint. The decision alternatives in operations research are called activities.

In forest planning a mathematical program addresses an optimisation problem in which the objective and constraints are given as mathematical functions and functional relationships. In recent years, mathematical programming techniques have been widely used for solving forest management planning problems, because it makes it possible to evaluate a combination of management alternatives with regard to several decision variables at the same time (Dykstra 1984, Johnson & Scheurman 1977). Mathematical programming produces efficient management plans. An efficient management plan means that it is impossible to improve an objective without impairing the value of some other objective or without violating the constraints (Pukkala & Pohjonen 1989).

Linear programming (LP) has been a common mathematical programming method used in forestry. The algebraic formulation for the linear programming problem is (Kilkki 1987)

$$\text{Max } z = \sum_{j=1}^{n} c_j x_j \quad (2.1)$$

s.t.

$$\sum_{j=1}^{n} a_{ij} x_j \leq d_i, \; i = 1,\ldots,m \quad (2.2)$$

$$x_j \geq 0 \;\; j = 1,\ldots,n \quad (2.3)$$

where the management goal of the decision maker is defined as an objective function (z). Constraints (d_i) can be decision variables of a decision maker or externally set restrictions. The constraints set by the decision maker may be seen as prediction variables of the utility function and thus the utility function (U) defined as follows

U=f(z,d_1,..., d_m)

or

U=f(z,d_1,..., d_m|a)

where a means other variables influencing the utility (here assumed to be constant) not under the control of the optimisation model.

Mathematical models are simplifications of the real problems, therefore they should have a heuristic role (Cocklin 1989a). Sometimes it is possible to use a 'trial and error' method to find the values of the constraints (d_1,..., d_m) and the value of the objective function (z) which maximise this utility function. This process may be referred to as Modelling to Generate Alternatives or MGA (Mendoza et al. 1987, Cocklin 1989b). MGA is often used as a framework for decision analysis (Gong 1994).

Another supporting technique is the Analytic Hierarchy Process (AHP) which is a mathematical method for analysis of complex problems with multiple criteria (Kangas 1991).

Mathematical programming can be seen as an assistant to give the decision-maker an idea of the production possibilities. For example, a production possibility boundary can be used to show the relationships between the different objectives (fig. 7). A set of efficient solutions depicting the boundary can be produced quickly by mathematical programming.

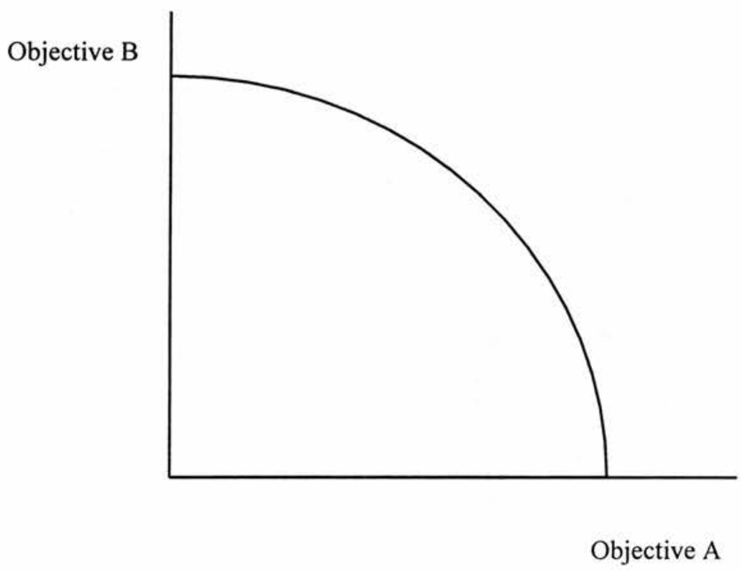

Figure 7. An example of the production possibility boundary.

In correspondence to the maximising problem (1.1), called the primal problem, there exists the dual minimising problem (Kilkki 1987)

$$\text{Min } w = \sum_{i=1}^{m} d_i v_i \qquad (2.4)$$

s.t.

$$\sum_{i=1}^{m} a_{ij} v_i \geq c_j,\ j = 1,\ldots,n \qquad (2.5)$$

$$v_i \geq 0,\ \ i = 1,\ldots,m \qquad (2.6)$$

where variables v_i are referred to as shadow prices. The dual formulation is useful when someone intends to implement a particular feasible solution instead of the optimal one since there are some factors (not reflected in the model) that make this solution desirable. For example, Kilkki (1987) recommends the use of reduced costs to examine whether or not it pays to include a new activity in the optimal solution.

$$RC = c_j - \sum_{i=1}^{m} a_{ij} v_i \qquad (2.7)$$

A reduced cost (*RC*) is the cost of including a new activity into the basic solution, and it is zero for all activities in the optimal basic solution. For every activity that is not in the basis of the optimum solution, the reduced cost indicates the quantity by which the coefficient of the goal function should be decreased (minimisation) or increased (maximisation) before the activity should be a candidate for the basis of the optimum (Dykstra 1984).

A mathematical model is always a simplification of the original problem: the analyst has to design models of specific forms. The main assumptions of linear programming are linearity, divisibility, and additivity.

Linearity (or proportionality) in the objective and constraint equations guarantees that changes in the activities affect the outputs proportionately (Kilkki 1987, Taha 1987). The assumption implies that average values will not change as quantities change, i.e. the output must not be so large as to affect factor and product markets. The difficulties arise, for example, when the costs and returns depend on the level of production and the objective function and constraint equations should describe this non-linearity. If we try to approximate a non-linear problem by means of LP, we should suspect that LP will overestimate the number of activities in the optimal solution, because increasing returns should call for a greater concentration on a few products (economies of large scale), i.e. if the most profitable activity becomes more profitable as its output expands it will pay to achieve the full benefits of specialisation by dropping other activities.

Some special solution methods are available if the problem is not in a linear form. The curved functions may be cut into short linear segments that approximate the original function (separable programming). It is also possible to use non-linear models such as quadratic or convex programming (Johnson & Scheurman 1977, Kilkki 1987). The disadvantage of non-linear programming is that the solution algorithms are not as effective as linear programming algorithms.

The **divisibility** assumption implies that all the activities in the problem may be divided into smaller and smaller parts (Kilkki 1987). A central theorem of LP is that the number of activities whose values are positive in an optimal solution will ordinarily be equal to the number of constraints in the problem. Thus, an optimal solution can be found by examining only the corners of the feasible region (Taha 1987). The theorem implies that in forest planning problems the number of calculation unit divisions equals the number of decision constraints.

Usually it is assumed in forest planning that the divided stands offer an adequate solution if the stands are large. Sometimes, however, the integer solution is necessary, because the fractions are not workable. Post-optimal rounding-off based on the level of activity in the solution, or reduced costs, can be done but unfortunately the rounding-off solution may be far from optimal. If rounding produces unacceptable errors integer programming is recommended.

An integer program is a linear program with an additional restriction that the input variables be integers (Hof & Joyce 1993). Problems with integer variables may be more difficult to solve than those with continuous variables unless the algorithms are tailored to use heuristic rules, as in the search for the nearest feasible integer solution.

Another assumption which causes difficulties in forest planning is **additivity**. This requires that activities are independent so that the sum of outputs of the individual activities will be equal to the output if these activities are combined (Kilkki 1987, Taha 1987). If the stands are not assumed to be mutually independent neither the assumption of additivity nor the assumption of a linear objective function holds. If the result of the combined activities may be different from the result when activities are treated independently, the problem is in this study referred to as combinatorial. Kilkki (1987) mentions that it is possible to combine the non-additive activities into a new set of activities that are additive. For example, treatment schedules of a set of stands marked for cutting may be joined and modified accordingly.

In LP one assumes that all the parameters of the model are known constants. Optimisation methods may however provide additional information concerning the behaviour of the solution. For example, linear programming provides a simple method for post-optimality analysis. The right-hand-side (RHS) constraints d_i are classified as binding or non-binding: if a constraint is binding the resource is regarded as scarce since it is used completely. The shadow price of a constraint expresses the marginal effect of one unit increase in a constraint on the value of the LP objective function. If the constraint is related to the input variable, the shadow price represents the unit price we would be willing to pay to increase the allocation of this particular resource. If the shadow price is greater than the actual unit cost, then the allocation should be increased until this relationship no longer holds. The interpretation of shadow prices may be relevant only for a relatively small increase in the value of the constraint because the current basic solution may become infeasible with a larger increase. The shadow prices can be used for pricing the resources (Hoganson & Rose 1984, Parades & Brodie 1988).

Sensitivity and post-optimal analysis are used to interpret the effects of simplifying assumptions typical for LP or to determine how sensitive the optimum solution is to making changes in the original model (Taha 1987). In sensitivity analysis the values of a_{ij}, c_j of linear programming are mainly of interest but in post-optimality analysis the effects of changes in constraints d_i are studied. In particular, we are often interested in how much a resource can be increased to improve the optimum value, or how much a resource can be decreased without causing a change in the optimum.

Methods to incorporate uncertainties into forest level planning are summarised by Gong (1993). For example, coefficients a_{ij}, c_j can be defined as random variables and thereafter bootstrap techniques and Monte Carlo repetitions used to simulate the expected value of the optimum (Hof et al. 1988, Pickens and Dress 1988). Post-optimality analysis is usually based on repetitive solution of the optimisation problem with different d_i constraint values. In chance-constrained optimisation, constraints are treated as random variables (Hof and Pickens 1991) and in goal programming the bounds may be treated as tolerance levels expressed in an interval instead of as fixed values (Mendoza & Sprouse 1989, Bare & Mendoza 1992).

Optimisation is used as an easy way to find management alternatives that are efficient with respect to the objectives included in the optimisation model. LP offers efficient algorithms to solve problems with a special structure. It is, however, obvious that an efficient solution to an optimisation problem is not necessarily efficient for the whole planning problem. For example, some issues that are not incorporated into the model may be so important that a solution which lies in the inferior region of the model may be preferred. More attention should therefore be paid in the evaluation of solutions, in terms of objectives which are outside the optimisation model.

The capability of linear, non-linear and integer programming for handling the interdependence of activities (combinatorial problems) is restricted. A method for dealing with combinatorics is successive linear programming (SLP) based on solving a sequence of linear programs (Palacios-Gomez et al. 1982). LP can thus be used to prepare partial plans for allocating the linearly related inputs and outputs if the remaining resources are allocated using appropriate, available analytical techniques such as combinatorial programming or heuristics.

Combinatorial programming algorithms are usually based on the use of a controlled enumerative procedure. The aim is to consider all potential solutions and eliminate those which are known to be unacceptable. Search is directed first to the discovery of a feasible solution and then to successively better and better feasible solutions until ultimately one is discovered which is shown to be optimal. For practical application the combinatorial programming algorithms are computationally too heavy.

A heuristic method is a procedure for solving problems in which the structure of the problem can be interpreted and exploited intelligently to obtain a reasonable solution, for example, when an analytic solution is unknown or computationally prohibitive to use, or as a part of an iterative procedure that guarantees the finding of an optimum solution (Silver et al. 1980).

Standard simplex algorithms may not be efficient enough for iterative use. Advanced methods such as decomposition (Danzig & Wolfe 1960) and upper-bound techniques (Danzig & Van Slyke 1967) make LP efficient also in large-scale problems (Barahona et al. 1992, Berck & Bible 1984, Gunn & Rai 1987, Liittschwager & Tcheng 1967; Nazareth 1980).

Owing to the special structure of the forest planning problem, a solution algorithm (fast and with a small memory requirement) can take advantage of both decomposition principles and the revised simplex. Lappi (1992) developed an LP-algorithm (JLP) based on generalised upper bound techniques, which utilises both the principles of decomposition and the revised simplex.

In JLP an optimisation problem can be presented as

$$\text{Max or min } z_0 = \sum_{k=1}^{p} a_{0k} x_k + \sum_{k=1}^{q} b_{0k} z_k \tag{2.8}$$

s.t.

$$c_t \leq \sum_{k=1}^{p} a_{tk} x_k + \sum_{k=1}^{q} b_{tk} z_k \leq C_t,\ t = 1,\ldots,r \tag{2.9}$$

$$x_k - \sum_{i=1}^{m} \sum_{j=1}^{n_i} x_k^{ij} w_{ij} = 0,\ k = 1,\ldots,p \tag{2.10}$$

$$\sum_{j=1}^{n_i} w_{ij} = 1,\quad i = 1,\ldots,m \tag{2.11}$$

$$w_{ij} \geq 0 \text{ for all } i \text{ and } j \tag{2.12}$$

$$z_k \geq 0 \text{ for } k = 1,\ldots,q, \tag{2.13}$$

where

m	=	number of treatment units
n_i	=	number of management schedules for treatment unit *i*
w_{ii}	=	the weight of the treatment unit *i* managed according to management schedule *j*
x_k^{ij}	=	the amount of item *k* produced/consumed by treatment unit *i* if schedule *j* is applied
x_k	=	obtained amount of output variable *k*, *k*=1,...,*p*
z_k	=	an additional decision variable, *k*=1,...,*q*
a_{tk}	=	fixed real constants for *t*=1,..., *r*, *k*=1,...,*q*
b_{tk}	=	fixed real constants for *t*=1,..., *r*, *k*=1,...,*q*
r	=	number of utility constraints

The problem is solved by finding proper values for the unknown variables w_{ij}, x_k and z_k. Term 'constraint' refers later to the utility constraints (2.9). Constraints (2.10) define the aggregated output variables x_k as the sums over the calculation units.

The constraint (2.10) can be written as

$$x_k = \sum_{i=1}^{m} \sum_{j=1}^{n_i} x_k^{ij} w_{ij},\ k = 1,\ldots,p \tag{2.14}$$

In JLP a specific concept domain refers to a subset of calculation units. A domain specific objective function or constraint can be defined in the above form by defining x_k^{ij} to be zero if unit i does not belong to the intended domain. Let D_t denote a subset of units (i.e. a subset of the set {1,...,m}) that are used on row t. Domains for different rows can be equal and x-variables from different domains can be included in the same constraint using additional z-variables. Then a linear programming problem with domain specifications is:

$$\text{Max or min } z_0 = \sum_{k=1}^{p} a_{0k} x_{kD_0} + \sum_{k=1}^{q} b_{0k} z_k \tag{2.15}$$

s.t.

$$c_t \leq \sum_{k=1}^{p} a_{tk} x_{kD_t} + \sum_{k=1}^{q} b_{tk} z_k \leq C_t,\ t = 1,\ldots,r \tag{2.16}$$

$$x_{kD_t} - \sum_{i \in D_t} \sum_{j=1}^{n_i} x_k^{ij} w_{ij} = 0,\ k = 1,\ldots,p,\ t = 1,\ldots,r \tag{2.17}$$

$$\sum_{j=1}^{n_i} w_{ij} = 1,\ \ i = 1,\ldots,m \tag{2.18}$$

$$w_{ij} \geq 0 \text{ for all } i \text{ and } j \tag{2.19}$$

$$z_k \geq 0 \text{ for } k = 1,\ldots,q, \tag{2.20}$$

In this study, JLP was chosen instead of a standard linear programming (LP) package. There are eight major adantages of JLP. First, JLP is efficient because it is tailored for the special (decomposed) structure of the forest management problem in question. Because JLP does not set restrictions on the size of the LP-model, both the short-term and long-term problems can be formulated in the same optimisation model. It is also possible to define several RHS constraint values to produce production possibility boundaries quickly.

Second, it is possible to define different management zones such as conservation or recreation areas as domains (subsets of calculation units) which have their own objectives and/or constraints. In JLP, the domains can overlap which is useful feature when preparing plans for forests managed for a combination of products and services.

Third, JLP has a flexible interface based on a command interpreter and transformation compiler. The transformation compiler can be used to add symbolic names for variables, define domains where different constraints should be fulfilled, develop heuristic rules to reject or select schedules for further analysis, or formulate mathematical functions to create new variables, schedules or treatment units.

Fourth, the decision variables for management alternatives (schedules) can be divided into physical variables (e.g. the amount of timber) and derived variables (e.g. the total income when the amount of timber is sold). In JLP there are different types of variables: constants, **d**-variables, **c**-variables, **x**-variables. **D**-variables describe data sets i.e. a logically related set of calculation units such as a farm or a forestry district. **C**-variables (class variables) describe calculation units. **X**-variables are variables describing treatment (management) schedules of calculation units produced by a simulation system. They correspond the variables x_k^{ij}. Constants and **d**-variables can be used as parameters in **ctran**-transformations and **c**-variables in **xtran**-transformations. **Ctran**-transformations can be used, for example, to define domains in problem formulations. **Xtran**-transformations can used to create new variables to describe treatment schedules. Constants can also be used as parameters in domain specifications. Constants are created and given values using the **constant**-command or created using the **xdat**-command. **D**-variables get new values when the data file changes. **C**-variables get new values when the treatment unit changes. **C**-variables are read from **cdat**-files or made by **ctran**-transformations. **X**-variables get new values when the treatment schedule changes. **X**-variables are read from **xdat**-files or made by **xtran**-transformations.

Fifth, JLP can also be used to calculate an integer solution based on a rounding-off algorithm.

Sixth, the algorithm can be used to solve goal programming problems. In the current version the linear combinations of MELA-variables can be used as utility variables.

Seventh, JLP provides some advanced tools for sensitivity and post-optimal analysis. The transformation compiler can be used to assist in sensitivity analysis by modelling the uncertainty of decision variables by using stochastic coefficients instead of original values. The additional benefit is marginal analysis of decrease and increase "shadow prices".

Eighth, the JLP package is portable and it is easy to tailor the programs according to available computing resources and problems. The package can deal with several input and output formats and contains subroutine templates for additional data input and reporting routines. For example, spatial models for the site-specific restrictions (e.g. zones around waterbodies) and harvesting activities (e.g. extraction) can be implemented in the GIS (see Nuutinen 1992) and the results of models (e.g. the codes for management zones and the totals of extraction) exported to JLP as **c**-variables.

2.3 Harvest scheduling models

There are three critical issues in operational planning of multiple-use forests. First, the integration of long-term and short-term planning (i.e. checking for temporal feasibility of the short-term plan); second, the integration of multiple-use planning with timber management planning (i.e. checking for spatial feasibility of the operational plan) and third, the evaluation of the effect of multiple-use constraints on the economic feasibility of the short-term operational plan (checking for economic feasibility). In addition, the effect of uncertainty on the optimality of the short-term plan should be estimated.

Harvesting scheduling is the application of mathematical programming techniques to determine the allowable cut and/or cutting budget over multiple rotations or cutting cycles. An overview of harvest scheduling models is given by Gong (1991) and Brodie & Sessions (1991), computerised systems are presented by Schuster et al. (1993).

There are a few computerised harvest scheduling applications based on heuristics such as HERO (Pukkala and Kangas 1993) and simulation techniques such as FORMAN (Jamnick 1990), HSG (Moore & Lockwood 1990), HUGIN (Bengtsson & Lundström 1987), and Indelningspaket (Jonsson et al. 1993). FORMAN (Jamnick 1990) is perhaps the best known simulation model in Canada. It is a sequential inventory projection method where the changes in the resource over time in response to specific activities are tracked under the control of the analyst.

Other techniques include a simulation approach based on the economic interpretation of the key dual variables of the LP-formulation (Hoganson & Rose 1984), stand sorting (Elwood & Rose 1990), combined simulation and optimisation (Arthur &

Dykstra 1980), mixed integer programming (Ghandforoush & Greber 1986), multi-objective and goal programming methods (Field et al. 1980, Kangas & Pukkala 1992, Mendoza 1987, Mendoza et al. 1987) and binary search (Johnson & Tedder 1983). In binary search there is only one decision variable such as maximum discounted net value that can be sustained and two choices i.e. either increase or decrease the initial harvest.

Computerised LP-models can be used to evaluate hundreds of thousands of decision variables in a fraction of time it would take to locate the best combination of decision variables by hand. The most common LP-based system in the USA is FORPLAN (Johnson 1987, USDA Forest Service 1987). It consists of an LP-package and two additional programs: a matrix generator and a report writer. For the analysis, calculation units (analysis areas) are delineated, a set of feasible management prescriptions defined, and both the effects and outputs of prescriptions and the costs and benefits for each combination of prescription estimated. Different resources may require different definition of analysis areas. In FORPLAN analysis areas may be contiguous (either homogeneous or non-homogeneous) or non-contiguous. Owing to the computational limitations stands are often aggregated into homogeneous, non-contiguous analysis areas.

The most common forest planning system in Finland is MELA (Siitonen 1983, 1993, 1994; Siitonen et al. 1995). In the MELA-system matrix generation is actually divided into two stages. In the first, a simulator produces automatically, according to user-defined parameters, a set of treatment schedules for each calculation unit. A choice of variables for the schedules are stored in a file. These schedules are then read into an LP-matrix where each activity is a schedule. An LP-problem is then defined and solved using a standard LP-package. The report writer is used to interpret the solution.

MELA was initially developed for long-term forest planning at the national level. The national and regional analyses are based on the sample plot and sample tree data of the Finnish National Forest Inventory (Tomppo et al. 1993). At the beginning the analysis were strata-based and the sample plots (or stands) were grouped into land or timber classes (calculation units). Increasing computing capacity and a more efficient LP-algorithm (Lappi 1992, Lappi et al. 1994) have now made area-based (site-specific) analysis possible. Individual stands are defined as calculation units and thus LP-solutions are directly linked to stands. There is no need for disaggregation algorithms.

The systems designed for timber production planning provide acceptable production estimates for the areas under non-restricted timber production. For multiple-use forests they may, however, produce overestimates of timber production possibilities. There are two reasons for this. First, the resource inventory data used for long-term planning are often based on sampling and the samples may be too small to contain representatives for all the different multi-production types such as nature conservation, recreation, and landscape. Second, it is often necessary to aggregate resource (inventory) units into homogeneous calculation units to make the calculations computationally efficient. Therefore the model cannot have any linkage to 'on-the-ground management'. Environmental constraints for the areas surrounding watercourses or technical constraints due to difficult terrain conditions are overlooked because neither the resource inventory nor the production model can describe them. For example, the limitation for the size of opening created by clearcutting is impossible to include within an aggregated model based on land or timber classes.

The applicability of linear programming in forest planning has also been discussed. Standard LP-systems fail especially in multiple-use planning. First, the relationships between inputs and outputs of the production processes may be non-linear. Second, the activities within a geographic area, e.g. the treatment of neighbouring stands, are not independent of each other in terms of activities themselves or their consequences. Thus, both the linearity and additivity assumptions of linear programming are violated. Third, it has been difficult to quantify and include non-timber benefits into the LP-model because of the lack of production functions or market values. There is a lack of joint production functions which could take into account interactions between different multiple-use activities. Kilkki (1987) states that it is possible to define even multiple-use objectives as LP-constraints. However, it is very difficult to determine the desired levels for the non-timber uses. If non-timber production functions existed, a production program would be chosen from simulated, feasible treatment schedules. Fourth, objectives such as a 'beautiful landscape' may not be measurable with quantitative units. Therefore, the requirement that in the LP-model the variables should be non-negative, continuous and measured on a ratio scale cannot be met. Methods to deal simultaneously with qualitative and quantitative values of forests are needed.

The increased economic and environmental pressure requires more attention to in-site planning. Systems should provide more land-use classes and constraints to help deal with multiple-use problems. The models should preserve the location and physical identity of the calculation unit which helps in translating the LP-solution into operational plans and management decisions. For example, the land areas under restrictions should be extracted from the timber management plan. Since the production possibility estimates of the long-term plan are overestimates (Nelson & Finn 1991), the plans have to be "corrected" using "rules of thumb" before implementation. Disaggregation models have been developed (e.g. Church & Barber 1992).

CRYSTAL (Jamnick & Walters 1993) is designed to allocate stratum-based harvest schedules for forest blocks. There is, however, increasing need to move towards area-based harvest scheduling (Howard & Nelson 1993) and contiguous analysis areas.

Gong (1994) states that forest management decision-making is an adaptive process where management activities to be undertaken in each period are determined based on information available in that period only - also taking into account future uncertainty in respect of the natural environment and the decision maker's adaptive behaviour in subsequent periods. Information on possibilities and consequences in the near future can be made as certain as possible by revising the plan whenever there are changes in decision parameters. The revised plan is then based on the current information and knowledge about the decision environment and its behaviour. Decision analysis - repeated in each period - focuses on formulating the appropriate representation of the actual problem and interpreting the results to help the decision-maker to understand the problem and make better decisions.

Hoganson and Rose (1987) present an alternative where several basic LP-formulations are merged into a multi-stage model where the management schedules are fixed in the short-run but they can vary in the long-run in response to the scenarios that occur. Treatment indices can be used to transfer treatments to timber classes i.e. to link the long-term plans based on aggregated data with the medium-term plans (Eriksson 1987).

In recent years, some mathematical programming methods have been developed for the integration of short-term and long-term planning (Nelson & Brodie 1990, Nelson et al. 1991).

SilviPlan is a decision support system to evaluate short-term, site-specific silvicultural operating plans in terms of their potential impact on long-term, forest-level strategic objectives (Davis & Martell 1993). In SilviPlan strategic and tactical models are linked with each other and a GIS.

Hokans (1983) describes a simulation approach where cutting stands are marked and the feasibility of choice is checked against adjacency constraints and a forest-level LP-solution. Other approaches for adjacency constraints include mixed integer programming (Jones et al. 1991), aggregation heuristics (Torres-Rojo & Brodie 1990), simulated annealing (Lockwood & Moore 1993), column generating algorithms (Weintraub et al. 1994), map colouring theory (Nelson & Errico 1993), and mixed integer linear programming (Hof & Joyce 1993). Recently some methods for aggregated analysis have been developed based on spatial reduction factors and spatial aggregation rules (Daust & Nelson 1993). Spatial aggregation rules include, for example, the percentage of area-per-pass that can be harvested without violating adjacency constraints (Nelson & Errico 1993).

GISFORMAN (Baskent & Jordan 1991) is a GIS-based spatial wood supply simulation model that controls the geographic distribution of harvest in respect to wildlife habitat values and extraction economics using harvesting rules. Wildlife habitat values include maximum opening size and adjacency delay constraints and extraction economics includes volume concentration and operating road cost values.

In conclusion, an operational planning method should take both long-term and short-term decision criteria into account. A possibility is to include both the long- and short-term decision variables in the same decision model. When evaluating hundreds of thousands of decision variables LP is an effective method compared to simulation techniques. An operational planning method should provide both forest-level and stand-level (site-specific) solutions simultaneously. The models based on aggregated analysis areas (calculation units) seem to have problems when disaggregating forest-level solutions on-the-ground treatments. The capability of the software to deal with data sets without sampling or aggregation is necessary. The environmental constraints are usually defined as management constraints or targets concerning - sometimes overlapping - zones. An operational planning method should be able to deal with subsets of calculation units.

2.4 Timber sale and logging planning

A timber sale and logging plan provides a schedule for interdependent activities and is a prerequisite for logging cost estimates: it includes a detailed plan and layout for the roads, the extraction points where logs are to be loaded on trucks and the cutting units to be extracted to the extraction points (Peltonen & Väisänen 1972, Eskelinen & Peltonen 1982).

Timber marketing is a part of timber sale and logging planning. The main questions for the forest manager are: what is to be sold, where is the point of sale (standing, felled at stump, at roadside, or delivered) and what is the value of timber to be sold. The estimation of value may be based on the empirical or analytical method (Stenzel et al. 1985). The empirical method is based on the regional average stumpage prices which are adjusted to match the location, extraction distance, timber quality etc. In the analytical method the stumpage value is calculated as the residual after all costs of production have been subtracted from the selling price of the final product. The net revenues of logging are derived by extracting the logging costs from the price of timber. In practice logging costs are usually calculated separately for sub-operations (felling, conversion and extraction) which may have different relationships between inputs and outputs.

The logging costs vary depending on the chosen logging system, the season and conditions of logging. The logging costs of a particular logging system and season depend on timber sale and logging conditions such as average extraction distance of logging unit, average terrain class and total outturn as shown in figure 8.

In practice, the extraction costs are influenced by the extraction distance, the volume harvested per hectare and terrain difficulty. In figure 8a the relative costs (Valkonen 1993) are shown for sawn logs extracted from a fully-stocked stand on terrain class 1 (fig. 9). It should be noted that the costs for short (3 meters long) pulpwood would increase faster as a function of extraction distance, because the size of load is smaller resulting in more round-trips. In figure 8b the relative costs are shown for short pulpwood in different terrain classes when extraction distance is 350 m, the growing stock 500 stems per hectare, and the size of parcel 500 m3 (Lindroos et al. 1993). According to Valkonen (1993) extraction costs in terrain class 2 are 4 % greater than in class 1. In terrain class 4 (see fig. 12) the costs increase by 22 % and therefore the forests of terrain class 4 are usually set aside from timber production as technically restricted areas. In figure 8c the relative costs are shown as a function of the size of parcel for short pulpwood in terrain class 1 when extraction distance is 350 m and the growing stock 500 stems per hectare (Lindroos et al. 1993). According to Valkonen (1993) the increase of the size of parcel from 100 m3 to 1000 m3 would decrease total costs by 8 % due to declining costs in planning, measurement and supervision.

Clearly, the size, form, and location of treatment units should be considered in timber sale and logging planning. For example, on the one hand, extraction routes may have to avoid environmentally sensitive (fig. 10) or technically difficult (figs. 11, 12) areas resulting in higher costs but, on the other hand, extraction costs may decrease as a result of synchronisation in time and space. In terms of mathematical optimisation, the relationship between the inputs and outputs of extraction is non-linear and the sum of costs and returns of individual treatments is not equal to the total costs and returns for the combined treatments. Thus, both the linearity and additivity assumptions of linear programming are violated and the production programs cannot be used as such in annual timber sale logging planning. The forest manager has to adjust the production program so that treatments are synchronised in time and space.

According to Kilkki (1987) there is no need for sophisticated planning methods in short-term planning because "spatial short-term planning may be left to the local foresters to be made within the framework of the long-term plan". In practice, however, it is very difficult to prepare a short-term plan which simultaneously meets both the targets set in the long-term plan (allowable cut) and the short-term goals (e.g. environmental protection, cost minimisation) and constraints (e.g. available money, manpower, infrastructure). Either the market situation is ignored and a cutting budget followed or the cutting budget is ignored to follow the market. The long-term plan is commonly neglected in order to improve the efficiency of expensive machines. Such deviations may lead to losses of timber within the total unit and total planning period.

The long-term plan may be based on a simplified decision model, using inaccurate, uncertain and incomplete data or, alternatively, the decision environment may have changed since the preparation of the plan. It should therefore be possible to modify the targets of long-term plans on the basis of current information. As a result the demand for up-to-date accurate forest data has increased.

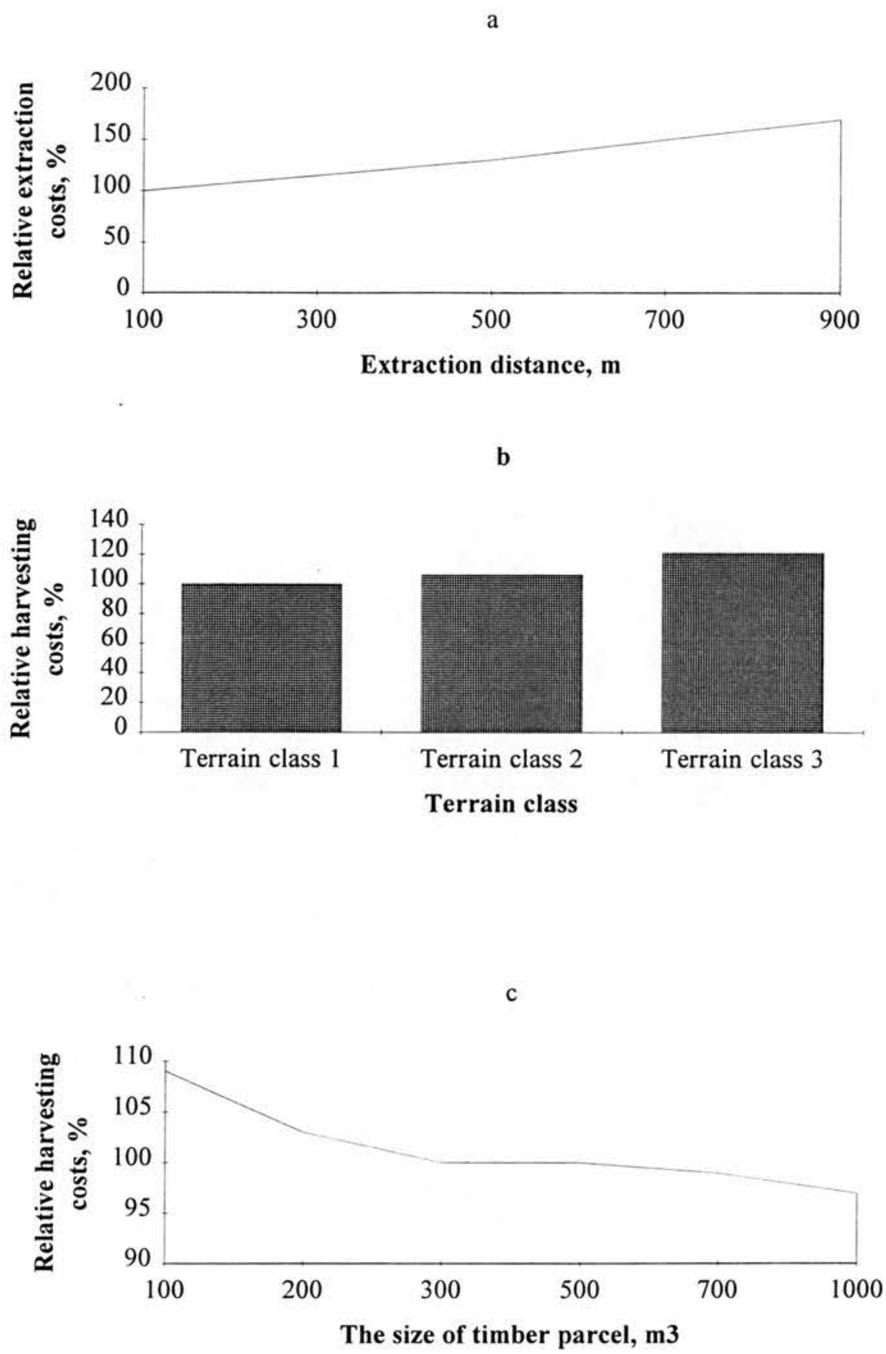

Figure 8. The effect of extraction distance (a), terrain class (b) and the size of timber parcel (c) on relative harvesting costs (Lindroos et al. 1993, Valkonen 1993).

Terrain class 1 is easy. The carrying capacity of soil has no effect on driving when loaded. The surface is fairly even. The slope is less than 15 % when driving unloaded and less than 10 % when driving loaded. Terrain class 2 is moderate. The carrying capacity of soil affects driving when loaded but there is no effect on load size. The surface obstacles may prohibit driving. The slope is less than 20 % when driving unloaded and less than 15 % when driving loaded. Terrain class 3 is difficult. The carrying capacity of soil has a cosiderable effect on driving when loaded. There are a lot of surface obstacles. The slope is less than 25 % when driving unloaded and less than 20 % when driving loaded.

Figure 9. In terrain class 1 the carrying capacity of soils, obstacles or slope do not restrict driving when loaded.

Figure 10. The access on sensitive soils and rocky areas is restricted during the summer months.

Figure 11. Access to and via some peatland areas is restricted around the year.

2.5 Pre-harvesting inventory

In Finland, there are several methods for measuring standing volume: ocular standwise inventory where the most important characteristics of each stand are estimated with the help of instruments such as the relascope (a prism used to measure variable-radius sample plots) and hypsometer (a prism used to measure tree length), and so-called relascope tables (Kuusela 1966); sampling where exact tree measurements are made over part of the compartment on circular or relascope sample plots, or on inventory strips; and total enumeration of trees where all the trees of a stand are measured. The final sale contract and salary payments have been traditionally based on either the measurement of logs or stacked piles of pulpwood at the roadside (fig. 13) before transportation to the mill, or on total enumeration of marked timber in pre-harvesting inventory. As a part of timber sale and logging planning, pre-harvesting inventory has been undertaken to collect data on the timber assortment volume to be harvested, as well as the quality and value of timber and logging conditions. When total enumeration has not been required, systematic sample plots have been used.

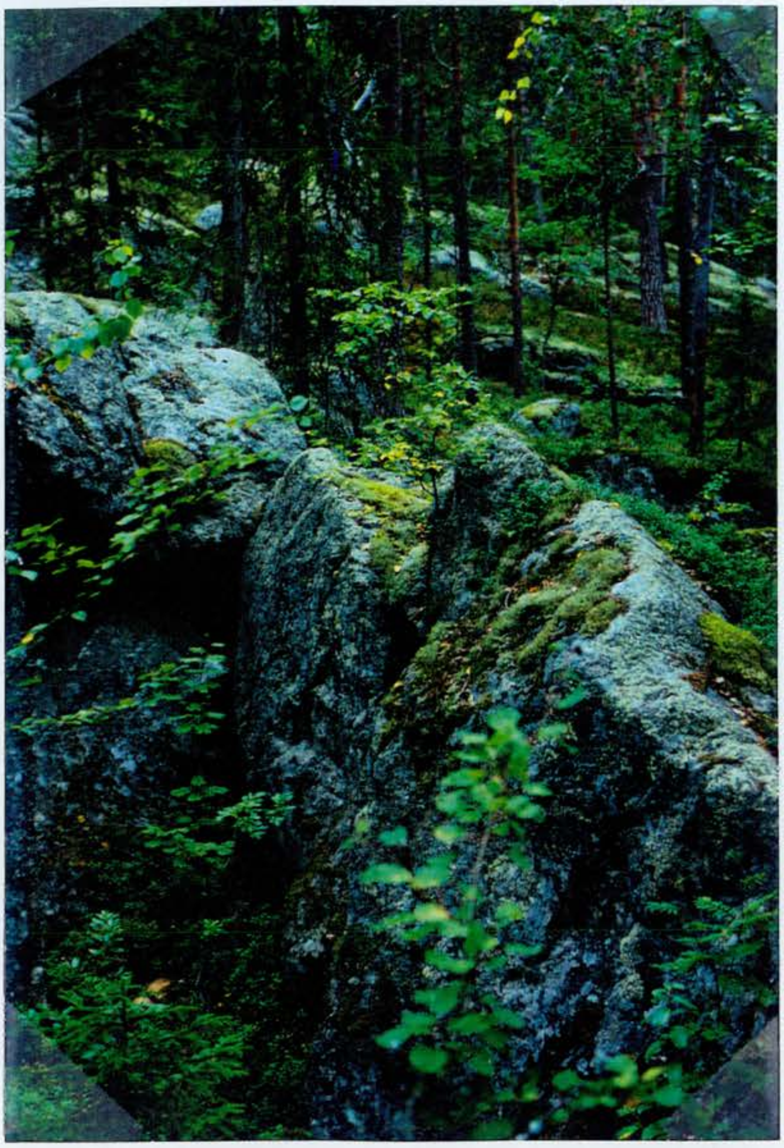

Figure 12. Stones and slope of terrain class 4 prohibit the access.

In the 1990's, however, forestry organisations have faced drastic changes. Forest workers have been trained to mark the extraction roads and trees themselves and the number of supervisor visits in the forest have been decreased. Currently, so called 'work measurement' (either the forest worker or the harvesting machine measures the trees) is accepted as the basis of contract payments and it has been assumed that the inventory data collected for long-term planning could be used also for timber sale and logging planning instead of separate pre-harvesting inventory.

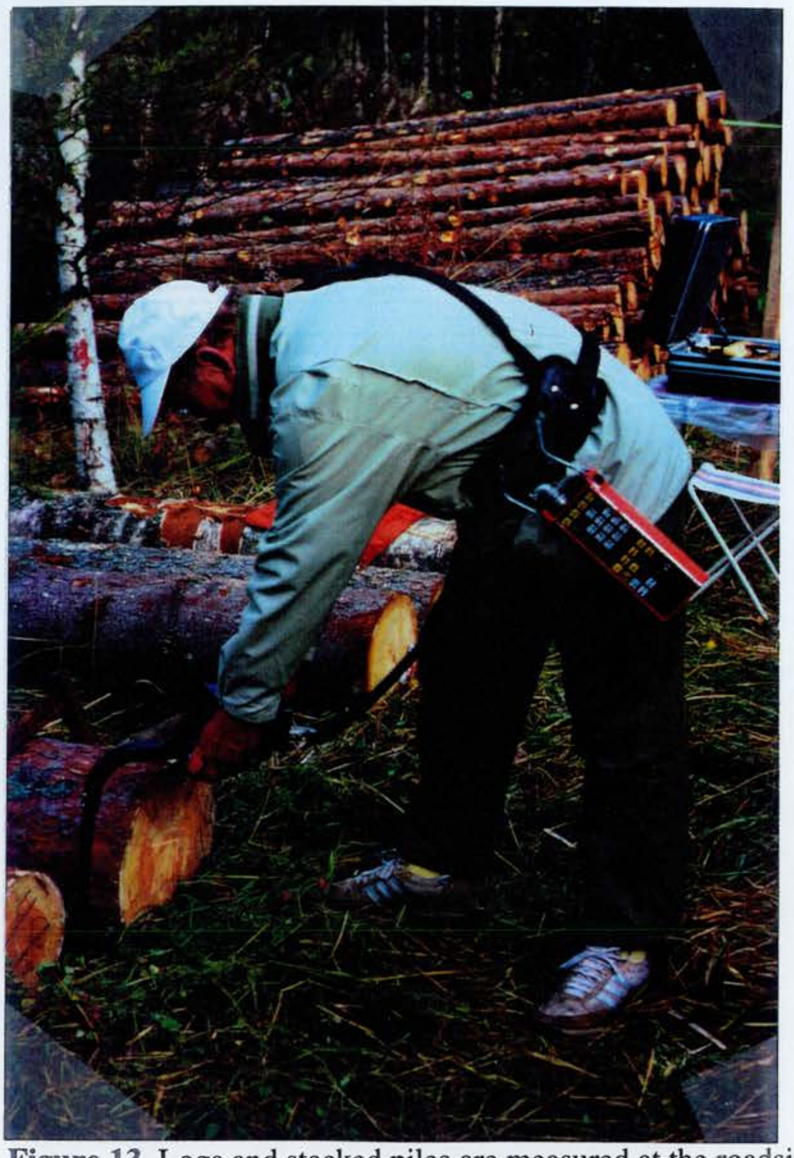

Figure 13. Logs and stacked piles are measured at the roadside

Most of the information needed is spatial. Usually the storage and presentation formats of spatial information are the same. Thus, the desired layout may set limits for the amount of details stored and vice versa: the contents of a map is fixed in advance when the map is constructed. A lot of important data is excluded and maps quickly become outdated. The integration of several maps is difficult and expensive because data are not recorded or stored in a standardised way. For example, the co-ordinate systems and map scales may vary and classifications can differ. Data are not shared and because of duplicated data there are additional problems due to inconsistencies between map versions. An additional problem may arise if the area of interest extends across adjacent map sheets because the edges do not necessarily match.

The development of data processing technology - such as computerised mapping and GIS - has made it possible to re-produce geographic data faster. For example, forest maps can be updated continuously whenever there are changes e.g. due to treatments; this approach for updating is referred to as transactions. In addition, it is easier to monitor the forests for inventory purposes periodically but more frequently using remote sensing and image processing techniques; this approach for updating is referred to as periodic update. Clearly, such technology has made it possible to use more current information. One purpose of using GIS is to provide stand-level information for making tactical and operational decisions. Some problems are solved via standardisation or via a GIS integration approach or via technology such as distributed database management systems (DDBMS).

The purpose of inventories for strategic planning is to collect data needed to estimate current and project future timber volume distributions by strategic planning stratum. There are, however, a few critical factors to consider. First, the standard error of timber volume estimates in standwise forest inventory data stored in corporate databases can be relatively large: estimates vary between 9-10 % (Nyyssönen 1955) to 17 % (Vuokila 1959) and 15-36 % (Laasasenaho and Päivinen 1986). If the reliability of data does not meet the requirements, an additional field survey is needed. In pre-harvesting inventory based on systematic sample plots the relative standard deviation of the total volume of the cutting unit has been estimated as 3-18 % (Lemmetty 1991). Second, the quality requirements of timber assortments may have changed during the planning period. Therefore original data should be used to calculate the timber assortment volume as and when required. Third, no information about logging conditions such as terrain and extraction distance, for example, is collected for long-term inventory. In reality, it would be cumbersome to find suitable combinations of treatment units in the field because of the need to identify sensitive areas and those suitable for specific logging equipment, for example, plus all the other cost and pricing factors which may affect the decision making e.g. the choice of sale method.

The productivity of standwise forest inventory (where aerial photographs are used, every stand visited) is approximately 40 hectares (i.e. 13 stands of an average size) per day. The total costs are 41 FIM (1989) per hectare of which two thirds are due to field work. Depending on the number of sample plots per hectare, costs of pre-harvesting inventory based on systematic sample vary between 0.35-0.40 FIM/m3

(Sunabacka 1985) to 0.20-0.70 FIM/m3 (Mäkelä 1990) and 0.20-1.00 FIM/m3 (Lemmetty 1991). If the number of measured sample plots were increased from 1-3 subjectively selected per stand used in standwise inventory to 5-14 systematic per stand, time spent would increase by approximately 1 hour per stand, assuming that the total time spent per sample plot (basal area, tally trees, sample trees) is 7 (Vuokila 1959) or 8 (Hämäläinen et al. 1990) minutes.

The choice of an inventory method depends on the purpose of the measurement, the required accuracy of the results and on the properties of the stand. The accuracy and precision of results depend on the variation in the inventory characteristics between the observations (i.e. heterogeneity of the stand) and on the inventory system e.g. the number of observations (Pukkala 1990). It is therefore essential to have an estimate of the confidence limits e.g. on timber volume so that a decision on the data acquisition method can be taken.

It is important to adjust the inventory system according to the stated requirement for the accuracy and precision and the amount of available time and funds. There are detailed formulae which can be used to optimise the choice of inventory method.

If the decision maker has unlimited resources available he or she may define the maximum acceptable error for any given parameter, at a stated level of probability. The number of observations can then be calculated.

According to economic theory we should continue to collect information until the increasing marginal cost of additional information is equal to the declining marginal benefit. The optimal accuracy for the description of an object system is achieved when the additional cost of getting more information is the same as the utility achieved by getting more accurate information. In strategic planning, the marginal value of inventory information about a stratum is the difference in the value of the objective function caused by a different set of decisions resulting from this information. Since most inventories are carried out under budget constraints, the marginal cost of additional information about a stratum is composed of the direct sampling cost plus the opportunity cost of not taking additional samples from the stratum with the next highest value of information.

Erroneous data may cause erroneous harvest decisions and an expected decrease in, say, net present value of future income. The expected inoptimality losses from erroneous harvest decisions are assumed to decrease after an inventory. In "cost-plus-loss analysis" the cost of performing the inventory and the expected loss due to future inoptimal decisions caused by erroneous data are estimated (Ståhl et al. 1994). Inventories are profitable when the values that can be lost by erroneous data are larger than the inventory costs. In other words, the inventory cost must not be higher than the expected decrease in losses.

Ståhl et al. (1994) present a method to determine optimal forest stand data acquisition policies The method suggest that inventory decisions could be treated simultaneously as silvicultural decisions and they should be made using probability distributions of values in the calculations instead of point estimates. Their numerical results showed that the profitability of inventories depends in a large extent on factors such as interest rate, stumpage value, compartment size, stand age, and prior distribution of tree stand volume. For example, the values that can be lost by erroneous decisions are much higher in a large compartment but neither inventory costs nor precision in estimated mean volume will increase very much with increasing compartment size. Different stands of the same planning unit may require different intensities of survey depending on this significance level or the degree of heterogeneity.

3. GEOGRAPHICAL INFORMATION SYSTEMS (GIS) IN FOREST PLANNING

The aim of this chapter is to outline the role of Geographical Information Systems (GIS) as a part of an integrated information system. GIS is introduced and thereafter the principles and some examples of spatial decision support systems in forest planning are presented.

3.1 Geographical Information Systems (GIS)

The aim of this section is to introduce Geographical Information Systems (GIS). First spatial data models are presented and compared. Then GIS is defined and different types of GIS introduced. The role of database management systems is described in more detail and thereafter the principles of GIS and database integration introduced. In addition, some GIS analysis methods are presented and, finally, the choice of GIS explained.

3.1.1 Spatial data models

The development of remote sensing technology for the purposes of inventory, updating and monitoring has generated the requirement for an integrated system to combine data from different sources (Campbell 1987, Goodenough 1988, Zhou 1988).

There are two main approaches to represent the spatial component of geographic information. In a vector model the features are represented by the points and lines that define their boundaries. In a raster model the space is regularly subdivided into cells (Peuquet 1984).

The vector model is complex but has the benefit of a compact and efficient data structure for the representation of features and usually also for the representation of their spatial relationships (topology). The spatial entities also correspond more closely to the real world entities they represent and the vector data model is therefore suitable for the precise positioning of features. The raster model has a simple but less compact data structure: representation of topology is difficult but the processing of remote sensing data and the overlays are easy (Peuquet 1984). An enhancement to the efficiency of data management is provided by quadtrees which utilize a tree structure to organize space by its regular decomposition (Gahegan 1989, Ibbs & Stevens 1988).

3.1.2 Definition of GIS

A Geographical Information System (GIS) is a computer-based system for the capture, storage, retrieval, analysis, and display of spatial data (Burrough 1986, Maguire et al. 1991). The main components of a GIS are data input, data management, data manipulation and analysis, and output. A GIS is more than a cartographic system, a Computer Aided Design (CAD) or a Database Management System (DBMS) (Cowen 1988): it can also be used to manage, analyse and output the data in a more efficient and meaningful way than manual techniques, spatial relationships being more interesting than the character of the site itself.

There are two basic types of map information: spatial information and descriptive (attribute) information. Spatial information describes the shape of geographic features and their spatial relationships to other features. The geographic feature types are points, lines (arcs), and areas. The spatial relationships between map features are not explicitly represented on the traditional paper map. The map reader must derive the relationships from the map graphics. Maps should therefore represent feature locations and their characteristics so that the interpretation can be made easily. The graphic symbols can be used to represent the geographic features with their associated attributes.

In a GIS the two types of data are linked together and the spatial relationships between map features are maintained so that the information in the attribute database can be accessed through the map or the map can be created based on the information in the attribute database. Map features are logically organised into sets of layers (i.e. themes of information).

There are two different perceptions of GIS. Some understand it to be a specific commercial software package, others an information system tailored for a specific purpose or institution. Accordingly there are different approaches to categorising GIS (Cowen 1988): a process-oriented approach where GIS is an information system consisting of several subsystems, an application approach where GIS is categorised according to the type of information being handled (urban GIS, forestry GIS, for example), a toolbox approach where a system incorporates a set of procedures and algorithms, and a database approach where the integration with database management systems is emphasised.

There are four main types of GIS software: a file processing approach, a hybrid system composed of a spatial software toolbox and a non-spatial database management system, spatial processing extensions sitting on a database management system or a fully integrated spatial and non-spatial database management system (Aronoff 1989).

3.1.3 Database management systems

The early database systems were based on file processing, i.e. separate computer programs were developed for each application to access one or more computer files. This approach has two disadvantages. First, if the data files are modified, the application programs have to be modified, too. Second, if there are several applications using (especially modifying) the same files, there should be a mechanism which controls the integrity of the database.

According to Aronoff (1989) a database management system (DBMS) is comprised of a set of programs that manipulate and maintain the data in a database. An example of a database management system is Ingres (Ingres Corporation 1991, Malamud 1989). There are three major benefits of a database management system approach. First, it provides a common interface between application programs and the database. Thus, the application programs are independent of the physical form of database. Second, it controls all the interactions between application programs and the database. Therefore, data can be shared in a controlled way and the integrity of the database is maintained. Third, it offers special services such as application development tools (e.g. 4-GL language) and a direct user interface (e.g. via a query language, user views) to tailor the way the data is presented. Thus, it is easy to implement new applications or allow non-programmers to search the database interactively. (Date 1990, Oxborrow 1986, Ullman 1988).

According to Aronoff (1989) the conceptual organisation of a database is termed the data model. There are three classic data models: the hierarchical, the network, and the relational, now complemented by object-oriented DBMS. The relational model is simple to understand and flexible to use. The data are stored as a group of related items stored together in records. Records are grouped together in two-dimensional tables. Two or more tables can be linked (joined) together using any attribute they have in common. Thus, there is no need to define any explicit relationships between tables in advance. The user can construct a query using some non-procedural query language such as an English-like Structured Query Language (SQL) (Date 1990, Oxborrow 1986).

SQL includes commands for query (retrieving data from the database), data manipulation (inserting, updating and deleting data in the database), data definition (adding new tables to the database), and data control (preventing access to private data in the database). The main advantages of SQL are: a simple data structure ("table"), powerful operations (e.g. relational join), reduced training costs (English-like language) and application portability (e.g. applications for minicomputer end-users can be developed on PC).

Interactive SQL is non-procedural (i.e. most statements are executed independently of the preceding or following statements) and there are several restrictions for "built-in functions" (e.g. SUM). For example, the constructs such as "loops" (e.g. find all the trees for a given stand and return to read next stand) or "if/then" pairs (e.g. different functions for different tree species) have to be implemented using high-level programming languages such as FORTRAN (Nuutinen 1991). The following example shows how SQL statements (used to retrieve data) are combined (embedded) within a FORTRAN module.

```
EXEC SQL DECLARE TREE_CURSOR CURSOR FOR
     *  SELECT researcharea, farm, stand, substand,
     *  arckey,tree,species, origin, numberperha, baperha,
     *  meand13, mind13, maxd13, meanheight, bioage, d13age
     *    FROM TREES T
     *    WHERE T.arckey = :ARCKEY
     *    ORDER BY T.arckey, T.tree
EXEC SQL OPEN TREE_CURSOR
EXEC SQL FETCH TREE_CURSOR INTO :t_researcharea,
     *    :t_farm, :t_stand, :t_substand, :t_arckey, t_tree,
     *    :t_species, :t_origin, :t_numberperha, :t_baperha,
     *    :t_meand13, :t_mind13, :t_maxd13, :t_meanheight,
     *    :t_bioage, :t_d13age
SPECIES     = t_species
DIAMETER    = t_meand13
IF (SPECIES.EQ.1) VOLUME=FUNCTION1(DIAMETER)
IF (SPECIES.EQ.2) VOLUME=FUNCTION2(DIAMETER)
```

3.1.4 GIS and database integration

The relational data model is most widely used for management of non-spatial data in a hybrid GIS (Morehouse 1985, 1989a). In the hybrid (toolbox) approach, specialised GIS-software functions as a query processor. An example is ARC/INFO (ESRI 1989, Dangermond 1986, Morehouse 1985, 1989a) where the GIS provides software tools for spatial management and the basic unit of data management is a coverage. In ARC/INFO powerful tools to create complex relationships among and between the generic objects of a more simply defined model are emphasised (Morehouse 1989b).

A cartographic layer in ARC/INFO is called a coverage. A coverage consists of topologically linked geographic features and their associated descriptive data. Topology is a mathematical procedure for explicitly defining spatial relationships e.g. identifying adjacent polygons. There are three basic layer (coverage) types in ARC/INFO: polygons, lines, and points. In addition, there are two variations: network (polygons and lines) and link (lines and points) coverages.

A polygon coverage may contain - in addition to polygon boundaries stored as arcs and nodes - so-called label points which can serve to identify each polygon in a coverage. The label point is the link between the polygon and its associated attributes (fig. 14). Tics are registration points representing the location of known points. Tics can be used e.g. to register layers to each other and to adjacent map sheets.

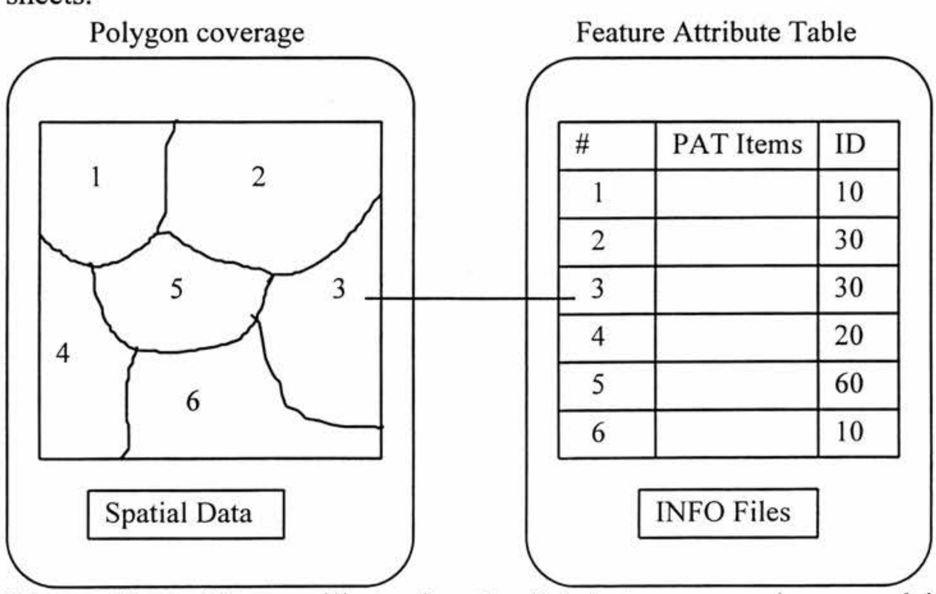

Figure 14. A diagram illustrating the link between a polygon and its associated attributes (ESRI 1991).

In ARC/INFO descriptive attributes associated with map features are stored in a data file known as a feature attribute table. In a feature attribute table a record stores all the information about one occurrence of a feature (point, arc or polygon) and an item stores one type of information for all features in the database. A feature attribute table can be an INFO data file or an Relational DBMS (RDBMS) table. In an RDBMS a record is referred to as row and an item as a column.

The connection between the spatial data and the attribute data is based on a one-to-one relationship between features on the map and records in the feature attribute table. The link is maintained through the unique identifier assigned to each feature. The identifier is physically stored in two places: in the table containing the x,y coordinate pairs and in the corresponding record in the feature attribute table. ARC/INFO automatically creates and maintains this connection and once this connection has been established, the information in the attribute database can be accessed through the map or the map can be created based on the information in the attribute database.

ARC/INFO includes a database integrator module, a mechanism to interface a number of databases and to access database tables from GIS software (ESRI 1989). There are, however, limitations on what type of relationships these interfaces can handle. Figure 15 illustrates the integration process. Using an example from forestry, if there is an experiment inside an inventory stand, an "artificial stand" is delineated around the experiment (real world in figure 15). Conceptually each stand may contain one or more experiment stands. In GIS the boundary lines of experiment stands and forest stands are delineated in separate coverages. The attributes related to forest stands and experiment stands are stored in a separate database (data dictionary in figure 15). GIS applications based on GIS tools work on cartographic data and DBMS applications sitting on DBMS deal with attribute (tabular) data. The Database Integrator (fig. 16) can be used to access the attribute database from a GIS (system architecture) based on a common attribute (key).

For example, a relate **INVENTORY** to link stands attributes stored in an Ingres table to stand polygons stored on an ARC/INFO coverage is based on a coverage item **INGKEY** and a table column **ARCKEY**.

The relate is defined as follows:

```
Arc: RELATE ADD
Relation name: INVENTORY
Table identifier: INVE
Database name: INGRES
INFO Item: INGKEY
Relate column: ARCKEY
Relate Type: FIRST
```

Thereafter those polygons which belong to landuse class 5 are selected from an Ingres database and shaded on the map using the following ARC/INFO commands:

```
Arc: RESELECT FARMSTANDS POLYS ^INVENTORY WHERE LANDUSE = 5
Arc: POLYGONSHADE FARMSTANDS 3
```

In integrated GIS the query processors sits on top of the database and both the coordinate and attribute data are stored in tables. An example is GEOVIEW (Waugh & Healey 1987) based on a relational database management system (RDBMS). The benefits of RDBMS as the basis of spatial extensions are based on the powerful and standardised query language facilities. There are, however, some major problems. First, it seems to be difficult to store the spatial data and maintain topology efficiently in a relational database. Second, complex spatial analysis functions are not easily implemented in a query language. Restrictions of SQL include limited types of GIS-functions which can be performed based on relational join, sub-queries, grouping functions and query combination operators such as boundary, overlap, intersection, contain, union, and difference. Third, data records in a GIS are interrelated and it is difficult to ensure the integrity of the multiple records in multiple files. Transactions are thus more difficult.

There are some possibilities to enhance SQL using a pre-processor which converts spatial operators into standard SQL or into a component that can be used to retrieve data (Herring et al. 1988, Ingram & Phillips 1987). In TIGRIS both spatial and attribute data are stored in a single object-oriented database (Herring 1987, 1989).

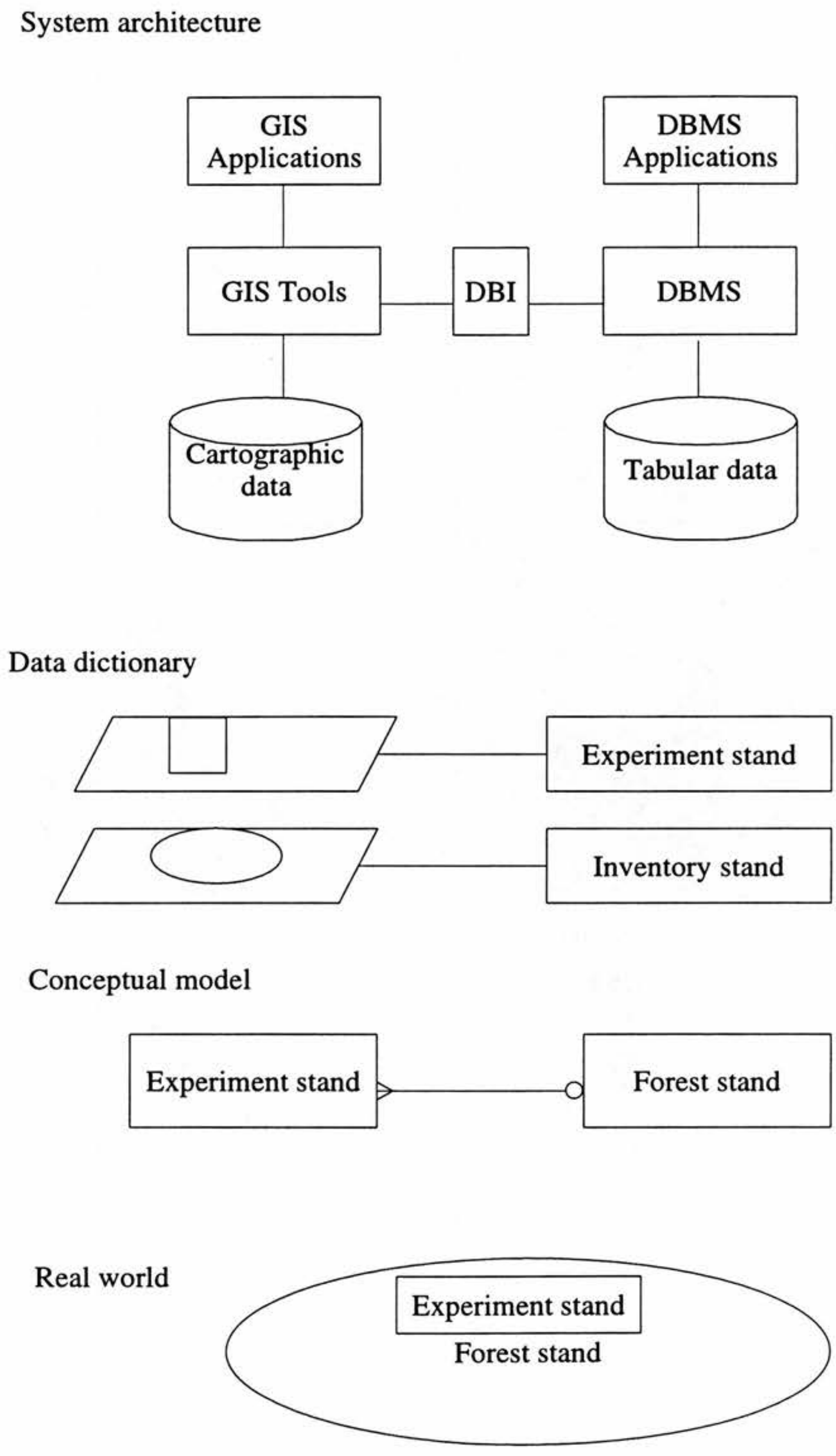

Figure 15. The principle of database integration.

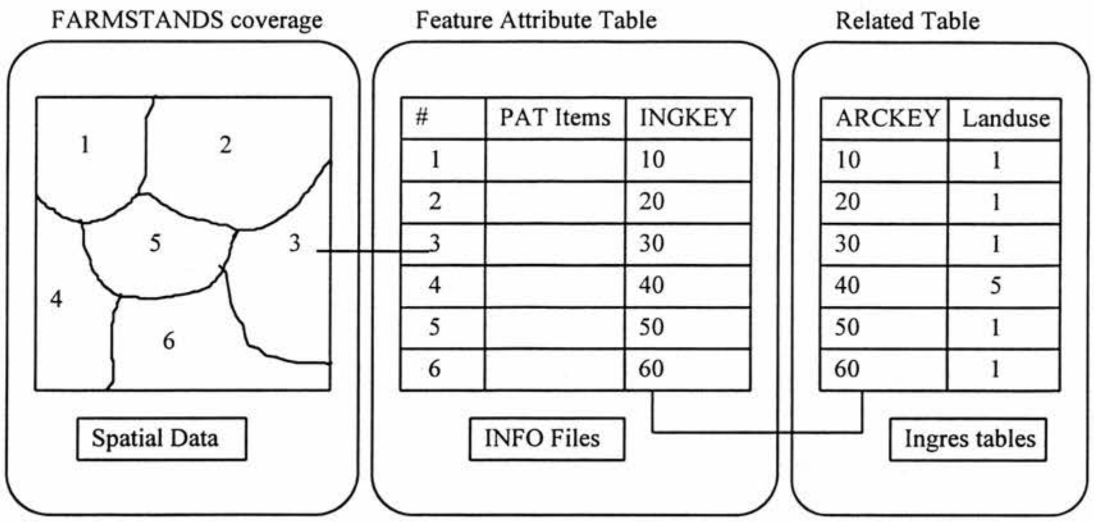

Figure 16. A diagram illustrating database integration.

3.1.5 GIS analysis methods

Map algebra (Berry 1987) or cartographic modelling (Tomlin 1990) treat maps as variables and they can be used to characterise physical and economic factors which affect timber accessibility. They involve the use of basic GIS manipulation functions in a logical sequence to solve complex spatial problems. For example, in a map of maximum potential stumpage each grid cell has a value representing the price-at-the-mill for all the products on a grid cell minus the costs of harvesting the products on that grid cell (Herrington & Koten 1988).

GIS analysis include overlays, neighbourhood, connectivity, proximity, network and terrain analysis (Aronoff 1989).

Overlays are divided into arithmetic and logical overlays of two or more layers. Neighbourhood operations are used to evaluate characteristics of the area surrounding a specified location. For example, topographic neighbourhood functions are used to calculate terrain parameters such as slope and aspect. Interpolation can be used to predict unknown values using the known values at neighbouring locations.

Connectivity function accumulates values over the area being traversed. Contiguity function can be used to measure the size of the contiguous area or the shortest straight-line distance across the area.

Proximity is a measure of distance between features. The basic parameters are: the target location, a unit of measure, a function to calculate proximity, and the area to be analyzed. For example, buffer zone generation is one type of proximity analysis.

There are three main types of network analyses: prediction of network loading, route optimization, and resource allocation.

The development of digital elevation models (DEM) and digital terrain models (DTM) and 3-D graphics has provided more advanced tools for both terrain analysis and visualisation (Burrough 1986, Raper 1989). Digital elevation models (DEM) or digital terrain models (DTM) refer to digital elevation data (a set of elevation measurements for locations distributed over the land surface) and its derivatives used to analyse the topography i.e. the surface features (Aronoff 1989). Digital representation of topography may be in the form of gridded matrices of elevations, series of parallel profiles, digitised contours, or triangulated networks called TINs (Carter 1988). Gridded matrices are inefficient when areas have low variation in relief. Contours, profiles and TINs take into account the finer resolution (Carter 1988, Kumler 1990). Conversions between different formats are possible. Sometimes special filtering is needed for example when generalising contours (Chen 1987).

DEMs can be used for neighbourhood analysis to calculate slope and aspect (Jenson & Dominque 1988). The accuracy and resolution of DEMs affect the analysis. The effect of DEM resolution is most apparent along topographic discontinuities (Chang & Tsai 1989). DEMs should be supplemented with additional elevation points along ridges and valleys and with additional terrain information such as shorelines and other planimetric features (Fahsi et al. 1990).

3.1.6 The choice of a GIS

For this study ARC/INFO was chosen because of some important benefits. First, the spatial toolbox approach has, for planning purposes, several benefits over the systems which are based on a spatial DBMS approach. The spatial analysis toolbox of

ARC/INFO can be used to overlay, buffer, and perform network and terrain analyses needed for harvesting planning. Second, ARC/INFO integrates three technologies: vector-based and raster-based mapping, and relational database management. Third, ARC/INFO provides data exchange routines essential for the operational linkage between separate databases and registers such as the stand database, the experiment register and the register for endangered species. Fourth, ARC/INFO is being used in a wide variety of applications. ARC/INFO is thus well documented and supported. Fifth, the software looks and operates nearly the same on all supported platforms. Also, the programming language AML is designed to support machine-independency of applications.

3.2 Spatial decision support in forest planning

According to new laws, regulations and policies (CEC 1992), planned activities should be evaluated before implementation. An operational planning system should contain methods to produce and describe the feasible management alternatives, and methods to evaluate these alternatives in respect of the decision criteria (utility).

There are several steps in decision analysis as shown in figure 17. First, goal analysis is used to identify the decision elements of the decision-maker and decompose them into goals, objectives, preferences, and attributes. The result of goal analysis is the decision model.

Second, the object system is described so that the elements of utility can be assessed or derived. The first task is to acquire and present all the information needed for the generation of management alternatives (that is production programs for the whole forest). Treatment stands are created based on forest stands and sites of specific interest.

Third, possible decision alternatives are identified and generated to assess the consequences of alternatives. Steps include preparation of input data, simulation, and optimisation to search for an efficient program. The GIS can be used to provide additional rules for feasibility and to illustrate the consequences.

Fourth, management alternatives are compared and evaluated with the aim of finding the alternative that best meets the stated objectives. Different management alternatives are evaluated by studying their consequences: each alternative should provide the input and output variables needed in the decision making. Assumptions made in problem formulation should be evaluated, too. Decision-makers can seldom explicitly express their risk management strategy but the preferences shown in the evaluation of plans may reflect their attitude toward risk and uncertainty. For example, they may reject plans which are based on the maximisation of the utility and instead prefer the management alternative which "maximises future options". A typical objective of forest management is to save for the future by maximising the final value of forest.

Fifth, the plan is implemented and followed-up. The task of follow-up is to provide feedback for the planning process. The information flow between decision support and actual implementation system components should be checked for errors or the lack of data.

Simulation models can be used to compute the consequences of alternative decisions in order to check their feasibility. Traditionally, the development of natural resources (e.g. forest growth) is represented as yield tables. Tables include a restricted number of regimes and the forecasts will be accurate only if the objects are managed exactly in accordance with the tables. A more flexible model is needed, which can predict the development of more than one variable at a time, for objects in different initial states and under different regimes.

There is a need to support the planning process via an easy-to-use information system (Kaila and Saarenmaa 1990). A decision support system (DSS) is a computer software system used to generate a series of feasible alternatives (Turban 1988). A DSS offers a framework for combining analytical models and multisource data under an interactive interface (fig. 18). A DSS may be able to deal with poorly defined, semi-structured or unstructured problems. It can also provide feedback on the consequences of management alternatives in graphic, tabular and map formats but still relies on human guidance and judgement which is given via a graphical user interface (GUI). A DSS focuses on a limited problem domain, utilises a variety of data types, is adaptable to the decision-maker's style of problem solving and can easily be modified to include new capabilities. A DSS is flexible, easily adapted to the evolving needs of the user and helps to achieve effectiveness rather than efficiency.

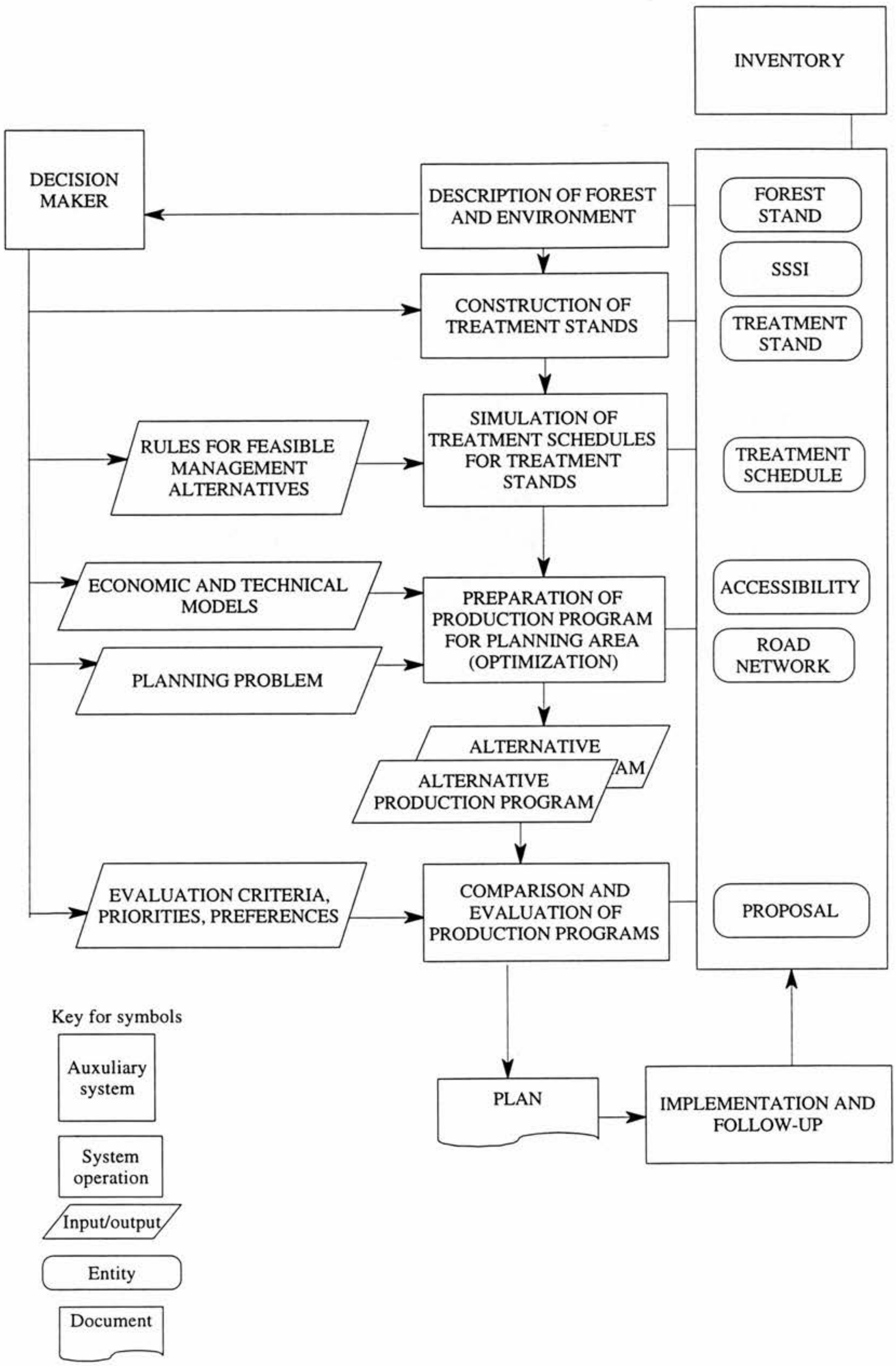

Figure 17. The procedure of decision analysis.

Another benefit is improved support for decision making via data integration, reporting, decision models and interactive 'what if'-analyses to compare alternatives; furthermore a DSS is appropriate for environmental data which typically come in large quantitities, are distributed in time and space, and require fast data access. The database management system has a central role in an environmental DSS: it provides a central and well organised interface for stand-alone systems and an interface or common blackboard between the different components (Guariso and Werthner 1989). The benefits of using a commercial database management system as a component of a DSS are that it provides a constant view of central storage; and takes care of redundancy, actuality, integrity, consistency, and security of data (see section 3.1.3).

A spatial decision support system (SDSS) is explicitly designed to support the analysis of complex spatial problems (Armstrong and Densham 1990). An SDSS provides a framework for integrating DBMSs with analytical models, graphical display, tabular reporting capabilities and the expert knowledge of the decision maker. The benefit of GIS is its ability to utilise different data sources together with spatial analysis and visualisation methods.

Traditionally, GIS in forestry has been used for mapping or monitoring to provide an up-to-date description of the existing site conditions. In future it should be used as a 'planner's assistant' (Gahegan & Roberts 1988, Smith T. et al. 1987).

A few attempts to integrate forest planning and geographic information systems have been made in recent years (Bobbe 1987, Bulger & Hunt 1991, Chambers 1986, Covington et al. 1988, Baskent and Jordan 1991, Reisinger et al. 1990, Davis & Martell 1993, Church & Barber 1992). The systems integrate different decision models, replicate manual processes and are flexible for what-if analysis. A DSS makes it possible to incorporate for example the changes in price and costs and re-run the analysis.

There are a few examples of models to aid planning. HPDSS, developed by Reisinger and Davis (1987), identifies sites where mechanised harvesting systems can operate productively and with minimum disturbance to the environment. Hepner et al. (1988) have integrated an expert system and a GIS as a decision support system for cross-country movement. The system is used to specify the mobility limitations and predict speed as a function of terrain factors such as soil conditions, vegetation and slope. Thieme et al. (1987) describe a system that determines barriers and suitable areas to automate road planning.

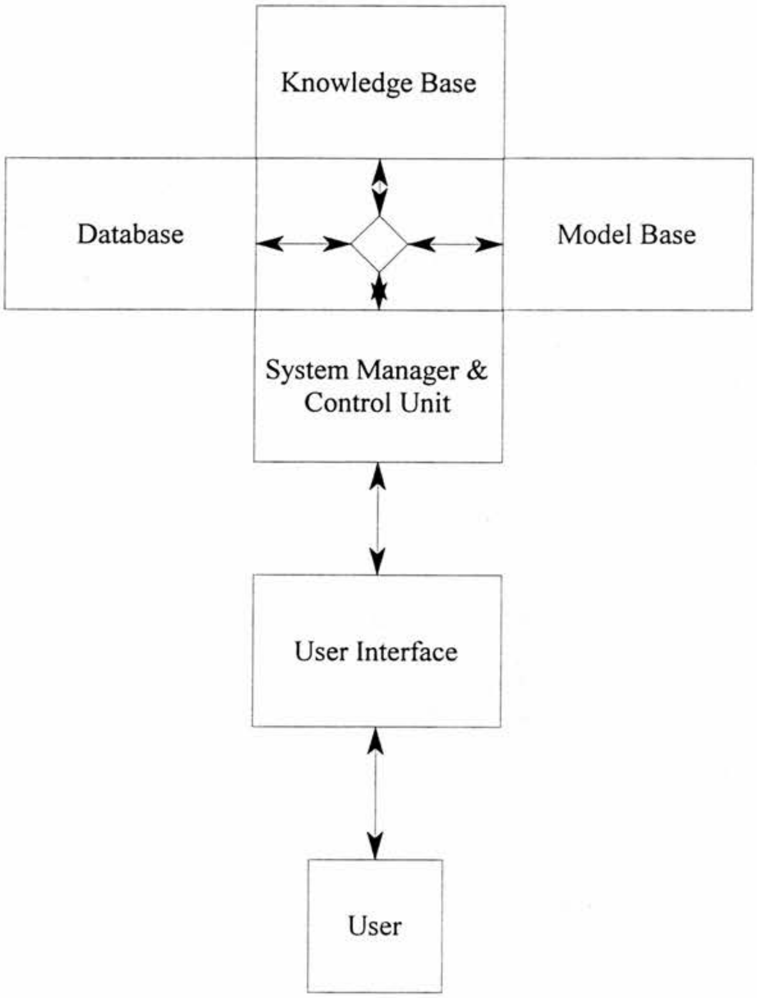

Figure 18. The proposed architecture of DSS according to Guariso and Werthner (1989).

Most applications are aimed at disaggregating a forest-level plan to the stand level (Covington et al. 1988, Davis & Martell 1993, Church & Barber 1992) or constructing an environmental impact statement for harvesting alternatives. This has been undertaken, for example, in the USDA National Forests (Bobbe 1987, Chambers 1986). Disaggregation or opportunity area analysis models bridge the gap between FORPLAN forest-wide allocations and site-specific resource management alternatives developed at the ranger district level. TEAMS (Covington et al. 1988) is an interactive, integrated decision support system for multiresource project analysis used to disaggregate the first decade of a FORPLAN solution. It is suitable for complex problems and integration of existing resource data. The components are a relational database management system, a GIS, a simulation system, an LP-package, a graphics package, a user-interface and other interface tools linking different subsystems. GISFORMAN is used to take into account spatial constraints in harvesting scheduling (Baskent & Jordan 1991). MONSU (Pukkala & Kangas 1993, Nuutinen & Pukkala 1992, Pukkala et al. 1995) is a DSS for multiple-use planning especially for landscape and recreation planning. These systems have not been able to incorporate site-specific constraints into the optimization process, whereas a prototype of forest management systems such as ARCFOREST (Leggat & Buckley 1991) can serve as a platform for the development of new DSS tools and techniques.

An advanced planning tool such as the MELA-simulator - based on stands as calculation units and supporting treewise simulation - linked with a GIS and JLP software as an operational information system would support complex site-specific analysis effectively. An operational information system, however, has to be redesigned with new technology (Bulger & Hunt 1991). For the operational information system, integration of system components is needed

- between system modules
- between man and machine, and
- between the planning system and auxiliary information systems.

In addition to the systems integration problem, the future issues related to integrated information systems include the communication of information quality to the user and and cost-benefit analysis of system implementation (Frank et al. 1991) .

The principles for the design and construction of an integrated information system are presented and the components related to the value of information are discussed in chapter 4.

4. INFORMATION SYSTEMS DESIGN FOR DECISION SUPPORT SYSTEM (DSS)

The aim of this chapter is to present the principles for the design and construction of an integrated information system and introduce the components related to the value of information. First, the systems integration problem is introduced. Second, the principles of software engineering are described. Then the issues related to the applicability of a planning system are presented. Thereafter the value of spatial information is discussed and, finally, the aim of the pilot study is presented.

4.1 The systems integration problem

The aim of this section is to introduce the systems integration problem. First, the main types of integrated information systems are presented. Second, the systems integration problem and the concept of system architecture is defined. An ideal structure for the architecture introduced together with some approaches for the module integration.

Abel et al. (1994) classify integrated systems based on a limited combination of the transformation, constructor and accessor linkage operations. There are two main types of integrated systems: the 'loose' type corresponds to the presence of transformation and accessor components and the 'tight' to all transformation, accessor and constructs. Two-component systems can be based on 'peer-to-peer architecture' where only transformation operations are present or embedded systems configuration which is defined by the availability of accessor operations. In an embedded system configuration one component (the master) has the capability to invoke actions by another (the agent) within a command stream expressed in terms of the constructs of the master's external schema. In many-component systems the use of a common agent by two or more masters for a specific function can provide particular benefits in fusion and usability. The common agent can be a database manager accessed by two different master systems or a user-interface integrating two different system components. (Abel et al. 1994).

The coupling of different systems is here referred to as the systems integration problem. There may exist incompatibilities between systems in terms of external, conceptual and internal schemas. The external schema describes the services provided by the component to another component (Abel et al. 1994). The differences in external schemas include, for example, differences in formats and protocols for commands and data transfer. Data sets can be copied from one component to another or data can be stored in a store directly accessible by several components or through shared memory. A transformation which alters the data values to conform to a different schema is referred to as a data translation (Pascoe & Penny 1995). A transformation which alters the location of the data set is referred to as a data movement (Pascoe & Penny 1995).

The conceptual schema describes the component designers' conceptualisation of the structures of the objects stored or manipulated, the primitive operations and the object-object and object-operation relationships and dependencies (Abel et al. 1994). The internal schema essentially describes the implementation of the conceptual schema using the constructs available within a particular hardware and software environment (Abel et al. 1994).

The implementation should pay attention to the architecture of an information system. The system architecture defines the assignment of functions to components and the command and data interfaces between components. An ideal structure for an information system is an integrated corporate database consisting of an RDBMS engine, interface programs, application programs and five groups of clients: the database client that receives database service requests and parses into SQL, model clients, spatial analysers, expert systems, document retrieval systems, and user interface i.e. the control centre of an information system (Loh & Saarenmaa 1992). All components should communicate via the windows environment and outside communication is organised through the corporate database and a user interface shell (fig. 19).

There are several approaches for module integration. A slave program can be integrated into a master program written in a high level language. The benefit of integration into a high level language program is the simplicity of implementation when the data flow is predefined. The problems arise when ill-structured problems are processed sequentially. A shell program such as an expert system or a GIS package can be integrated using additional procedures in a macro language. The benefit of integration into a shell program is that the hooks or programming interfaces are usually well developed and documented. The problems arise when the hooks are not general enough and the extensions therefore are limited. A main control program and some resident and suspended programs can be integrated into an operating system. The benefit of such integration is the familiar tools it offers to users (Loh & Saarenmaa 1992).

In chapter 3, a framework for a DSS needed for forest planning was presented. In this study, the components of the integrated information system include a relational database, a GIS, a simulator, and an optimization package. The database and GIS coverages are constructed by copying data sets from existing data files (data movement). In addition, data translations are needed to alter the data values to conform to a different schema defined for the corporate database. The resultant database can be accessed from the GIS and other application programs which take care of the needed data translations. The communication between application programs (modules) is arranged via data files. Application programs and procedures written in FORTRAN, SQL and AML are used to control the communication.

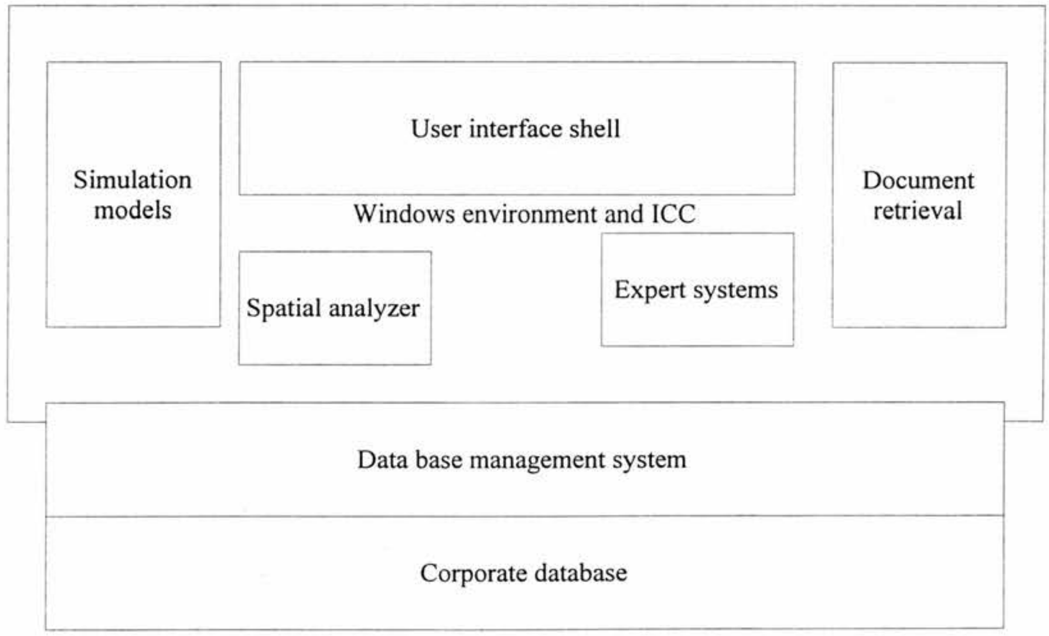

Figure 19. An integrated information system according to Loh and Saarenmaa (1992).

4.2 Systems analysis and design

In software engineering, a methodology is a collection of methods based on a common philosophy that fit together into the so called 'life cycle' of a project (Lamb 1988). The stages of a life cycle are strategic planning and analysis; logical and physical design of the database (data model) and applications; system implementation (programming, documentation) and maintenance.

The CASE (Computer-aided software engineering) philosophy involves using a computer to integrate corporate planning (upper CASE), systems analysis and systems design (middle CASE), and systems development (lower CASE) into one system. CASE is a combination of software tools used to automate the process and structured software development methodologies.

The purpose of systems analysis is to analyse how a company actually functions (i.e. what are the activities) and what information services are related to those functions. Usually current problems due to redundancy or out-of-date data or heterogeneous systems are described. In addition, both the objectives of an agency (statement of mission and business plan of organisation) and the objectives of a project (aim, task, quality requirements such as accuracy, resources such as time, staff, money) are defined. The planning methodology usually provides a structure, referred to as a corporate model, into which planning attributes such as the goals, objectives, responsibilities, resources, and problems can be entered. The model consists of diagrams and dictionary entries.

The systems analysis is followed by the systems design phase where the solutions are presented. Systems design includes logical and physical design of both database and application. Logical design consists of a data model and work flow diagrams based on the analysis of data survey (what products are required and how often, what input data are available, and who is responsible) and an inventory of existing systems (data linkages and compatibility, system interfaces). The user profiles including tasks, responsibilities, co-operation, and related communication, data and product (media, format, contents) requirements should be defined. The resulting work loads (the number of simultaneous users, data volumes, response times) should be estimated. In addition, data sources, hardware and software and the interface with existing information systems should be evaluated.

Entity Relationship (ER)- and work flow diagrams can be used, for example, to analyse existing data modules and management of transactional updates to multiple database management systems (Armstrong & Densham 1990, Kowalewski &

Schmidt 1989). An example is shown in figure 20. The Entity Relationship Diagram (ERD) describes the data relationships. There are six basic concepts in ERD-modelling: an entity (or an object), an entity type, a relationship, a relationship type, the cardinality, and the attribute. The three basic symbols used in the ERD-model are: rectangular boxes represent entity types, diamond shaped boxes represent relationship types, arrows represent relationship types. There are also a few extensions. Ellipses can be used to represent attributes and the key attributes can be indicated by a double ellipse. The information on direction and cardinality of relationship types can be added to the arrows.

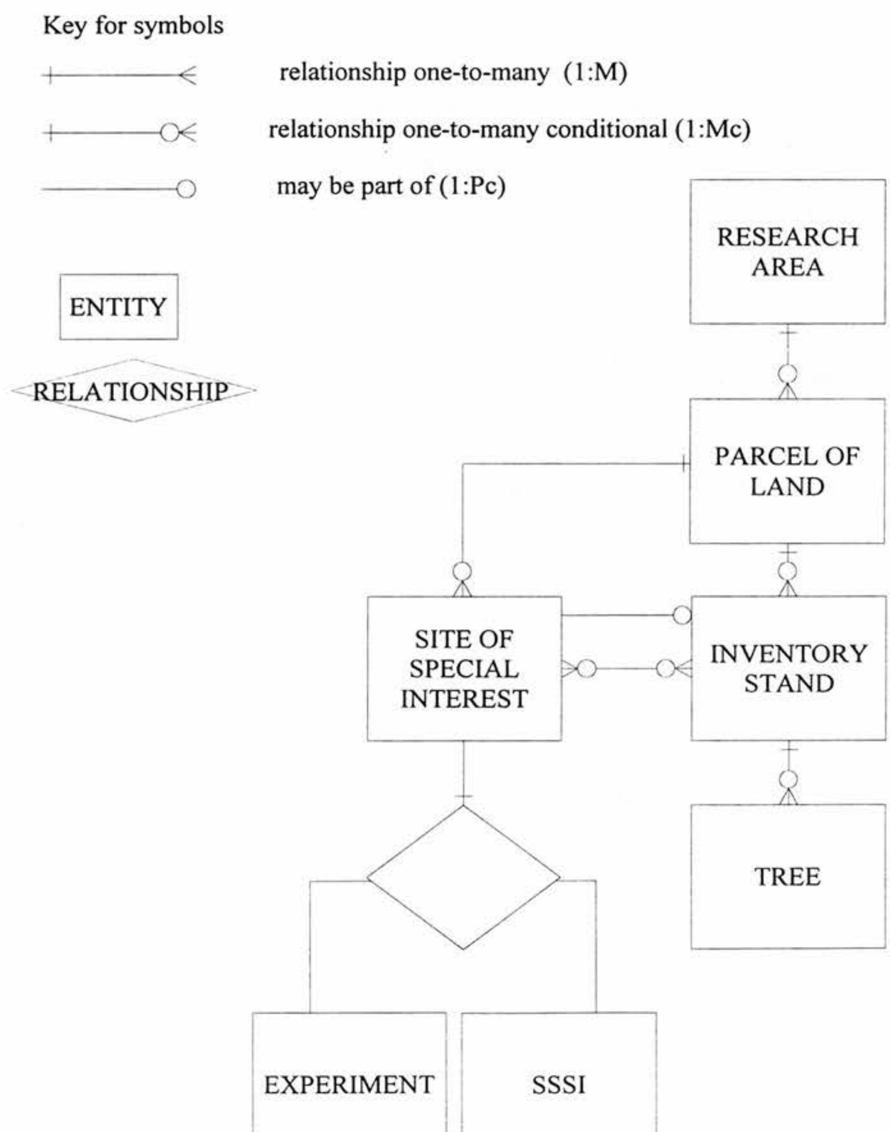

Figure 20. An example of an entity-relationship diagram (ERD).

Physical database design concentrates on file types, files, records, annotation, data format, inter-file relationships, and access keys. There are several important factors to be considered in physical data base design such as operational efficiency and effective response time. Attention should be paid to the requirements for data management of transactional updates and potential risks such as hardware and communication failures, data availability, unauthorised access, numbers of distributed users, wide area networks, high transaction volumes, automated system interfaces, and multiple database management systems. There are different mechanisms for data sharing and exchange between modules: the rudimentary form based on separate files, the operational form based on an RDBMS with flexible tools and language such as SQL and the functional form based on a set of inter-program communication protocols and a user interface shell. Requirements for large-scale GIS are presented by Smith T. R. et al. (1987).

In database design the following issues should be addressed: the study area boundary, what coordinate system will be used (coordinate registration using a tic file), which spatial data layers and feature attributes are required, and how the attributes are to be coded and organised (the coding schemes, and the storage allocation). For a large geographic database it is important that the logical view of the data should be continuous. At the same time, however, the physical storage should allow fast random reading and writing of map elements. Smaller areas e.g. map sheets can often be combined spatially into larger units or study areas.

A preferred strategy for implementation (hardware, software, communications, processes, people, organisation arrangement) should be outlined with reasons for choice. Emphasis should be given to end-user participation (teamwork), the integration of existing commercial and public domain software and new technology via in-house development work should be considered. Alternative architectures for GIS are explored by Abel et al. (1992).

Applications are packages of data, software, and hardware. Application design defines general requirements for an information system, identifies the applications to be accessed via a menu system, describes a menu system, and outlines generic tools. An implementation strategy covers generic tools and applications. Interface layout can then be designed based on user profiles and finally a system architecture (hardware and software) recommended.

Software development methodology and related tools such as structured (Yourdon 1989) or object-oriented (Booch 1991) analysis and design may improve the productivity, quality, functional specification and design during the project life cycle.

The principle of object oriented systems analysis is to identify the abstractions (things, roles) and mechanisms/transactions related to the application to be developed using domain analysis and to illustrate these as class and object diagrams. The objects are examined from the outside to define the attributes which identify them (location and/or key) and the operations (i.e. message passing mechanisms) we may want to perform upon them. The major transactions and message passing mechanisms in the system are identified and illustrated as state transition diagrams. Object-oriented design (OOD) creates models of software systems as collections of co-operating objects. It defines a notation and process for constructing complex software systems, and offers a rich set of logical and physical models with which we may reason about different aspects of the system under construction. Abstraction means identification of key abstractions. Encapsulation means keeping the interface and implementation of each class separate so that it will be possible to change the representation of the abstraction without disturbing any of its clients. Interface captures the outside view of the class. Implementation comprises the representation of the abstraction as well as mechanisms that achieve the desired behaviour. Modularisation means dividing a program into modules which have connections with other modules.

Object-oriented mechanisms, such as message passing programming languages, provide better tools for complex situations (Egenhofer & Frank 1989). For example, object-oriented database management systems help to model different versions of information about the same object or to propagate errors through analysis. An object-oriented GIS is described by Gahegan & Roberts 1988.

A structured analysis method, the Yourdon method (Yourdon 1989) was chosen for this study. The benefit of the chosen model is that it is generic and can be implemented either using structured or object-oriented techniques. The Yourdon method consists of tools and techniques. The tools used include a context diagram, data-flow diagrams (DFD), entity-relationship diagrams (ERD), data dictionaries and process specifications (Yourdon 1989). The concepts of the Yourdon method seem to work well with integrated GIS and relational database systems chosen as tools for this study (Paananen 1994).

The modelling starts by drawing a context diagram to identify the system boundary and to define the interfaces between the system and external entities (sources and sinks). The single bubble illustrates the boundary between the application system and the rest of the world. External entities may be auxiliary systems, organisations or people with which the system communicates. Data stores (created outside of the system or by the system) may be shared between the system and external entities.

The DFD is used to illustrate the functions that a system must carry out. There are four basic symbols in the DFD diagram: a rectangular box for an external entity (terminator), an arrow for data-flow, a "bubble" for process, and a rounded box for a data store. In addition, control processes and control flows may be used for real-time systems modelling. For each event there should be one process ("bubble") whose function is to provide the required response. The processes may either generate an output or store information for subsequent events. Another rule defines that each store on the DFD must correspond to an object or a relationship in the ERD.

The data dictionary describes the data elements. The information includes the meaning of the data flows and stores, the composition of aggregate packets of data moving along the flows, the composition of data sets in stores, the relevant values and units, and the details of relationships. The data dictionary serves the design and implementation.

The process specifications are used to describe the behaviour of each bottom-level process in the DFD. The descriptions can be given in structured English, as pre/post conditions, decision tables or using some diagramming tools e.g. flow charts and structure charts. The specifications are needed for the design phase when the software architecture (e.g. the hierarchy of modules) is defined. The tool depends on the chosen implementation technique.

4.3 Applicability of a planning system

There are two important factors which affect the applicability of a planning system: the **correctness** of the model and program, and the **reliability** of the input data, both of which should be considered before the model is implemented.

Correctness is considered in two stages: **verification** and **validation**. Verification is to guarantee that the model is built according to the specifications; validation concerns function - the model is structurally valid when it produces observed behaviour and reflects the way in which the real system operates. The model is, however, always a simplification of reality. Therefore, common questions in forest modelling to be considered in validation are: is it reasonable to approximate non-linear problems with linear methods, can phenomena be treated as random processes or is it possible to represent continuous phenomena by their discrete equivalent.

There may be modelling errors in objects and fields, statistical errors in prediction models or modelling errors related to spatial analyses such as scale change, reclassification, overlay, data conversion, distance calculation, or surface representation such as spatial resolution of a DTM in relation to land form.

It is important to know how to describe error in the database and how it is propagated (transferred) through the GIS processes (Burrough 1992, Goodchild & Gobal 1989). Even if there is still a lack of standard models of error propagation through sequences of GIS-functions, there are a few possibilities to deal with the errors.

It is possible to warn the decision-maker about meaningless operations. A map library and a resource directory may be a solution. A resource directory is a directory of data sets and processing operations that support the choice of data sets and analysis.

Some methods such as explicit modelling of random variation may be used to inform the decision-maker about the random variation or errors. In Monte Carlo simulation the observed data are replaced by a set of random variables drawn from appropriate probability distributions. The products should be presented with associated estimates of their reliability e.g. a map product with a map of prediction errors (Heuvelink et al. 1989) or an indicator of the types of errors introduced by GIS processing (Lanter & Veregin 1990). A set of confidence limits can be displayed as statistical surfaces or as a thematic overlay.

The suitability of different data models for error modelling varies. Pixel-based maps appear to have some advantages (Heuvelink et al. 1989).

The **quality factors of software** are correctness, robustness, extendibility, reusability and compatibility (Meyer 1988). The additional requirements for good software are efficiency, portability, verifiability, integrity and ease of use. Correctness is the ability of software products to perform their tasks, as defined by the requirements and specification. Robustness is the ability of software systems to function even in conditions not expected when the model was prepared. Extendibility is the ease with which software products may be adapted to changes of specification. Extendibility is usually based on two principles, namely, design simplicity and decentralisation. In decentralised systems a change will probably affect only a small number of modules. Reusability is the ability of software products to be reused, in whole or in part, for new applications. Compatibility is the ease with which software products may be combined with others. The extendibility, reusability and compatibility of software are closely related to modularity principles.

4.4 The costs and value of information

Aronoff (1989) defines five types of benefits from a GIS-based information system: an increased efficiency, non-marketable services, benefits of new marketable services, benefits of better decisions, and intangible benefits. The increased efficiency is usually measured as saved time. The non-marketable services include e.g. better report formats. The benefits of new marketable services can be divided into increased revenues from sold products/services and into revenues from selling acquired GIS expertise. The benefits of better decisions are due to improvements in the decision-making process in which more accurate information and faster and more flexible analysis capabilities are used. Intangible benefits are derived mainly from the improvement in internal and external image and communication of the organisation.

According to Smith and Honeycutt (1987) the value of the information is the value of reducing or eliminating the uncertainties before making a decision.

Spatial analysis results are usually based on the utilisation of multisource data of varying data quality and precision. There are errors due to data acquisition, processing, analysis or conversion (Lunetta et al. 1991). The combined effects of spatial and attribute errors may limit the value of predictions (Bolstad & Smith 1992). The decision-maker should be aware of the accuracy and reliability of data.

The factors of data quality may relate to the individual data elements (micro level components) or to the data sets as a whole (macro level components). The micro level components are positional accuracy, attribute accuracy, logical consistency, and resolution. The macro level components include completeness, time, and lineage.

The quality of forest inventory data meets the cost and accuracy requirements of long- and medium-term forest planning (see section 2.5). When stored in a GIS, the inventory data will be available for several applications which may have different requirements. However the incompatibilities between available data sets and processing modules should be taken into account in the design of spatial analysis procedures. Measures are required to prevent inappropriate use of GIS.

The corporate data base should meet the requirements, be accurate and well-documented. The data quality should be verified before data input. However, a statistically valid field verification may be more expensive than the application can justify. Therefore the costs of assessment should be weighed against the benefits of the accuracy information i.e. the value of increasing certainty in decision making.

The data base should also be cost-effective. There are three possibilities to achieve this: first, the data are collected and stored at the finest level of detail required. Second, the database may be a compromise. Third, different levels of accuracy for different data sets may be used. Since there is a trade-off between the increase in accuracy and the cost of data collection and management, the appropriate level should be chosen. There is always a point where the costs of potential errors and the probability of their occurrence is higher than the cost of adopting a higher accuracy standard. The level of error which is accepted represents the risk in using the data.

Cost-benefit analyses can be used to determine the net economic benefit of an information systems (Dickinson 1989, Dickinson & Calkins 1988 and Smith & Tomlinson 1992).

Unfortunately, it is difficult to do systematic cost-benefit analysis objectively, because the quantification of the benefits is difficult. For example, the organisation and the data flow may change so drastically due to new information system that no accurate estimate about the increased efficiency can be made. It is even more difficult to predict how the decisions would be changed and what would be the value of "better decisions", especially because there are errors related to the selection of the data to be included, the analytical methods to be used and the way the results are presented. The value of intangible benefits - possibly even the benefits - is unknown.

Relative ranking of alternatives, for example in respect to the value tied to actual use of information may be an easier way (Dickinson 1989). Another simple method for the evaluation of technology change is the calculation of opportunity costs. The opportunity cost describes the difference in net income when the new or old technology is used.

Owing to the difficulties in the cost-benefit analysis, a pilot study is often recommended for the evaluation and justification of system acquisition. Pilot projects can be used to collect knowledge of the decision-making process, to test the functionality of underlying technology, collect enhanced understanding of technological potential and request additional functions, to identify generic functions and parameters, to design and develop software tools, and to package a set of application modules (Bulger & Hunt 1991, Leggat & Buckely 1991).

4.5 The role of a pilot study

The purpose of this study is to evaluate a corporate GIS in operational forest planning i.e. to estimate the value of geographical in-site information for forest management planning. In the pilot study, special attention is paid to the problem of the inappropriate use of existing information.

The pilot study is divided into stages. A pilot system is selected and pilot data for a small but representative area acquired. Second, a case study is implemented. The changed requirements for data sets, data organisation and models that take advantage of the new technology are defined and the suitability of existing data, data organisation and planning models is analysed.

5. DESIGN OF A GIS-BASED FOREST PLANNING SYSTEM FOR THE FINNISH FOREST RESEARCH INSTITUTE (METLA)

The aim of this chapter is to outline a timber sale and logging planning system based on a GIS. First, planning in research forests managed by the Finnish Forest Research Institute (METLA) is introduced. Second, timber sale and logging planning is described in more detail. In particular, the possibilities of the current system to meet new requirements are analysed and the possibilities of new technology to replace or modify old processes are discussed. System requirements are then examined and, thereafter system design, architecture and implementation of databases and processes presented.

5.1 Introduction

The aim of this section is to analyse the management of the research forests at the disposal of Finnish Forest Research Institute. First the management needs are presented and the planning processes explained. Then the recent changes in the organisation and management objectives are introduced and the resulting problems of the planning system are examined. Thereafter the needs and possibilities of adopting new technology are presented, and related to the study.

The Finnish Forest Research Institute (METLA) has some 140,000 hectares of state forest at its disposal. Some 80,000 hectares are so-called commercially managed forests. On these there are 20,000 experimental plots (fig. 21). The research forests also include about 60,000 hectares in areas set aside for nature conservation purposes. The conservation areas are categorised as national parks, park forests, strict nature reserves or nature trails. The total forest area is divided into so called research areas for management purposes. A research area consists of one or several land parcels. The size of research areas varies from 590 hectares to 14,127 hectares. (Metsäntutkimuslaitos 1989).

The responsibility for long-term forest management planning has been centralised in the research area office in Helsinki. The forest plan for a research area is made every ten years in Southern Finland and every 20 years in Northern Finland.

Figure 21. An experimental plot. The device in the photo is used to collect litter.

The plan is based on forest inventory using aerial photographs and field survey. The basic inventory unit is a forest stand i.e. a homogeneous forest area in terms of site and growing stock characteristics (Poso 1983). Before field survey, additional management units such as conservation and experimental areas are delineated on the maps. For example, the plans of the experimental areas (i.e. stands where experimental plots are located or stands which are reserved for experimental purposes) are collected from research foresters responsible for the management of experiments.

During the inventory, 1:10,000 forest maps are produced using a vector based mapping system, NALLE (Auvinen 1987). The stand attributes are stored in sequential attribute files, which are used for statistical calculations. The attribute files and mapping system are loosely integrated to produce thematic maps (Karpio 1988, Koivunen 1988). For the experiment data there is a register that contains general information about the purpose and approximate location of the experiments (Lehto & Isomäki 1993). The forest plan includes a list of inventory parameters and treatment proposals for each stand. The stand list is not updated between periodic inventories.

The cutting budget is calculated according to the standwise treatment proposals (Metsäntutkimuslaitos 1988). Some deterministic simulation methods can be used to check how well the future structure of the forest area corresponds to the goal forest. The forest plan guides annual short-term planning (e.g. timber sale planning) in research areas in the form of the overall production goal and standwise treatment proposals.

In Finland, non-industrial forest owners can sell timber standing or at the roadside. Until 1991 the pricing system in Finland was based on the national agreement between forest industry and forest owners. The price system had two different prices: one for standing (stumpage) and one for roadside sale. In principle, roadside value refers to the value of timber at the roadside and stumpage value to the value of standing timber for the industry. Therefore stumpage price should reflect product price after the various processing costs (such as transportation and logging costs) have been deducted.

The stumpage price in Finland used to be greater than the actual stumpage value. There are three main reasons. First, roadside value of timber is the same within a region even if the transportation costs from the roadside storage to the mill varied within a region depending on the actual transportation distance and road conditions. Second, stumpage price was not dependent on factors such as logging conditions even if the difficulty of terrain resulted in higher production costs and, thus, a decrease in stumpage value. For example, managing a habitat specifically to conserve rare species or to preserve research material may cause increasing costs - both on sites and on surrounding areas. Third, the difference between roadside and stumpage price was greater than the actual logging costs (i.e. the costs of felling, conversion and extraction of timber to the roadside) because the agreed price included additional support for long-term timber production.

In December 1991 the price agreement was given up. Since then roadside price has been getting closer to the roadside value. The roadside unit price is given as a regional average unit roadside price of the timber assortment. Stumpage price is derived by subtracting the regional (experienced) average unit logging costs (FIM/m3) of the chosen logging system from the regional average unit roadside price (FIM/m3) of the timber assortment. The average costs are still used because there are no methods available for the estimation of actual costs as a function of logging conditions.

Traditionally research areas have prepared an annual sale proposal based on the forest plan. The central office in Helsinki has then merged the proposals and invited sales by tender from selected purchasers. If a buyer purchases standing timber, he requires information on tree species and dimensions of timber to be sold, the approximate quantity of timber, where the timber is to be sold (standing, at roadside), conditions of harvesting, and any restrictions imposed on harvesting. There were some problems related to this practice of sales at roadside and centralised sales. Sometimes local purchasers might be prepared to pay a higher price for good quality logs - especially if the standards could be agreed before felling.

The organisation of the METLA changed in 1992. The responsibility of forest management including timber sale was decentralised to research stations. Simultaneously the forest management strategy was clarified. The main objective of forest management in the METLA is to take the needs of research into account (Metsäntutkimuslaitos 1993). The aim of management is (according to the law concerning state forests) "to manage, protect and utilise the forest and land property and at the same time look after the public interests (employment, nature conservation, recreation etc.) and attain the best commercial result". The structure of forests should be varying enough to provide material for different forest functions. The planning should support strategies and management of the research forests as a whole. Traditionally only standwise management is possible.

The protective and social outputs are the main objectives in park-like forests. Often the protective and social outputs can be achieved also in commercially managed forests with minor modifications e.g. by defining demands other than timber production as constraints for management. For example, harvest scheduling must contain spatial constraints that restrict clear cutting on adjacent stands (due to the limit of the size of contiguous openings) or treatments near to experiments.

The current centralised inventory and planning system is designed for periodical inventory and long-term timber production planning (fig. 22). Forest inventory and planning produces a stand list, forest map, and cutting budget. The cutting budget defines allowable cut. Stands are marked for cutting two years before actual harvesting. This process is referred to as logging planning and the product is called a logging plan. When a district manager prepares a logging plan he tries to follow the given treatment proposals and - simultaneously - keep in mind the spatial and economic feasibility of operations. In principle, he should aim at the rational arrangement of working areas, because the synchronisation of logging operations will reduce the costs of supervision per unit of timber volume as a result of reduced walking and travel time for the supervisory personnel. The plan defines the cutting method, and estimates of timber volume and workload for the budget.

In the current information system, there are no routines to "manually" update the stand database after treatments or "automatically" update the growth of trees. A field survey has to be made quite often to collect information on timber volume. Before the implementation of the plan the researchers who have experiments under or near planned treatments should be informed about the plan in case the treatments should violate the experiments. The logging plan is circulated at research stations. If the plan is feasible, a more detailed work and timber sale plan is prepared a year before harvesting. The work plan includes information on the number, average size, branchiness, and height of stems, cutting method, terrain class for cutting and extraction and extraction distance. The sale plan includes information on the location of the timber parcel, the proposed sale method and sale date, the average size, quality and total volume for each assortment, and a description of storage and transportation conditions. An additional field inventory is often needed to collect information on terrain conditions and estimate timber volume more accurately, for example. This is referred to as pre-harvesting inventory.

In principle, management units should be redefined whenever changes are detected. A problem of short-term planning based on standwise forest inventory is how to deal with frequent changes. The long-term plan regards inventory stands as permanent management units. In practice, there may be changes in management goals, silvicultural guidelines, or site-specific land-use objectives after inventory and therefore stand delineations and treatment proposals made in the field are often outdated. The current system has only a limited number of routines for monitoring stands reserved for experiments or stands leased from experiments after field inventory. Therefore, reservations may be either neglected or unnecessarily taken into account in logging planning due to the time gap in the information flow.

A corporate GIS can serve different applications. The main purpose of the integrated stand and map database system is to guarantee up-to-date stand descriptions. When the attribute data becomes out-of-date, due to treatments or natural processes, it should be possible to update stand descriptions using manual or simulation techniques, respectively. Clearly, if the forest inventory database can provide an up-to-date estimate of timber volume, no pre-harvesting inventory is needed - especially when work measurement has become a part of extraction work. In addition, the stand database can be integrated with the experiment register so that the experiments can be easily found and the related restrictions for the treatments retrieved. The circulation of logging plans can be given up. It is also easier for district managers to measure trade-offs between different sale methods. For example, to evaluate the costs and benefits of different sale methods in particular conditions, the district manager has access to site-specific restrictions (ecological constraints on timber production, barriers), description of available logging systems, economic models and some methods for environmental impact analyses (fig. 23).

The METLA launched a project "The information and planning system for research forests" in the summer of 1990. A corporate database would assist both researchers and research areas in data management (fig. 24). Goals, objectives and rules such as thinning guides are set based on issues, concerns, and opinions. In addition, forest planning requires information on available resources such as money and manpower. Forest planning defines targets and means such as harvest level, treatment area and treatment proposals for forest management. Forest management includes operative control and provides operational plans (work plans, budgets, timetables) for forest work. Forest work produces forest products and services. Data acquisition is divided into two components: data collection (forest inventory) and data exchange (auxiliary data). The initial plan was to develop an integrated decision support system (DSS) based on a corporate database (an integrated stand and experiment database) and a forest simulator (MELA). Soon it was realised that spatial analysis could only be implemented using a specific "toolbox" such as a GIS.

The research areas are hoping to replace pre-harvesting inventory and two-phase planning with a corporate database. Unfortunately, the data accuracy requirement is higher for timber sale planning than for long-term planning. The non-standard, out-of-date, missing and inaccurate data may cause serious problems. It would be very expensive to collect all the data at the most accurate level. There is a trade-off between the increase in accuracy and the cost of data collection and management. In addition, the standard forest inventory does not collect all the information concerning, for example, extraction conditions needed for timber sale and logging planning.

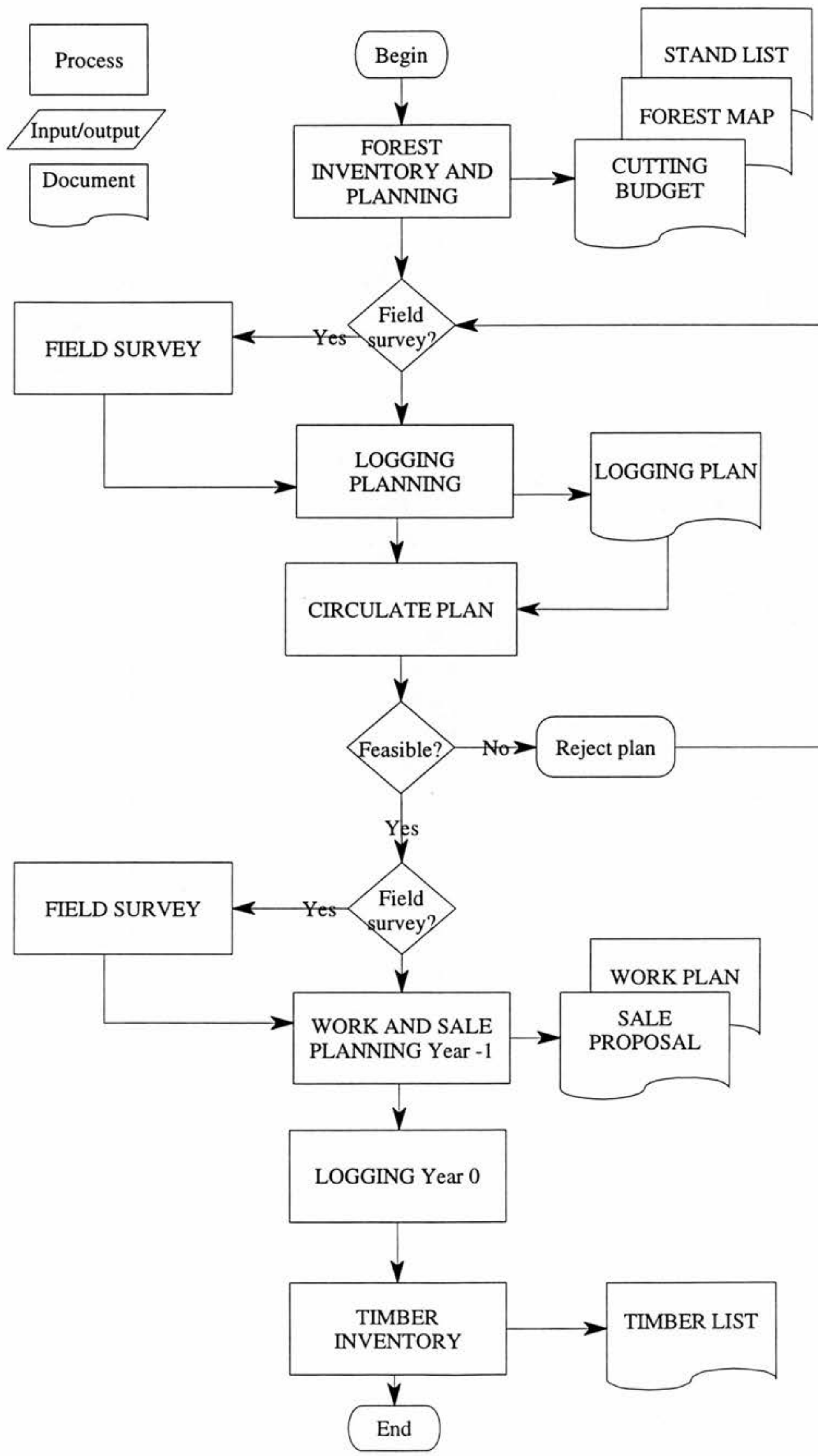

Figure 22. The procedure for timber sale and logging planning in the METLA.

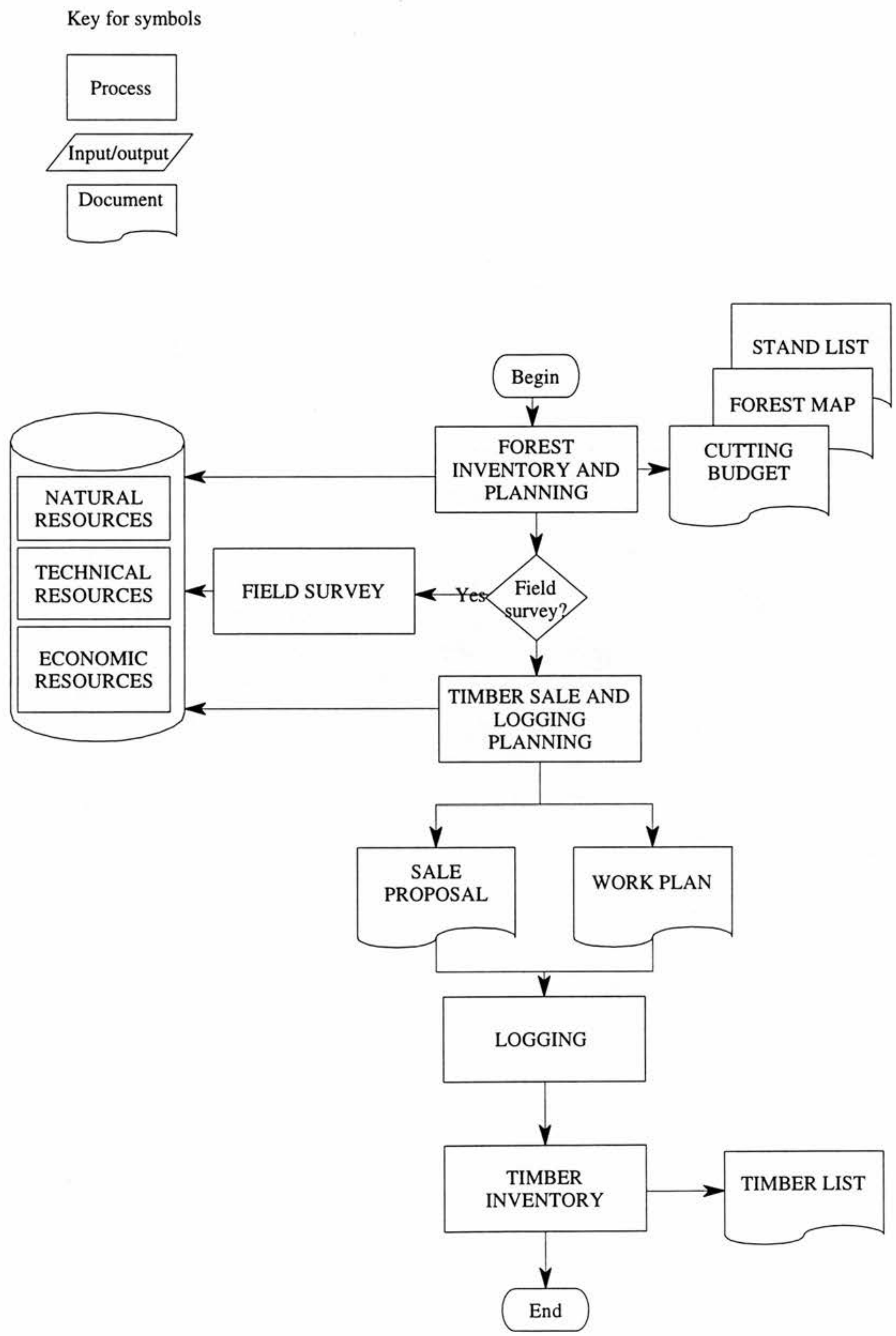

Figure 23. A corporate GIS in timber sale and logging planning in the METLA.

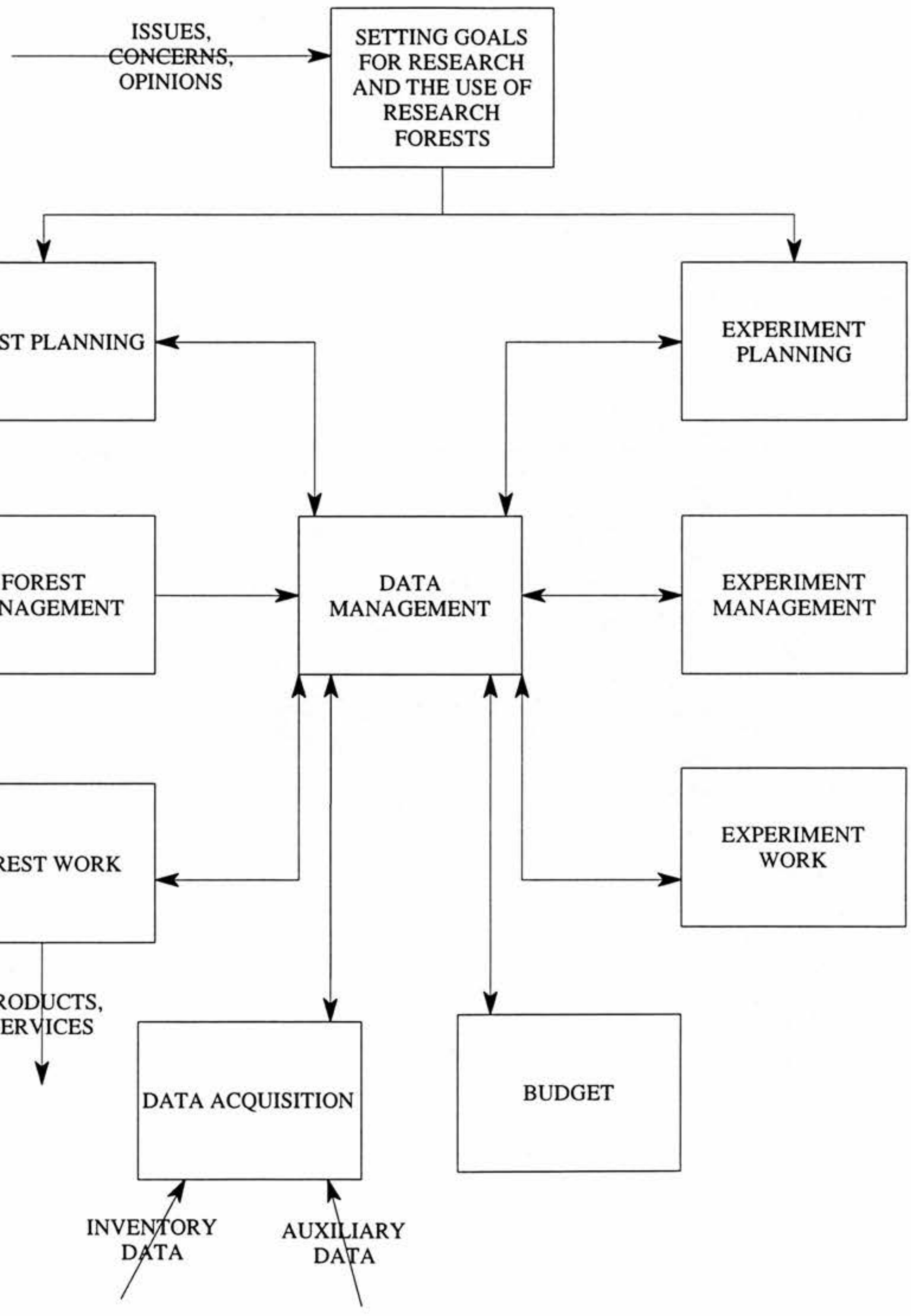

Figure 24. The corporate model of forest data management in the METLA.

Therefore, the suitability of existing inventory and map data for timber sale planning should be analysed before giving up the current practice. A case study can be used to illustrate how well the system will meet the requirements, to evaluate candidate software components, to test the design, and identify potential problems. In this research, a case study is used to test the capabilities of GIS and a relational database management system (RDBMS) as a data management and planning tool and to analyse the possibilities of replacing the pre-harvesting inventory with an integrated GIS and planning system.

The aim of this study is to test the system design and to identify the obstacles to system implementation. The purpose of this chapter is to design a system that can be used for timber sale and logging planning. First, the problem is analysed. Second, the requirements of the system development are defined. Third, the system is designed. Fourth, the system architecture is presented. Fifth, the database and processes are described in more detail.

5.2 Analysis of the production system

The aim of this section is to examine timber sale and logging planning in more detail. The phases and suboperations of logging are described. Thereafter the productivity of logging is analysed.

In timber sale planning, the logging costs should be estimated as a function of logging conditions. The required information in logging cost analysis (Stenzel et al. 1985) are the cutting unit volume (m3), the costs of logging (FIM/m3), and the price of timber on the roadside storage point (FIM/m3).

The average unit cost of logging does not cover variations due to differences in logging conditions. There are four important factors that affect the costs: the size and density of harvested trees, the extraction distance, the terrain of the timber lot, and the size of the timber lot defined as the total volume of timber in a storage point (Peltonen & Vesikallio 1979, Imponen & Kaila 1988, Valkonen 1993, Lindroos et al. 1993).

Logging is usually subdivided into three main phases: felling, extraction and long-distance transport. Within each of these phases there are a number of field operations such as the conversion of the felled trees into logs, the moving of the wood and its loading and unloading. Trees are harvested using whole tree, tree length or short wood systems. The combination of jobs or sub-operations is here referred to as a logging system. The various sub-operations are interdependent so that an earlier operation influences the subsequent one and a later operation may require some preceding jobs to be done in a particular way.

Extraction (i.e. off-road transport) is a term used for transporting or moving timber to extraction (storage) points, usually located along permanent routes of transport. An extraction point is a storage place where timber is collected for processing and/or reloading for further transport. Extraction methods comprise forwarding with animals or tractors, skidding with animal or tractors, or winching (yarding) with cable equipment.

There are two main approaches for modelling the productivity of logging operations: the table approach in which the output rate is stored in a database and a functional approach in which the productivity is derived as a mathematical function of influencing factors. The output rate (productivity) of a forest tractor is usually expressed in terms of volume per unit of time (e.g. m3/hour) for a given distance and terrain class.

In principle, the actual driving time (min) is calculated as the road distance (m) divided by the speed of travel (m/min). Straight line distance is measured on the ground plane "as the crow flies". The road distance depends on e.g. the optimal density of the road system and the feasible pattern of roads for a given topography. Standard distance measurement may be based on the homogeneous patterns of terrain units surrounded by a systematic road net. In reality roads are winding and terrain units irregular. The winding factor includes the lengthening due to the horizontal and vertical curves and the difference in altitudes (Sundberg & Silversides 1988). Von Segebaden (1964) introduced two spatial correction factors: V and T. The V factor will take into account that roads are not straight or equally spaced, meet in junctions and can terminate as "dead end roads". The T factor will also take into account that extracted timber is often concentrated at landings, and not necessarily at the nearest landing. The V and T factors are calculated as a "real" average distance divided by the "base" average distance where the latter is derived from a map showing the regular pattern of terrain units and roads. The "real" average distance of the V factor is derived by putting a grid of points over a map of the existing road system and measuring the distance from each point to the nearest road. The T factor is derived from direct measurements of straight line distances between grid points on maps or random points in the field.

Real transport distance is the actual road travelled and the speed of travel depends on the trafficability of the route over the terrain and the capability of the vehicle to travel across the terrain (Valentine 1986). In practice there are three main factors which restrict the vehicle movement over the terrain: slopes limit mobility, vegetation acts as a barrier and some soils may be prone to decreased load-carrying capacity especially under conditions of increased soil moisture (Haarlaa 1973, Sundberg & Silversides 1988). Slopes, up-hill, down-hill or side-hill, have a great influence on cross-country movement and off-road transport.

Site classification combines classes of vegetation with the properties of the physical environment (soil, terrain, geology), climate and hydrology. Terrain classification contains information about land as a working surface for vehicles rather than as a medium for tree growth. Traditionally terrain is described in terms of the ability of a machine to work or travel over it, or in terms of machines which can be used on it. These descriptions are subjective and they become out-dated as technology changes.

Classification schedules for practical purposes have been developed for a rating of the terrain conditions on the basis of the dominant terrain features such as slope, carrying capacity of the ground (ground conditions) and configuration of the ground roughness (surface structure) (Rowan 1977, Eriksson et al. 1978).

The most common way of expressing a slope is to give the difference in elevation between two points in percent of the horizontal distance. In a terrain type schedule the slopes are divided into five classes: 0-10, 10-20, 20-33,33-50 and > 50 % (Staaf & Wiksten 1984). Steepness refers to major slopes - sections shorter than 50 m should be disregarded. There are two critical values of steepness: the angle of repose of the soil and the maximum slope below which tractors can work satisfactorily (usually 40-60 % depending on the type of the soil and its moisture content). On steeper slopes cable equipment is preferred to tractors.

The carrying capacity of the ground, i.e., its capacity to resist physical pressure, primarily depends on soil type and moisture (Staaf & Wiksten 1984). The variables that best describe the carrying capacity of the ground are soil type and rainfall per year (Valentine 1986). Ground conditions (i.e. an expression of carrying capacity) are divided into five classes, also. Use of separate map layers for each primary factor such as soil type and slope is recommended (Eriksson et al. 1978).

Surface structure, usually characterised by the existence, height and nature of obstacles of more than 50 cm height or depth, may also be described by five classes. Mobility in the stand is an important environmental feature, especially in thinning: the denser the stand the more difficult is the felling and processing of trees and the extraction of timber, for example.

In practice, also the size of the load and terminal time affect directly the output of extraction (Staaf & Wiksten 1984) and the total extraction time is the product of the number of loads transported per time unit (dependent on both the speed of machine and the load size) and the load size.

There are three phases of the round-trip: travelling empty, travelling between the loading stations partly loaded and travelling fully loaded. The transport distance of the forwarder and the wood should be distinguished and the transport distance expressed as the weighted average of the travelled distances of the logs.

The dimensions of the average tree (usually expressed in diameter at breast height, DBH) influence the output and the costs of transport, the latter declining at increasing average tree diameter at breast height. Harvesting of small trees requires a high labour input in relation to the yield of timber. In addition, sorting of timber influences the cost of transport across the terrain. The more assortments, the longer the time that is required to obtain a full load.

The terminal time (i.e. time for unloading and loading) depends on the number and type of timber assortments, the location and density of timber piles, the method of loading and unloading (i.e. equipment and requirements concerning piling) and the layout of the landing (e.g. the size and the carrying capacity). The size of load depends on the practical hauling capability of the vehicle and the optimum loading capacity in given logging conditions.

5.3 System requirements

The system should facilitate implementation analysis, where the feasibility of proposals (i.e. the combination of treatment stands marked for cutting) in terms of economy (optimal sale method and logging costs as a function of terrain conditions and the multiple-use constraints) and ecology can be checked against the (sustainability) guidelines of the forest plan.

Short term and long term planning should be operationally integrated into one system so that the decision maker will be able to adjust either short term objectives or long term strategic goals - or both - to ensure that "in-site" plans are consistent with long term strategies. The system should be able to illustrate up-to-date production possibilities and offer some tools for sensitivity and post-optimal analysis.

To deal simultaneously with multiple objectives, the system should be able to utilise different sources and scales of information. It should be possible to keep the forest inventory database (including map data) up-to-date. A forest simulator is required to update forest inventory and simulate short-term and long-term future treatment alternatives. The purpose of simulation is to forecast what will be the future yield of the compartment if it is treated according to a particular treatment regime (i.e. a sequence of treatments during the planning period where planning period can be divided into two or several subperiods). The future growth of the stand and the effects of treatments are forecast using some growth prediction method such as the yield table method, stand growth models, or single-tree growth models.

A yield table describes the development of the most important stand characteristics (Koivisto 1959). Because the stand development varies in different conditions or under different management regimes, there should be separate tables for different conditions and for different management schedules. The main benefit of the yield table method is its simplicity. The disadvantage is that some correction methods are required if the actual forest conditions differ from the conditions for which the yield table is made. Therefore prediction methods that are based on mathematical functions are preferred. The stand growth models can be used to estimate the development of stand characteristics as a function of site and present stand characteristics (Nyyssönen & Mielikäinen 1978). The stand growth models may fail if each variable of interest is estimated using a separate model and the different stand characteristics are not be logically related to each other. To avoid this drawback single-tree growth models can be used. The single-tree growth models express the growth of an individual tree as a function of tree, site and stand characteristics (Ojansuu et al. 1991). The benefit of this approach is that all the stand characteristics can be calculated as the sum of tree dimensions and the risk of using illogical relations between different stand characteristics is minimised.

Clearly, the method based on single-tree growth models seems to offer the best solution for the prediction of stand development provided that the stochastic elements such as birth and death of trees are included.

An LP-package needs to be used to search for efficient combinations (production possibility boundary) and to compile alternative plans based on the schedules. Because the effect of combinatorics (or interdependence of activities) on costs and returns should be taken into account, the integrated planning system should be able to utilise some advanced spatial and economic models and to deal with the non-linear and combinatorial problems.

A GIS is required to store forest maps and assist in the design of harvesting layout, provide site-specific information on treatment stands (i.e. homogeneous units in terms of possible treatments), zones (e.g. treatment stands next to waterbodies) and related activities (see chapter 3). A GIS is also used to identify sensitive habitats which should be left undisturbed or habitats of special interest, which should be maintained and managed for future purposes. Different types of spatial functions are required to combine information from different coverages such as stand and slope coverages, and to extract conservation areas and road buffers from cutting stands. Spatial queries are needed to extract adjacency information or to estimate the terrain class as a function of soil type and slope for the logging routes. Network analysis and statistical operations are needed to calculate the total outturn, average extraction distance and average terrain class for the stored cutting unit.

There are many functional requirements for a GIS used as a decision support tool in forest planning. Since the number of map sheets may be large, efficient data storage and handling routines are needed. To deal simultaneously with multiple objectives, the system should be able to utilise different sources and scales of information. The ability to manipulate several coverages at the same time is essential. The flexibility of data integration and cartographic modelling operations is important. For example, generation of new data objects is needed to locate experimental plots on the map and to create buffer zones around plots, roads and conservation areas. An intersection operation is required to extract the conservation areas and buffers from stands marked for cutting. Adjacency analysis is essential to implement so called adjacency constraints for preventing the final harvests on adjacent polygons. A DTM with modelling capabilities is required to estimate the terrain class as a function of soil type and slope. Statistical operations are needed to calculate the total outturn, average extraction distance and average terrain class of the whole cutting unit.

The GIS should be able to export data for input to the simulation modules or import data from external models to the coverages. The GIS should also include a large "toolbox" (program library) and a programmable interface to allow the development of special applications.

5.4 System design

The aim of this section is to outline system design. The context diagram, entity-relationship diagram and data-flow diagram are presented.

In figure 25 the forest planning system is outlined. Information on stands and experiments is stored in stand and experiment registers, respectively. Related maps are stored as GIS coverages. The stand and experiment registers are auxiliary systems which are used to add, query, modify and report databases for other purposes. A district manager (planner) activates the application when preparing a plan for a particular planning area. The planner (an external entity) sends a request (along the data flow arrow). The forest planning application queries a GIS to provide data on forest stands, sites of specific interests and experiments. These are used to create treatment stands (calculation units) for a simulator. The simulator produces a set of treatment schedules that are used for optimisation. The planning application reads the shadow prices (the results of optimisation) and produces reports for the planner.

Figure 26 presents an entity-relationship diagram (ERD). Each research area can have zero, one or more management goals. Each research area has one forest management plan (i.e. medium-term tactical forest plan) and a forest management plan concerns one and only one research area. A forest management plan contains targets and means for achieving a given long-term strategic management goal. A research area is responsible for operational short-term planning of treatments (including logging and timber sale) within the guidelines of the forest management plan, available material resources such as men and machinery and annual budget.

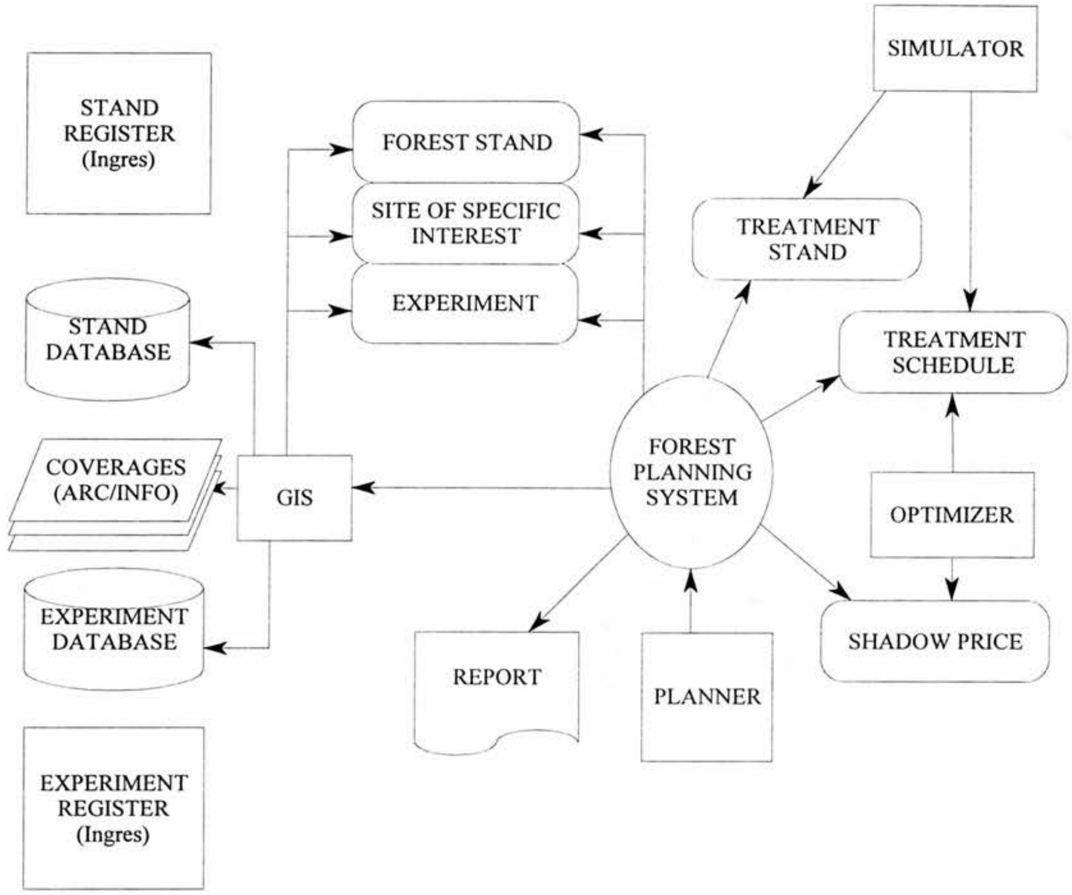

Figure 25. The context diagram for a forest planning system.

A research area consists of zero, one or several parcels of land and each parcel of land belongs to one and only one research area. A parcel of land can contain zero, one or more inventory stands, while every inventory stand must be located inside of one parcel of land. Inside an inventory stand zero, one or more inventory trees may be measured. Every inventory tree grows inside one inventory stand.

In the planning process, a research area defines zero, one or more analysis areas (AA). An analysis area can be a parcel of land, a group of parcels of land or a part of a parcel of land. An analysis area can be subdivided into zero, one or more treatment stands according to treatment rules defined for a particular planning situation. A treatment stand is a basic management unit which is homogeneous in terms of site, growing stock (i.e. inventory stand description) and management possibilities. Therefore, a treatment stand may be an inventory stand or a part of a inventory stand but never a group of inventory stands. An inventory stand may be divided into several treatment stands.

There may be zero, one or more sites of special interest (SSI) within a parcel of land. For example, an experiment and a site of specific scientific interest (SSSI) are subtypes of site of special interest. A site of special interest can be an inventory stand, a group of inventory stands, a part of an inventory stand or totally outside the inventory area. An inventory stand can contain zero, one or more (possibly adjacent or overlapping) sites of special interest.

The first task of short-term logging planning is to define a list of treatment stands with cutting proposals based on the guidelines of a forest management plan. The list is referred to as a logging plan. A separate set of rules can be used to define treatment stands for cutting, silvicultural work or forest improvement. If the purpose of short-term planning is to prepare a logging plan and a proposal for a timber sale contract, treatment stands are delineated for cutting purposes. The treatment stands which are included in the logging plan can be referred to as treatment stands marked for cutting.

In practice, areas which have specific requirements for management are separated based on sites of special interest. If a site of special interest is an SSSI, a site of special interest is extracted from the analysis area. If there is an experiment inside an inventory stand, an "artificial stand" is delineated around the experiment. The experiment and the "artificial stand" are then extracted from the inventory stand and a new treatment stand is defined. If the experiment requires logging operations, the proposals are retrieved from the experiment register. The remaining inventory stand is defined as a treatment stand. Thus, the original inventory stand is split into two treatment stands. If a site of special interest is an environmentally sensitive area such as a zone around a water course, an "artificial stand" is created and a new treatment stand is defined with a set of feasible management regimes. Thus, several types of site of special interest can be taken into account in logging planning. If there are several overlapping sites of special interest, a priority order defines the management goal of a site.

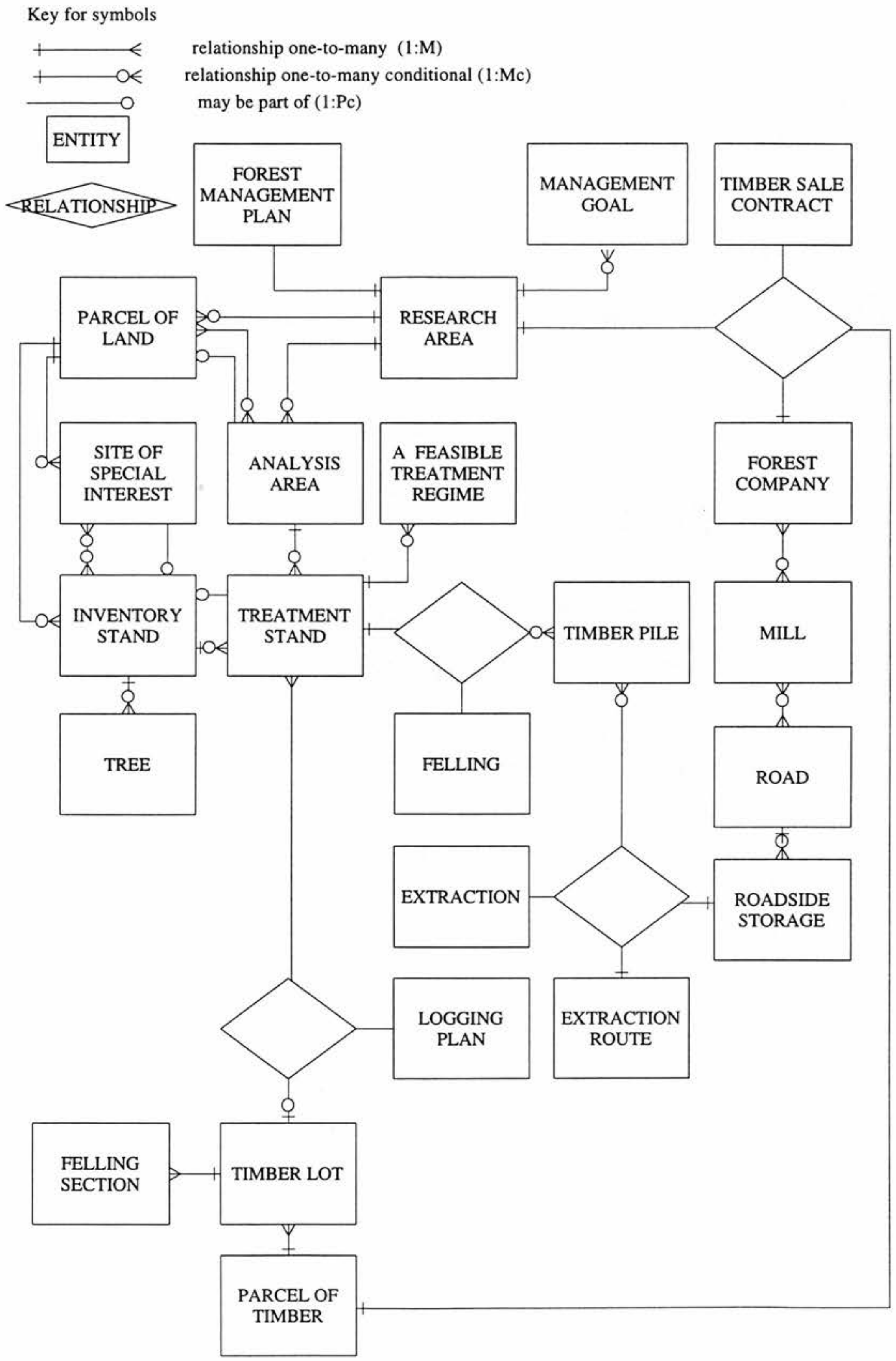

Figure 26. The entity-relationship diagram (ERD) for timber sale and logging.

Every treatment stand has zero, one or more feasible treatment regimes based on the current state of the forest. Stand-level treatment alternatives consist of various harvesting and thinning options. Thinning and harvesting alternatives are the only stand-level treatments considered in this study.

A group of treatment stands (cutting stands) cut at the same time using the same method is a timber lot. The timber lots cut at the same time form a felling area. For timber sale purposes a felling area can be referred to as a parcel of timber. In actual work planning, a felling area can be divided into felling sections.

When a parcel of timber is defined, a research area can make a timber sale contract with a forest company. If timber is sold standing, a forest company will take care of felling, conversion, extraction and transportation of timber. If timber is sold at roadside, a research area takes care of felling, conversion and extraction.

After felling, timber is stored in piles within a treatment stand marked for cutting. Timber is then extracted to a roadside storage along an extraction route. Timber can be transported from a roadside storage along a road to a mill owned by one or more forest companies. Extraction routes and roads form a transportation network and a roadside storage can be seen as a node in the network. The area under treatment stands and transportation network can be referred to as work site.

Figure 27 presents the data-flow diagram (DFD) for the planning application. It contains the following processes: (1) create planning project, (2) simulate treatment alternatives, (3) generate production program by solving optimisation problem, (4) store production program, and (5) evaluate production program. Process (1) creates treatment stands and corresponding calculation units for the simulation based on the information about the forest stand, sites of specific interests and experiments. Process (2) simulates treatment schedules for each calculation unit according to the given parameters and instructions. Process (3) selects a combination of treatment schedules for calculation units by solving the optimisation problem. Optimisation parameters refer to economic models used to calculate the values of decision criteria such as net income. The optimisation results (shadow prices) are used to find those schedules that belong to the production program. The production program is stored in the database for evaluation.

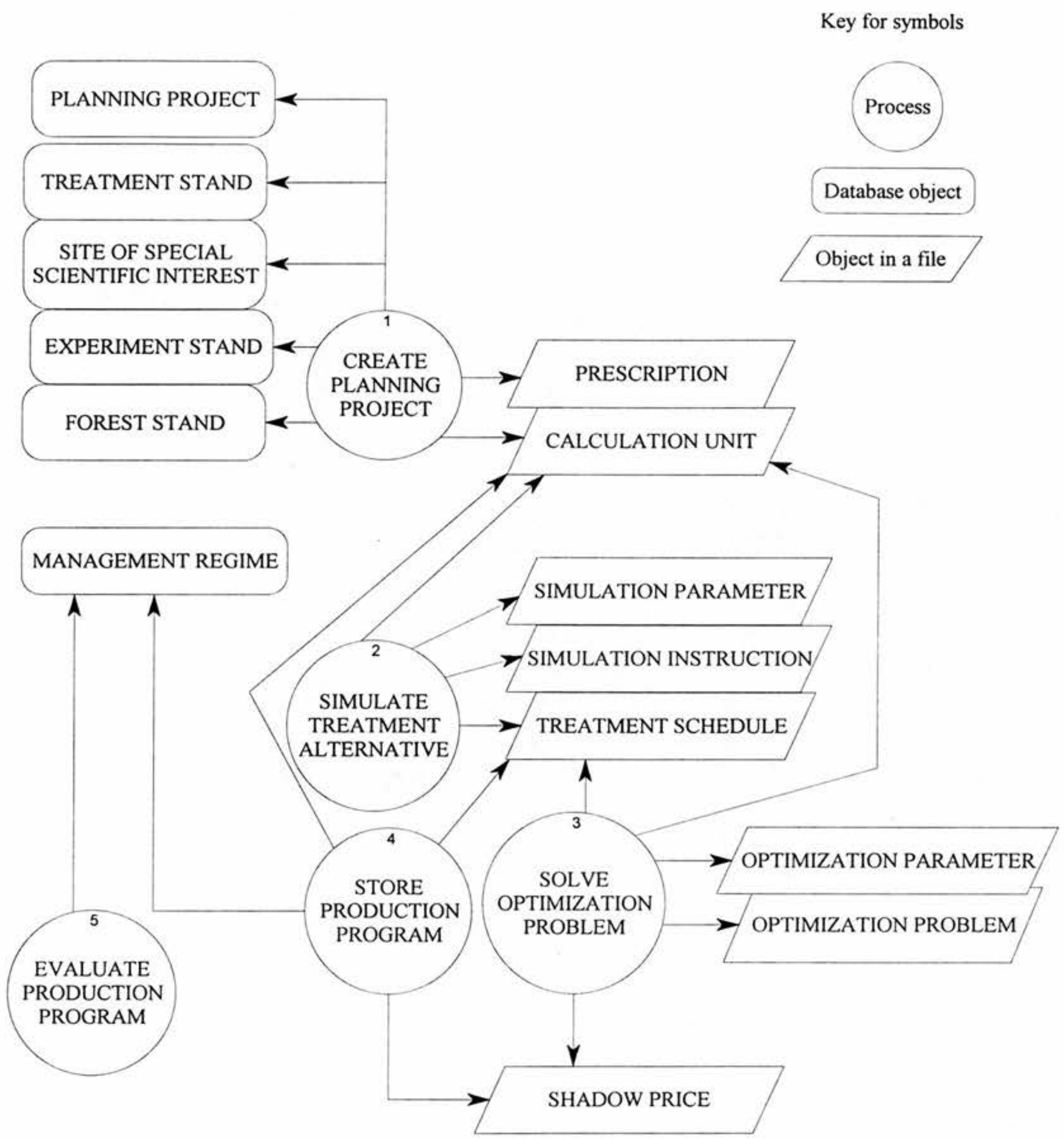

Figure 27. The data-flow diagram (DFD) for the planning process.

5.5 System architecture

The integrated planning system has the following components (fig. 28): a GIS (ARC/INFO), a relational database management system (Ingres, Ingres Corporation 1991), a forest simulator (MELA) and a linear programming package (JLP). The system is an integrated set of commercial software and internally developed programs. Ingres and ARC/INFO are commercially available software packages.

MELA (Siitonen 1983) and JLP (Lappi 1992) are software packages written in FORTRAN by Siitonen (1983, 1993, 1994) and Lappi (1992) at the Finnish Forest Research Institute. The author developed interface modules which are described in section 5.7 in more detail.

The METLA has purchased an RDBMS called Ingres (Saarenmaa et al. 1990). Ingres (Ingres Corporation 1991) is a relational database management system plus a complete set of integrated software productivity tools. Tools include a screen forms manager, a report writer, an application generator, a query language and a programming language interface.

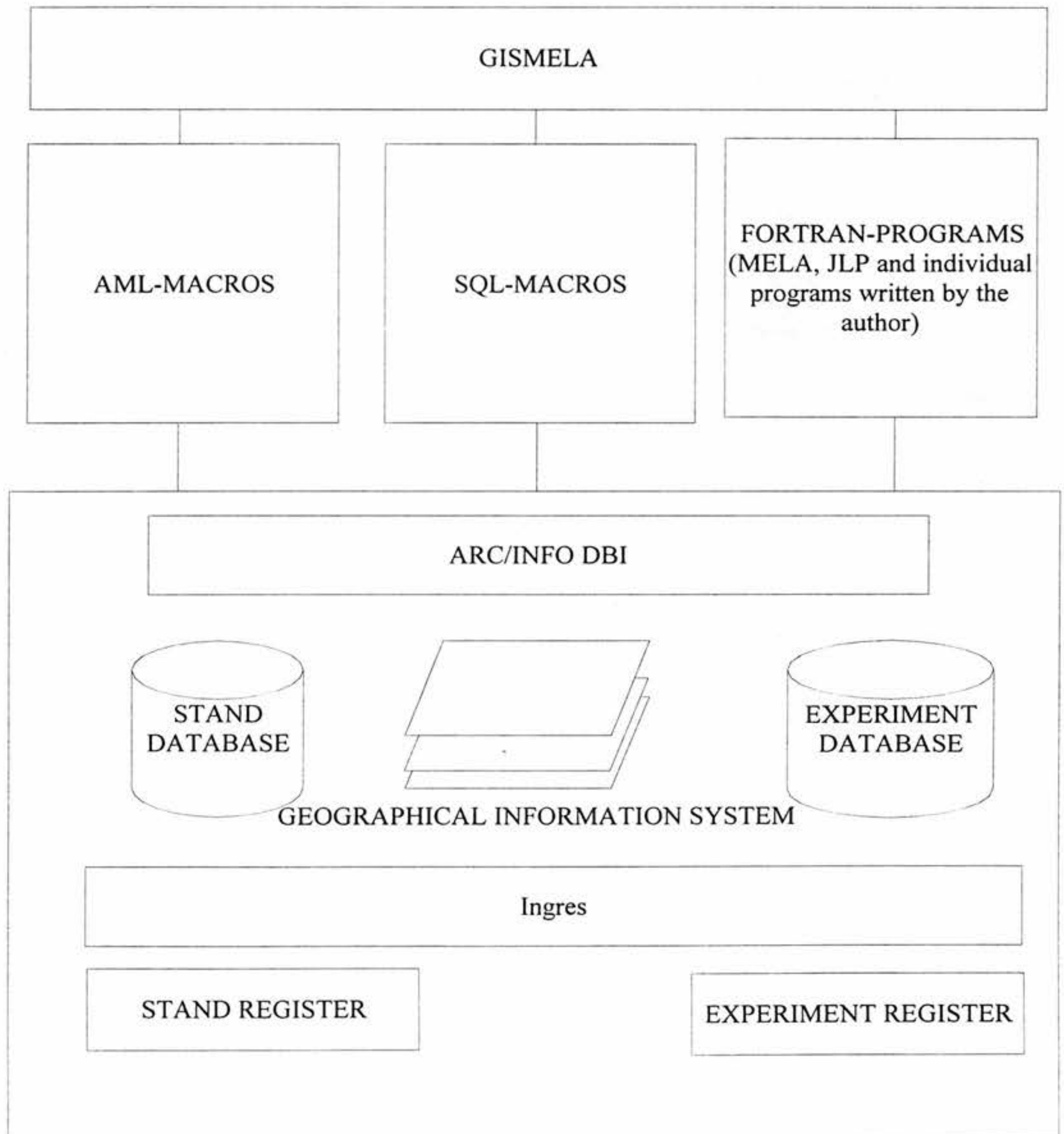

Figure 28. The system architecture of a forest planning system.

Ingres was one of the main reasons why ARC/INFO (ESRI 1989) was chosen as a GIS. A functional interface to Ingres was an essential requirement for a GIS.

The MELA forest simulator is used to keep stand descriptions uptodate and to simulate a number of possible treatment alternatives for each stand.

For each calculation unit, a finite number of feasible treatment schedules is simulated. The simulation of the schedules consists of states and events. Events are natural processes (for example ingrowth, growth and mortality of trees) or human activities (for example cuttings, silvicultural treatments, drainage of peatland, fertilisation). Branching of the simulation is due to several optional human activities in the same state.

The MELA simulator contains a general forest simulator based on individual trees (Siitonen 1983). The calculation units are described by a three-level data structure in a MELA data input file (**.VES**): a tree stand is described by one or more sample plots, and each of these sample plots has a set of description trees. The development of the calculation units is predicted via sample trees on sample plots according to the characteristics of each tree and its site. Each tree is described by a number of variables such as frequency (represented by number of trees per hectare), tree species, breast height diameter, height and age.

The calculation units are supposed to be independent of each other as far as the growth process is concerned. The development is simulated by models describing the ingrowth, growth, and death of trees (Ojansuu et al. 1991). Only expected values of the models are used in the simulation. The main simulation variables for trees are number of stems per hectare (that each tree represents), tree species, diameter, height and age. These simulation variables are transformed into volumes, timber assortments and values using respective models. Tables for volume and timber assortments of the stems are obtained from stem curve models (Laasasenaho 1982).

The automated branching of the simulation is controlled by general decision rules or dedicated simulation instructions for each calculation unit (**.TOI**). A parameter file including general decision rules is used to guide the chaining of changes caused by natural processes and treatments. The parameters concern the possible years of changes, the shortest possible interval between changes, the other changes similar to the proposed one which are checked for the shortest interval, permitted prechanges and the probability of change. The treatments are chosen with respect to the averages of calculation units. The initial specification of a management schedule is independent of the total acreage for which it is applied, reflecting the assumption of linearity in costs and returns.

One management schedule is a set of periodic (e.g. growth and outturn) and state variables (e.g. volume) in the middle and at the end of the subperiod, respectively. The decision variables available for storing include, for example, volume, increment, drain and cutting removal by tree species and timber assortments, value, gross income, costs, net income, net present value discounted with different interest rates, in total, 1000 variables for each subperiod.

A linear programming package called JLP (Lappi, 1992) was used to find management alternatives that are efficient with respect to the objectives included in the optimisation model (see chapter 2.2 for more details).

The stand database and coverages were created by the author. Data were imported as transfer files created from the original data files of TAUNO database and NALLE mapping system by the author. The interface between ARC/INFO and Ingres can be classified as a embedded system configuration (see chapter 4) where ARC/INFO has the capability to invoke actions by Ingres within a command stream expressed in terms of the constructs of the ARC/INFO's external schema. Interface to link ARC/INFO coverages with Ingres table was based on relates defined by the author. Programs together with AML- and SQL-macros (see chapter 4) were developed by the author to export and import data sets between Ingres database and other components such as MELA and JLP.

5.6 Database implementation

The main objective of database design is to find out the coverages and attributes for timber sale and logging planning and to take into account the needs of a variety of users (land-use planning, strategic forest planning, forest management, and experimental planning) within a specific geographic area. The completeness and accuracy of the database determine the quality of the analysis and final products. If the GIS must support a large diversity of applications and users, a systematic approach to GIS design and implementation is recommended (Smith et al. 1987, Armstrong and Densham 1990, Kowalewski and Schmidt 1989, Bayham and Leppert 1991).

There are several factors that influence a GIS database design: the data needs of applications that will be developed, availability and format of existing data required to support the applications, update and maintenance procedures, size of the database, hardware platform/configuration, number and sophistication of users, organisational structure of the users and facility, schedule, budget, and management support.

Once the necessary features and their attributes have been identified, the geographic features can be organised into layers of data. Typically, layers are organised so that points, lines and polygons are stored in separate layers. The main components to be designed for the ARC/INFO database are: the cartographic layers, feature attribute tables, and lookup tables (Chambers 1986). In addition, the specific parameters for each attribute, and types of values to be stored should be defined. Sometimes it may also be useful to define special tables to look up e.g. drawing symbol. These tables are referred to as look up tables.

The tabular database design is accomplished through a process called data normalisation (Date 1986). During the process, data are organised into a series of tables that are related to each other by common keys. In practice this means that a simple key is assigned to all cartographic features and all descriptive attributes about the feature are stored in separate lookup or related tables (see fig. 16 in chapter 3). For example, in a stand coverage, each stand can be identified with its unique identification number. The inventory data are then maintained in a RDBMS such as ORACLE or INGRES. Another table may provide more detailed information about the stand, for example measured sample trees.

The structure of the implemented database (appendix 1) is illustrated in figure 29. In this study, inventory stand attribute data and treatment proposals for experiments are stored in an Ingres database. SQL macros (appendix 2) were created to produce inventory reports for stands and summary views of cutting units for the timber sale. A view is only a virtual table that does not actually exist but looks to the user as if it does. The view acts as a kind of window through which we can see the total volume of timber derived from standwise inventory data. For example, in the following a view FOREST_INVENTORY (summarizing the total forest area and total volume) is defined based on a table CURRENT_STAND where stand inventory data such as the area and the volume of first and second storey of trees are stored.

```
CREATE TABLE CURRENT_STAND
      (arckey     NUMBER(13) NOT NULL,
      year        NUMBER(4) NOT NULL,
      area_ha     NUMBER(7,2) NOT NULL,
      volume1     NUMBER(5,1) NOT NULL,
      volume2     NUMBER(5,1) NOT NULL);
CREATE VIEW FOREST_INVENTORY AS SELECT SUM(area_ha)
forestarea_ha, SUM((volume1+volume2)*area_ha) volume_m3 FROM
CURRENT_STAND;
```

5.7 Process implementation

The aim of this section is to present the implementation of processes i.e. system interfaces and additional modules.

5.7.1 Creation of a planning project

The MELA input data are read from a file (**.VES**) which contains 31 stand variables for each stand or sample plot and 10 tree variables for every description tree (appendix 4). The sample plots and trees have to be furnished with site and tree variables necessary for future calculations. In this study, the software from the inventory and planning system of the University of Joensuu was modified to create treewise data from standwise inventory data (fig. 30).

Measured stand characteristics should include at least the following variables: forest type, mineral/peat land, basal area or number of stems per hectare, mean height and mean age. Sometimes recorded variables include the following attributes: altitude above sea level, temperature sum as degree days, mean diameter, minimum diameter, maximum diameter. If not measured, altitude above sea level is retrieved from a digital terrain model, temperature sum as degree days modelled using a climate model, and mean diameter using a regression model.

If no sample trees are measured in the field inventory, description trees are collected from a theoretical stem-diameter distribution. For stands where trees have no DBH, the number of stems is estimated and the number of stems is divided into diameter classes. For stands where trees have DBH, the basal area and/or the number of stems can be estimated. If the number of stems is recorded, the number of stems is divided into diameter classes as for small trees. If the basal area is recorded, the stem-diameter distribution is derived using a Weibull-function. Thereafter, sample trees (diameter classes) representing a number of stems per hectare are furnished with other variables such as height and age. The input variables of a height model include height above sea level, temperature sum as degree days, basal area of the stand, mean diameter of the stand, tree species, tree diameter and tree age.

The interface between the Ingres-database and the forest simulator had to be implemented by the author using embedded SQL because of the limitations of interactive SQL (see chapter 3 for more details on embedded SQL).

The flowchart of the **DBMSVES**-routine used to create MELA input data based on stand data stored in database tables is presented in figure 31. The programs (including **read_farm**, **read_stand** and **read_tree**) are listed in appendix 3. The output is written into MELA input files (**.VES** and **.TOI.**)

The MELA simulator is used to update the stand data. A FORTRAN routine **VESDBMS** was written to import the updated "view" into the database (appendix 3).

5.7.2 Simulation

The length of planning horizon and subperiods, the frequency and methods of treatment are user-supplied parameters and stored in parameter files (**.PAR** and **.TPD**). The activity list (see appendix 4) includes for each activity the possible years of changes, the shortest possible interval between changes, the other changes similar to the proposed one which are checked for the shortest interval, permitted prechanges and the probability of change. For this study, the possible years of changes and the shortest possible interval between changes were edited to correspond to the chosen planning horizon of 1, 3, 6, 10 and 10 years. The parameters were saved in files **SHORT.PAR** and **SHORT.TPD**.

The defined activities were first thinning, thinning, cutting of hold-overs, seed-tree cutting, shelter-tree cutting, clear-cutting, clearing, scarification, pine planting, spruce planting, birch planting, supplementary planting, tending of young stands and natural processes (growth, dying).

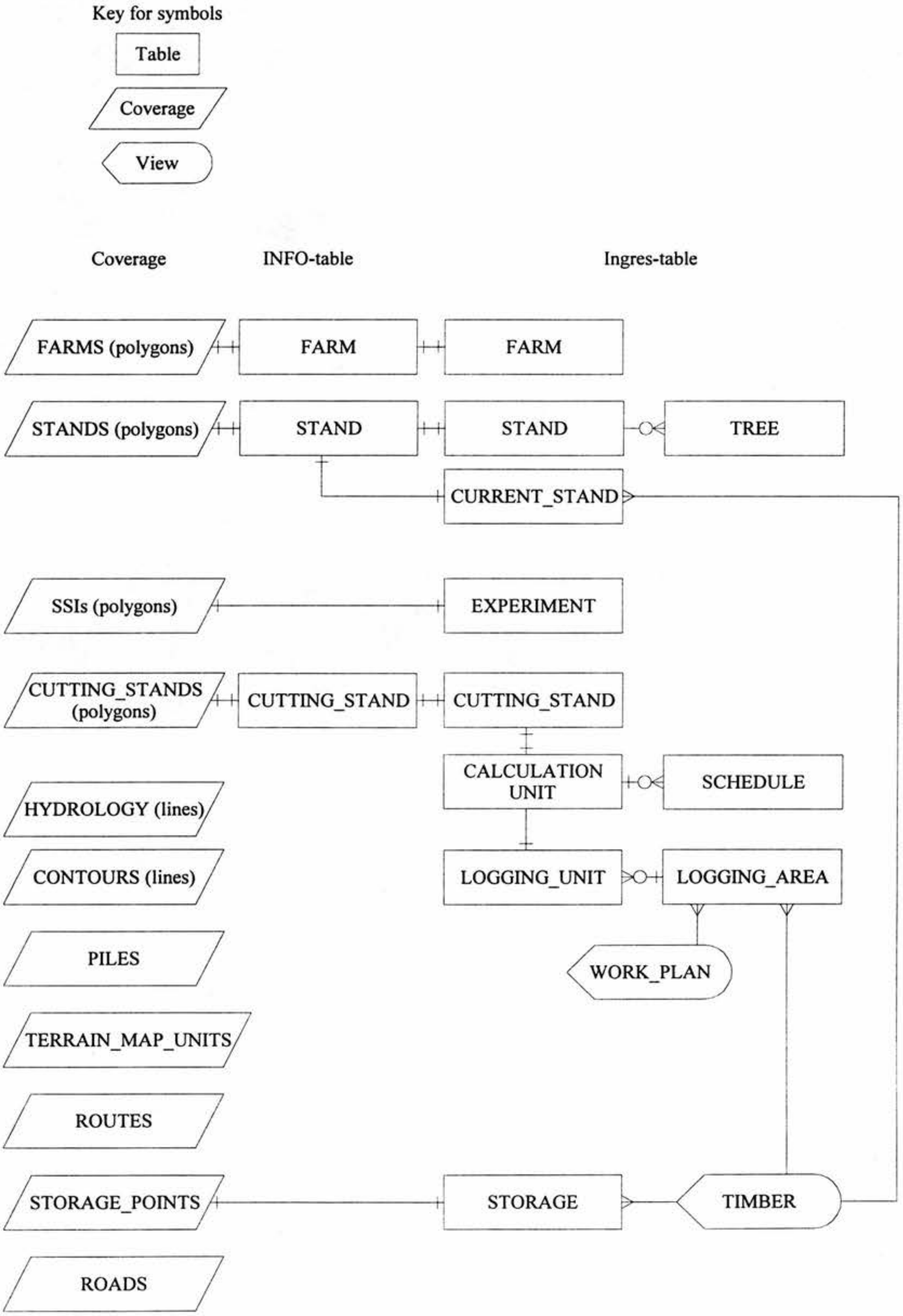

Figure 29. The structure of the database. (The links between coverage boxes are inappropriate because the coverages are geo-referenced within a GIS.)

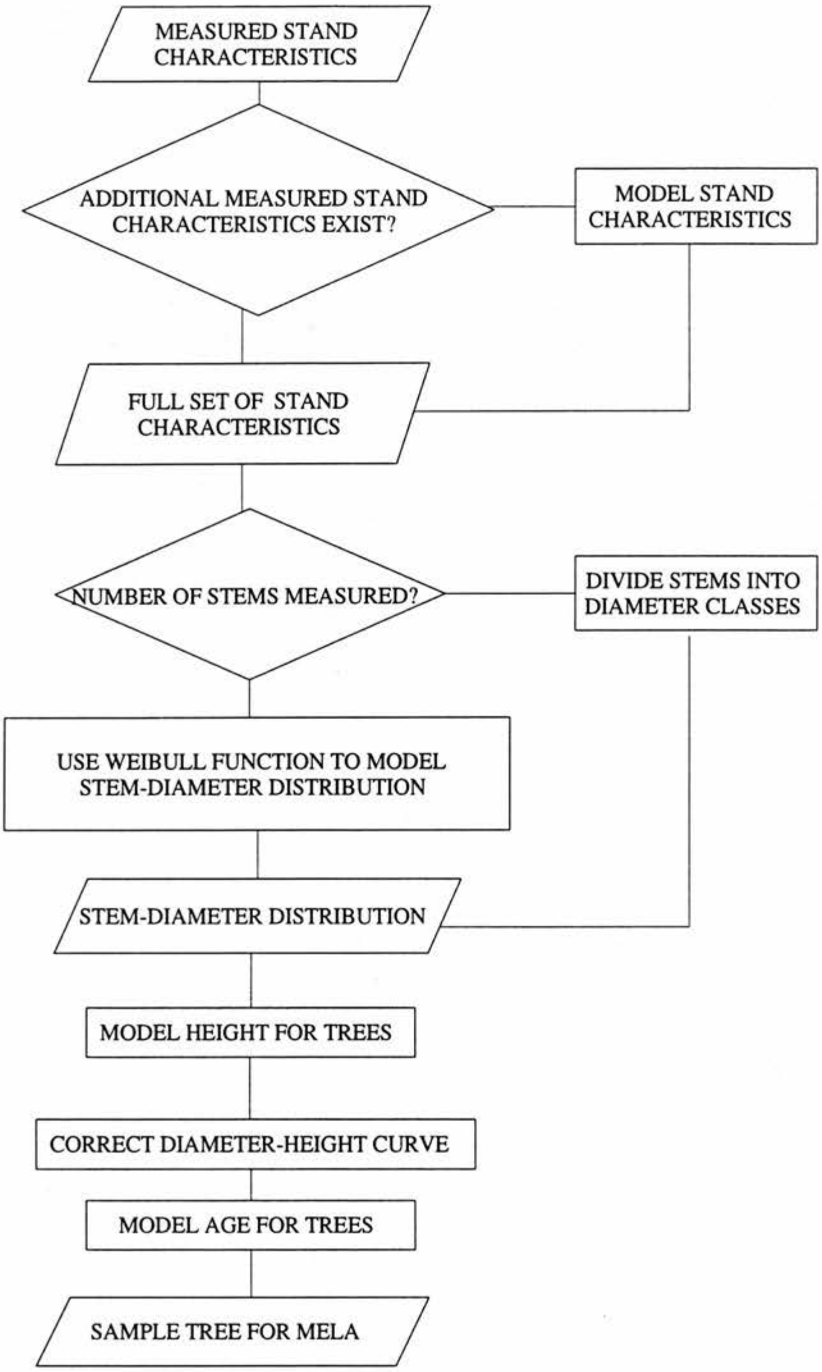

Figure 30. The procedure for the generation of sample trees for MELA.

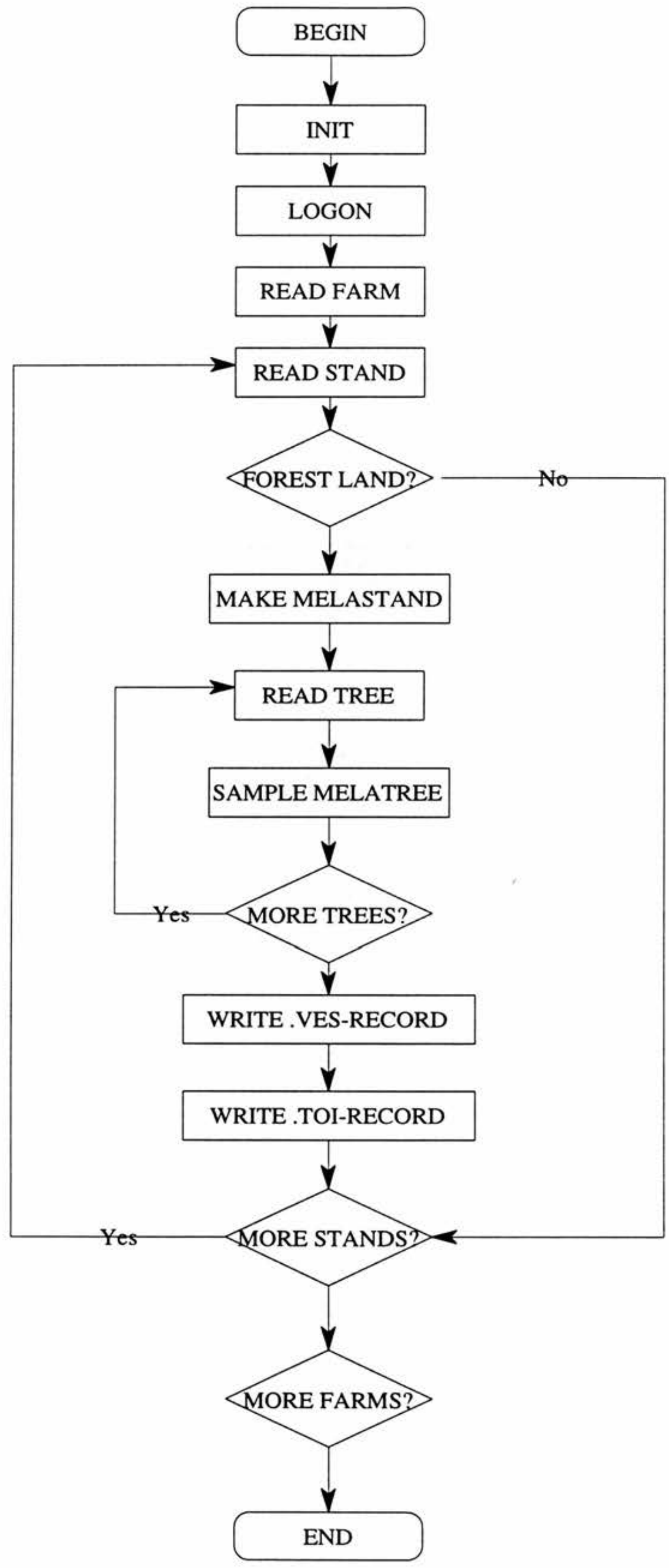

Figure 31. The procedure for the processing MELA input data.

5.7.3 Optimization

Simulated schedules (**x**-variables) from MELA output files are imported into JLP together with the treatment stands corresponding to calculation units (**c**-variables) from a GIS coverage. The **C**-variable can define, for example, the treatment class of calculation unit or the average extraction distance of the timber lot or parcel to which the calculation unit belongs. JLP macros were used to read data and an additional module **ADDNS** was written to add **c**-variables from a file exported from a GIS.

```
xform m
xdat SCHEDULES
xvar
x1001,x2001,x3001,x4001,x5001,x1002,x2002,x3002,x4002,x5002,
x1004,x2004,x3004,x4004,x5004,x1005,x2005,x3005,x4005,x5005,
x1006,x2006,x3006,x4006,x5006,x1007,x2007,x3007,x4007,x5007,
x1008,x2008,x3008,x4008,x5008,x1035,x2035,x3035,x4035,x5035,
x1181,x1182,x1184,x1185,x1187,x1188,x1190,x1191,x1193,x1194,
x2181,x2182,x2184,x2185,x2187,x2188,x2190,x2191,x2193,x2194,
x1195,x2195,x3195,x4195,x5195,x1370,x2370,x3370,x4370,x5370,
x1454,x1458,x1462,x1466,x1470,x1474,x1478,x1498,x1499,x1500,
x2454,x2458,x2462,x2466,x2470,x2474,x2478,x2498,x2499,x2500,
x501,x502,x503,x504,x505,x506,x507,x508,x509,
x1501,x1502,x1503,x1504,x1505,x1506,x1507,x1508,x1509,
x5501,x5502,x5503,x5504,x5505,x5506,x5507,x5508,x5509,
x700,x1700,x2700,x3700,x4700,x5700,
x823,x1823,x2823,x3823,x4823,x5823
cvar ns
read
write/* SCHEDULES
system addns batch
init
xdat SCHEDULES.xda
xform *
xvar
x1001,x2001,x3001,x4001,x5001,x1002,x2002,x3002,x4002,x5002,
x1004,x2004,x3004,x4004,x5004,x1005,x2005,x3005,x4005,x5005,
x1006,x2006,x3006,x4006,x5006,x1007,x2007,x3007,x4007,x5007,
x1008,x2008,x3008,x4008,x5008,x1035,x2035,x3035,x4035,x5035,
x1181,x1182,x1184,x1185,x1187,x1188,x1190,x1191,x1193,x1194,
x2181,x2182,x2184,x2185,x2187,x2188,x2190,x2191,x2193,x2194,
x1195,x2195,x3195,x4195,x5195,x1370,x2370,x3370,x4370,x5370,
x1454,x1458,x1462,x1466,x1470,x1474,x1478,x1498,x1499,x1500,
x2454,x2458,x2462,x2466,x2470,x2474,x2478,x2498,x2499,x2500,
x501,x502,x503,x504,x505,x506,x507,x508,x509,
x501,x1502,x1503,x1504,x1505,x1506,x1507,x1508,x1509,
x5501,x5502,x5503,x5504,x5505,x5506,x5507,x5508,x5509,
x700,x1700,x2700,x3700,x4700,x5700,
x823,x1823,x2823,x3823,x4823,x5823
cdat INDEX
cform *
```

```
cvar ns,melakey,coverkey,planyear,arckey,inveyear,ha,x,y,
zone,adjacency,d_distance,schedule,cuttingyear,cuttingmetho,
c1181,c1182,c1184,c1185,c1187,c1188,c1190,c1191,c1195,
e_season,e_distance,e_terrain,loggingsize,
haulageseason,haulageclass,storage,storagesize,
timberparcel,timberlot,gis1,gis2,gis3,gis4,gis5,
land,subclass,soil,hydro,site,stones,tax,develop,quality,use
,sitehist,siteyear,standhist,standyear,siteprop,standprop,
regenprop,urgency
```

The user interface of the JLP-package (i.e. macros written in JLP command language listed in appendix 6) is used to define heuristic rules to reject simulated treatment alternatives that conflict with the management goals of individual treatment units and redefine economic variables such as logging costs and resulting net income to take into account combinatorics of activities.

The following example shows how rejection is defined in a JLP macro.

```
*===========================
*multiple
*     1 timber production
*     2 conservation
*     5 experimental area
*===========================
*begin
xtran
if
(use.ne.1.and.(x1007>0.or.x2007>0.or.x3007>0.or.x4007>0.or.>
x5007>0.)) then reject
/
make
*end
```

Rejection is utilised to produce production possibility boundaries under different management strategies. For example, it is possible to set aside certain treatment classes from timber production by rejecting treatments of calculation units belonging to that particular class and compare the production possibility boundary (produced running the LP-model iteratively under different RHS-constraint values) with the one when all calculation units are supposed to be in timber production.

In JLP, the costs and returns of harvesting for marked cutting stands are calculated as a function of logging conditions such as the total outturn, the average extraction distance, and the terrain class of the whole logging unit composed of several cutting stands. For optimisation, the linear costs and returns of MELA are then replaced with the costs and returns calculated as a function of a combination of activities. All the decision variables that are affected by the changes in costs and returns (e.g. the net present value) are re-calculated (figure 32).

Models implemented are actually production functions for logging operations based on physical variables describing treatment schedules (**x**-variables) and treatment stands (**c**-variables) and run-time parameters such as up-to-date market prices derived from statistics (Maaseudun tulevaisuus 1989) and read from auxiliary files. The logging costs are calculated as a function of manual cutting costs and extraction costs. The time (min/m3) is converted into monetary units (FIM/m3) according to the standard wage rates and machine cost rates.

```
if method_1.gt.0.and.loggingsystem=manual.and.density1.ge.1)
then t21=1.248*1.045*(1+0.07*mmethod)* >
(1/(exp(1.46-0.00531*snow-0.000000000201*(snow**5)+ >
0.428*log(density1)- 0.124*(log(density1))**2+ >
0.162*sqrt(density1)+0.104*log(e_distance)- >
0.0535*sqrt(e_distance))/60))
end if
...
if (method_1.gt.0.and.loggingsystem=manual) then
machinehour=((t21*x1193)+(t22*x1194))/60
machinecosts=machinehour*machinehourmk
end if
```

Thereafter, the total logging costs per hectare, per stand and per logging unit are calculated.

The costs of manual cutting depend mostly on the average size and the quality of trees. The effect of terrain is a minor factor. The average productivity of manual cutting in the Suonenjoki research area is 8 m3/day (the average in Finland varies from 5-9 m3/day) and the average man day costs 320 FIM (the administration etc. costs of 15% are included in the unit price). Another way to define costs is to define the average costs of logging (FIM/m3) for pulpwood and saw logs based on the annual statistics produced by METLA.

The calculation of extraction costs is based on the time spent on extraction and the average unit price of the machine hour. The calculation of effective extraction time (in min/m3) is based on the formulae of Rummukainen et al. (1993) where the effective time spent on extraction (min/m3) is dependent on extraction distance (m), density of timber assortment (m3/100 route m), depth of snow and logging method.

To get the total working time we need to add time spent on short stops (4.3% of usage time), time when machine is standing still (19.5%), and time when machine is moving between piles (5.3%).

The JLP-macros (appendix 6) were written and stored as nested files which can be used for running the model. The user defines the decision problem: an objective function and constraints. All the variables describing the state and change of management schedules - including redefined and recalculated variables - in different subperiods are available as decision criteria (objective variable and RHS-variables). Constraints may apply to inputs, outputs and forest structure.

The planning procedure is iterative and evolutionary. A series of computer runs are made under revised conditions until the overall design of the management schedule is satisfactory (fig. 32).

When specification is complete, the problem is solved. The optimal solution and objective function values are displayed. It is not always possible to include all the decision criteria in the LP model. If the utility is not necessarily linearly related to the variables included in the optimisation, management alternatives (production programs) should be compared by the decision maker in a subjective way e.g. using thematic maps. The optimal solution indicates the treatment alternative for each treatment stand and thematic maps to illustrate solutions can be produced when the calculation units and schedules are stored in a database.

After examining the outputs, the user may want to analyse trade-offs associated with different goals, constraints or prescriptions or to continue iteration to check the effect of the synchronisation of logging on the optimal solution or stop the iteration sequence either to continue optimisation with a different goal or to report the achieved solution.

In timber sale and logging planning, a user might want to give a simple constraint to specify the required alternative for certain stands or to fix the logging unit for the operative subperiod. Before that he or she may want to examine maps of selected attributes or to print out the current state (e.g. land-use, treatment proposal) of a given stand to determine if it should be cut this year, and to list the total volume of chosen cutting units.

In conclusion, the user interface of JLP integrates spatial data and economic models effectively into a heuristic optimization model. A more dynamic integration of simulator and optimization might be useful for the generation of new alternatives for different logging systems.

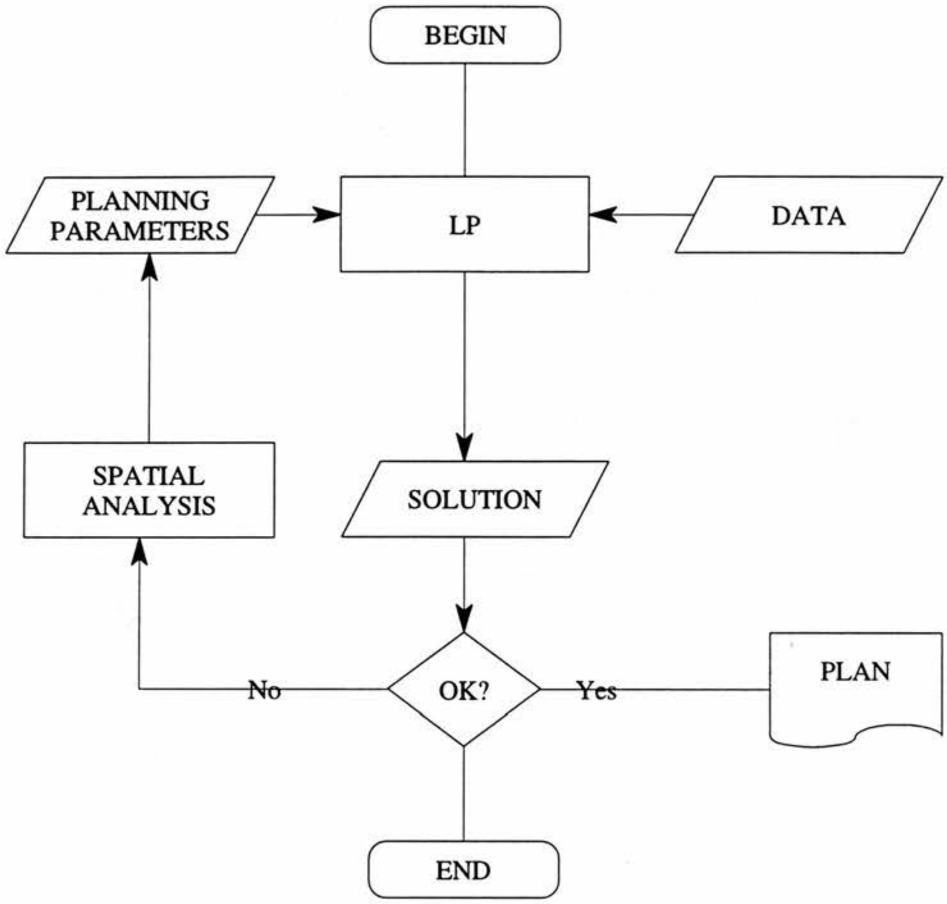

Figure 32. Iterative use of LP for heuristic optimisation.

6. A CASE STUDY: TIMBER SALE AND LOGGING PLANNING

The aim of this chapter is to present a case study. First, the background for the case study is introduced. The case study area is then presented and the material described. Thereafter the production possibilities under different management strategies are analysed. The analysis of site-specific restrictions is based on the advanced LP-formulations designed for this specific purpose. The combinatorial model developed as a part of this study is tested for a fixed timber lot. Finally, the sensitivity of the solution is analysed.

6.1 Introduction

The METLA needs trained workers and equipment to take care of the experiments. Since there are forest workers and farm tractors available, most timber sales are delivery sales and the logging system is based on manual cutting and farm tractor extraction. On the one hand this approach may lead either to intensive use of forest resources or a non-rational utilisation of forest workers in the areas where there are too many forest workers with respect to timber resources. On the other hand this may result in extensive utilisation of forest resources in the areas where there is plenty of timber in relation to forest workers. Clearly, the district manager should know the production possibilities of the forest area and the pre-set requirements to decide on the timber sale method, based on the actual forest conditions, available resources, and market conditions.

On the one hand a forest owner may estimate the production possibilities assuming that areas set aside from timber production or in restricted timber production belong to the timber production zone. Overestimates of timber production possibilities may lead to non-optimal decisions and losses. An estimate for this loss may indicate the amount the forest owner might be prepared to pay for better information. On the other hand the forest owner may face some utility losses if externally set constraints decrease the area in timber production. This utility loss tells how much the decision maker might want compensation from society. This study describes an approach by which the forest owner can estimate the losses due to non-optimal decisions or externally set constraints.

Decision analysis should provide information on decision alternatives and their consequences. There are three basic requirements for the decision analysis. First, a decision model should be able to integrate the guidelines of a strategic long-term plan with the operational short-term requirements. Second, the model should be able to handle multiple-use requirements. Third, uncertainty in the decision variables should be minimised.

This chapter will present a combination of GIS analyses and mathematical optimisation which can be used to assist in timber sale and logging planning. It is possible to evaluate the effect of environmental constraints on production possibilities and test the spatial and economic feasibility of work plans before the implementation.

In this study, the process consists of five main stages. In the first stage, the data (i.e. **x**- and **c**-variables) are prepared. In the second, the production possibilities under different management strategies are studied. In the third, the effects of combinatorics are studied. In the fourth, several alternative plans are prepared using optimization. In the fifth, the sensitivity of results is analysed by modelling the variation in the coefficients using the transformation compiler.

6.2 Study area

The Kaupinharju case study area is located in the Suonenjoki research area, North Savolax, Finland (fig. 33). Suonenjoki research area has an existing management plan for the period of 1989-1999 (table 1) prepared using the traditional long-term system. The total area of the Suonenjoki research area is 591 hectares, of which 86 hectares is set aside for research purposes. The research area is divided into several land parcels. According to the management plan the average volume of timber is 78 m3/hectare in timber production area and 80 m3/hectare in the whole forest area. Standing volumes are low because the area has been heavily exploited under the management of the previous land owner. In the past, annual cutting has been approximately 12 hectares/year, and total removal 1146 m3/year. Timber has been sold mainly at roadside (99.2 %).

The allowable cut for the forest land in timber production according to the forest management plan is 1215 m3/year (total usable timber of 1111 m3 of which 692 m3 is saw logs and 419 m3 pulpwood) i.e. 2.8 m3/hectare in timber production/year. The average annual regeneration area is 4 hectares of which 2.8 hectares is clearcut and

1.2 hectares naturally regenerated. The average total returns from timber production are estimated to be 243000 FIM/year and the costs 99000 FIM/year. The productivity and cost estimates of logging are 8 m3/day and 68 FIM/m3, respectively. Timber production requires 31 days for silvicultural work and 152 days for cutting. Experiment management requires 20 days per year. These estimates are regarded as guidelines in annual timber sale and logging planning which is usually directed at one land parcel at a time.

The Kaupinharju parcel or study area (table 2) covers 114.6 hectares in the Suonenjoki research area, of which 109.8 hectares are productive and approximately 5 hectares un-productive forest. There are 3.1 hectares set aside as conservation area and 13.4 hectares reserved for experimental purposes. The total area in timber production is 93.7 hectares. The total volume is 10276 m3 of which 7679 m3 is in timber production. About 15 % of the forested area is covered by stands which may be regenerated in the coming 10-year period. In figures 34 and 35 these are classified as mature stands (development/management class 6). The study area is bordered by two small lakes, Saarikaiset and Salmikainen. The location of set aside areas is shown in figure 36.

Table 1. Information on the management plan of the Suonenjoki research area.

Entity	Value	Unit
Timber volume in 2019	156.0	m3/hectare
Allowable cut 1989-1999	1215.0	m3/year
Allowable cut per hectare 1989-1999	2.8	m3/hectare/year
Annual regeneration area 1989-1999	4.0	hectare/year
Annual clearcutting area 1989-1999	2.8	hectare/year
Annual timber sale income 1989-1999	243000.0	FIM/year (1988)
Mean annual timber sale income 1977-1987	182206.0	FIM/year
Minimum annual timber sale income 1977-1987	71617.0	FIM/year
Maximum annual timber sale income 1977-1987	201343.0	FIM/year
Annual timber production costs 1989-1999	99000.0	FIM/year (1988)
Annual work days/harvesting 1989-1999	152.0	days/year
Annual work days/silviculture 1989-1999	31.0	days/year

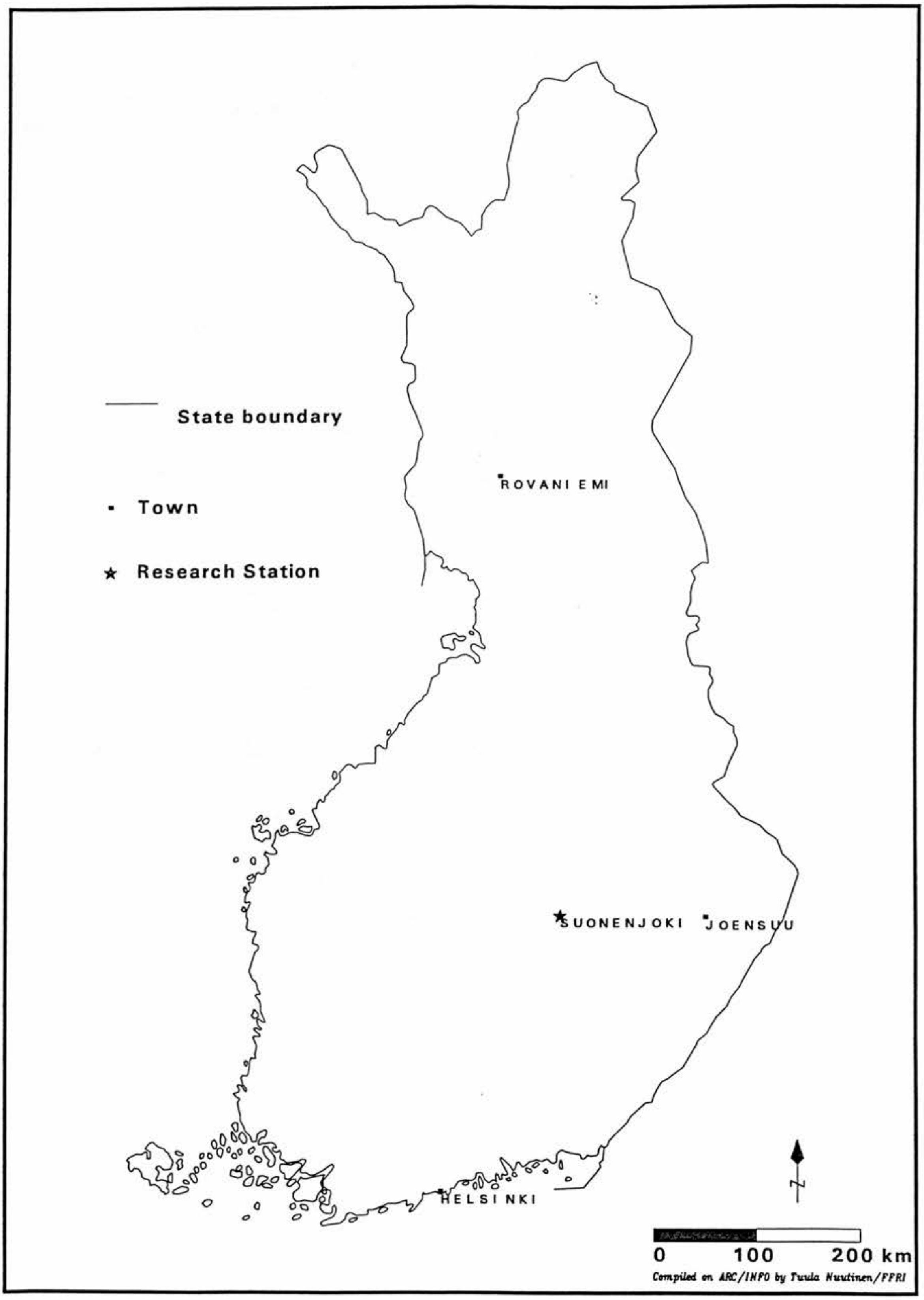

Figure 33. Map showing the location of the study area.

Table 2. Information on the Kaupinharju study area.

	Forest land	In timber production	Unit
Number of inventory stands	87		
Forest	114.6		hectare
Productive forest	109.8	93.7	hectare
Conservation area	3.1		hectare
Experimental area	13.4		hectare
Total timber volume	10276.0	7679.0	m3
Mean timber volume	95.0	85.0	m3/hectare
Total annual growth	382.0	239.0	m3/year
Mean annual growth	3.6	3.1	m3/hectare/year

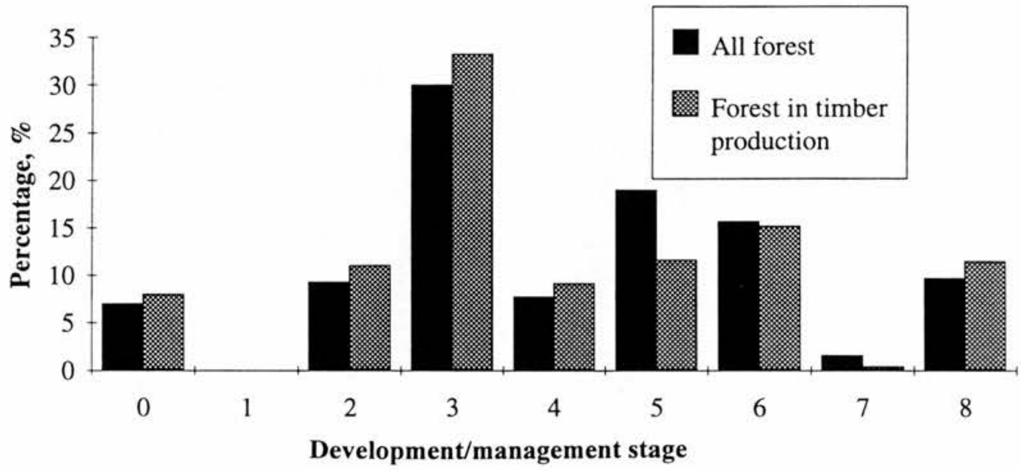

Figure 34. The distribution of development/management stages in the study area.
0=not forest land
1=open forest land
2=seedling stand
3=sapling stand
4=pole stand
5=timber stand
6=mature stand
7=shelterwood
8=seedtrees

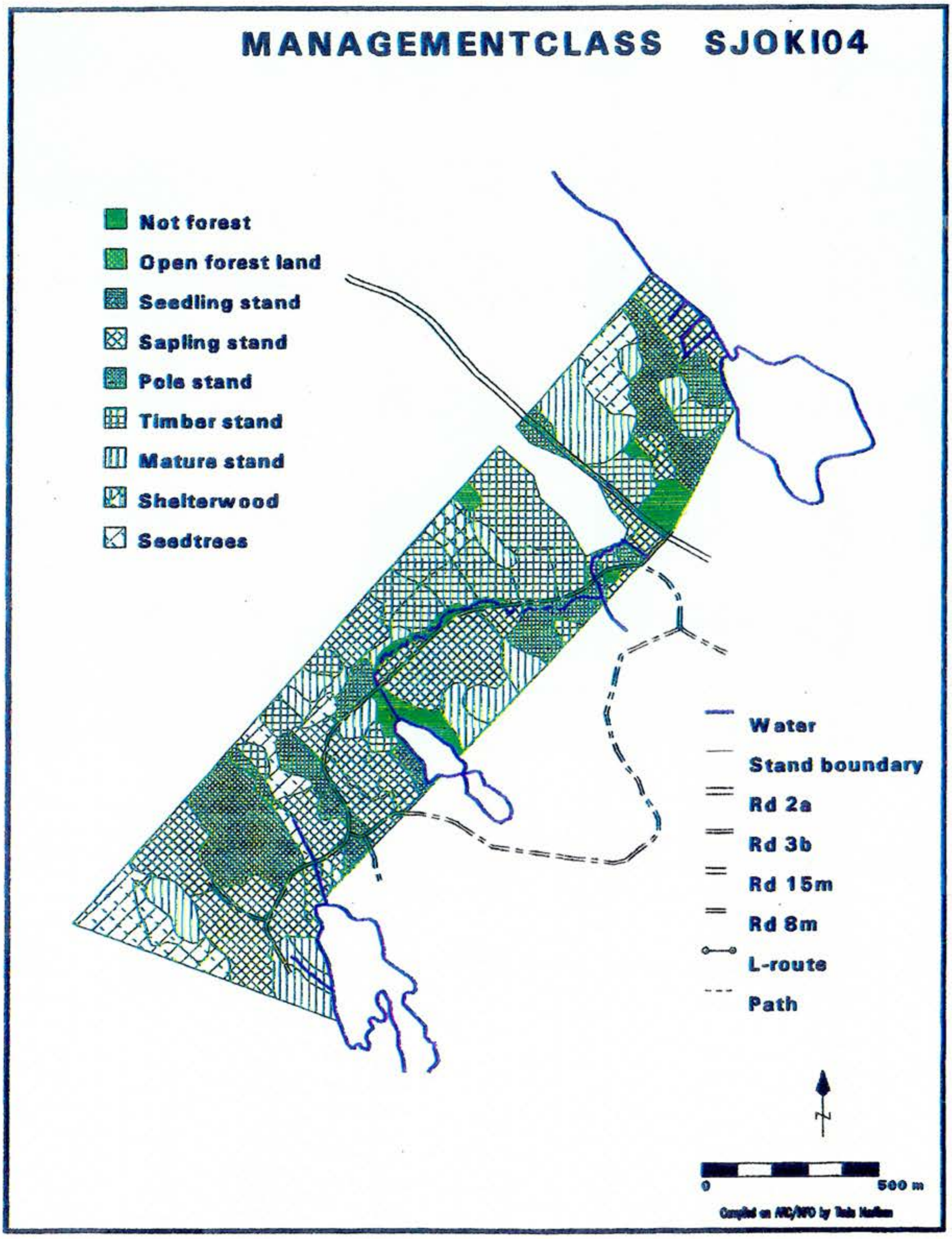

Figure 35. Management stage map of the study area.

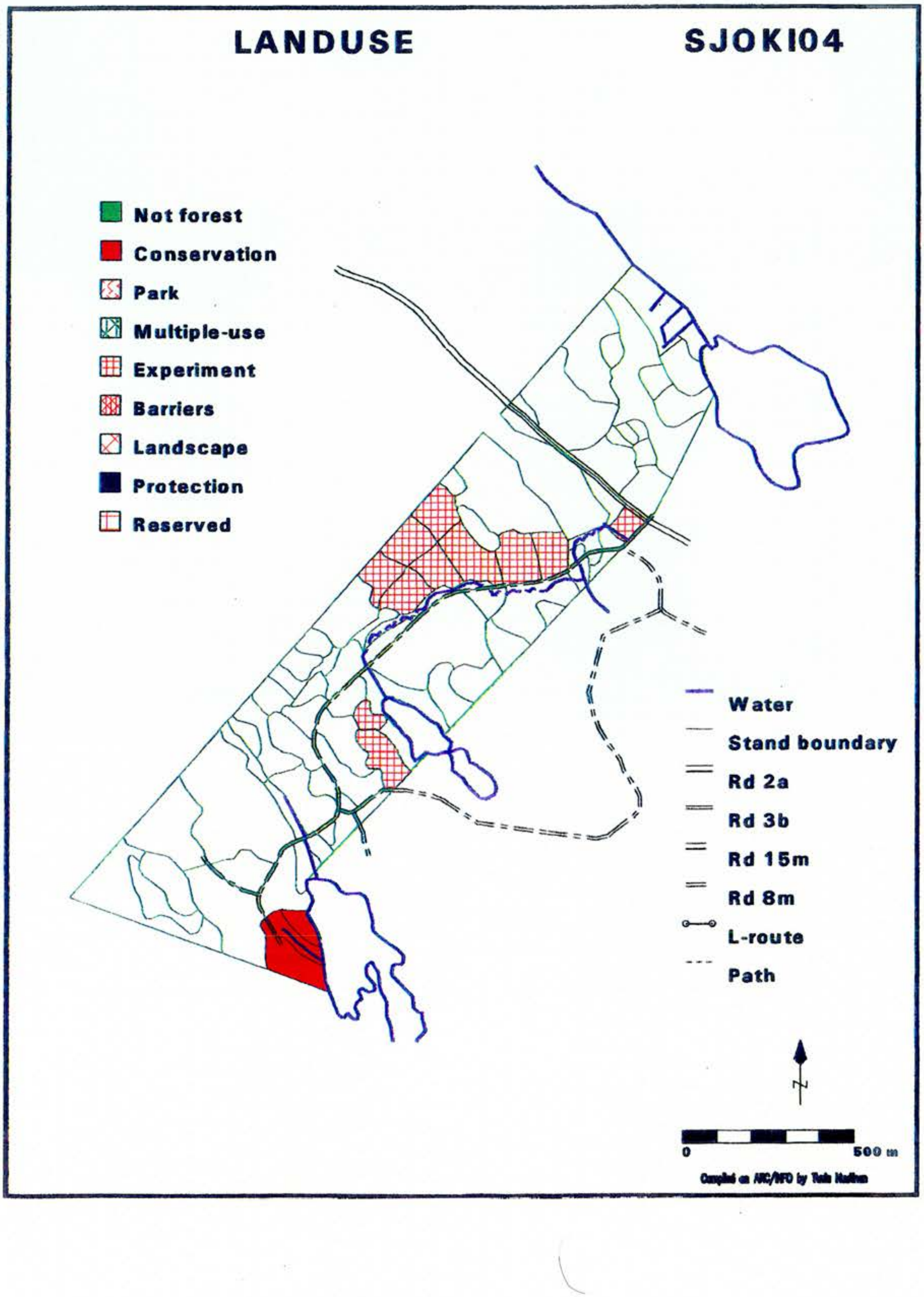

Figure 36. The landuse map of the study area.

6.3 Data preparation

The forest model consists of inventory data (tree stands) and site (terrain) information. The case study area was surveyed using ordinary compartment (stand) inventory methods during the years 1984 and 1987 by the team of foresters from the Research Area Office of METLA. The compartments were delineated on an aerial photograph. The delineation is based on land-use, multiple-use and stand characteristics. The stand characteristics of each compartment were measured using ocular compartment inventory. The field measurements in one compartment include the following stand variables that are surveyed separately for each tree species and canopy layer: age, mean height, basal area or stocking, and minimum, mean, and maximum of the diameter distribution.

The compartment data together with base map information were entered into the computer at the Research Area Office in Helsinki. The road network and compartment boundaries were digitized (1:10000) using a vector based mapping system NALLE. An identification number was given for each compartment so that the tree stand attributes could be joined later with the map information using a common identification number as key. The related stand descriptions were stored in a database called Tauno. Tauno is a system developed at METLA.

In this study, NALLE transfer files were created and FORTRAN-programs to convert NALLE map data into ARC/INFO coverages were written (see appendix 3). The ARC/INFO-coverages created are: land parcels (or "farms"), stands, roads, and hydrology (see appendix 1). In addition, contour lines were digitised from a topographic map and a digital elevation model was created using ARC/INFO: because information for map production did not include details required for a DEM, some were added manually. A coverage of slopes was created from a TIN. Thereafter routines were written in SQL to transfer the corresponding attribute files from Tauno-database into a Ingres-database (see appendix 2).

A coverage was created for terrain units that are homogeneous with respect to soil and slope by overlaying two coverages: inventory stands and slopes. The resultant coverage is here referred to as a terrain map. The terrain classification is based on the terrain classification model for Swedish forestry. This primary classification model describes terrain in terms of three main factors, namely: ground conditions, ground roughness and slope. The ground conditions and ground roughness are derived from the forest inventory database. In principle, soil type, forest type and moisture affect the ground roughness. Moisture differs in different seasons. However, in this study the effect of season was not taken into account because delivery sales are made only in winter time.

Attribute queries and spatial analysis were used to create a treatment stand coverage (fig. 37). Forest stands were classified as possible non-timber, controlled or restricted area if inventory characteristics so indicated. In addition, those stands adjacent to recent clear-cutting areas were classified as restricted area. Protection zones were generated around waterbodies and watercourses. First the protection zones were combined and then overlaid with inventory stands to produce a treatment stand coverage with associated treatment class attributes.

The map in figure 38 shows stands in non-timber, controlled or restricted classes as multiple-use areas, zones around waterbodies and watercourses as protection areas, and stands adjacent to recent clear-cuttings as adjacent.

The FORTRAN program **DBMSVES** (see section 4.7.1) was used to prepare the MELA input data. Data from the GIS were exported into a file using an AML-macro (appendix 5).

In this study, the temporal linkage between long-term and short-term was carried out by relevant choice of planning subperiods. The planning horizon of 30 years was chosen. The planning horizon of 30 years was subdivided into three five subperiods of one, three, six, ten and ten years. For each calculation unit a set of feasible management schedules was simulated by the MELA simulator according to rules given in the files **SHORT.PAR** and **SHORT.TPD** (appendix 4). Up to 50 different treatment schedules were simulated for each compartment. The main differences between the schedules of a compartment were in the timing of thinning, and in the timing and mode of regeneration. Each schedule was described by several parameters such as removal, income and costs associated with the treatments, or the state of the stand at a particular year. The simulation results (**x**-variables) were loaded into the database together with **c**-variables describing calculation units using FORTRAN programs **XDADBMS** and **CDADBMS**, respectively (appendix 3).

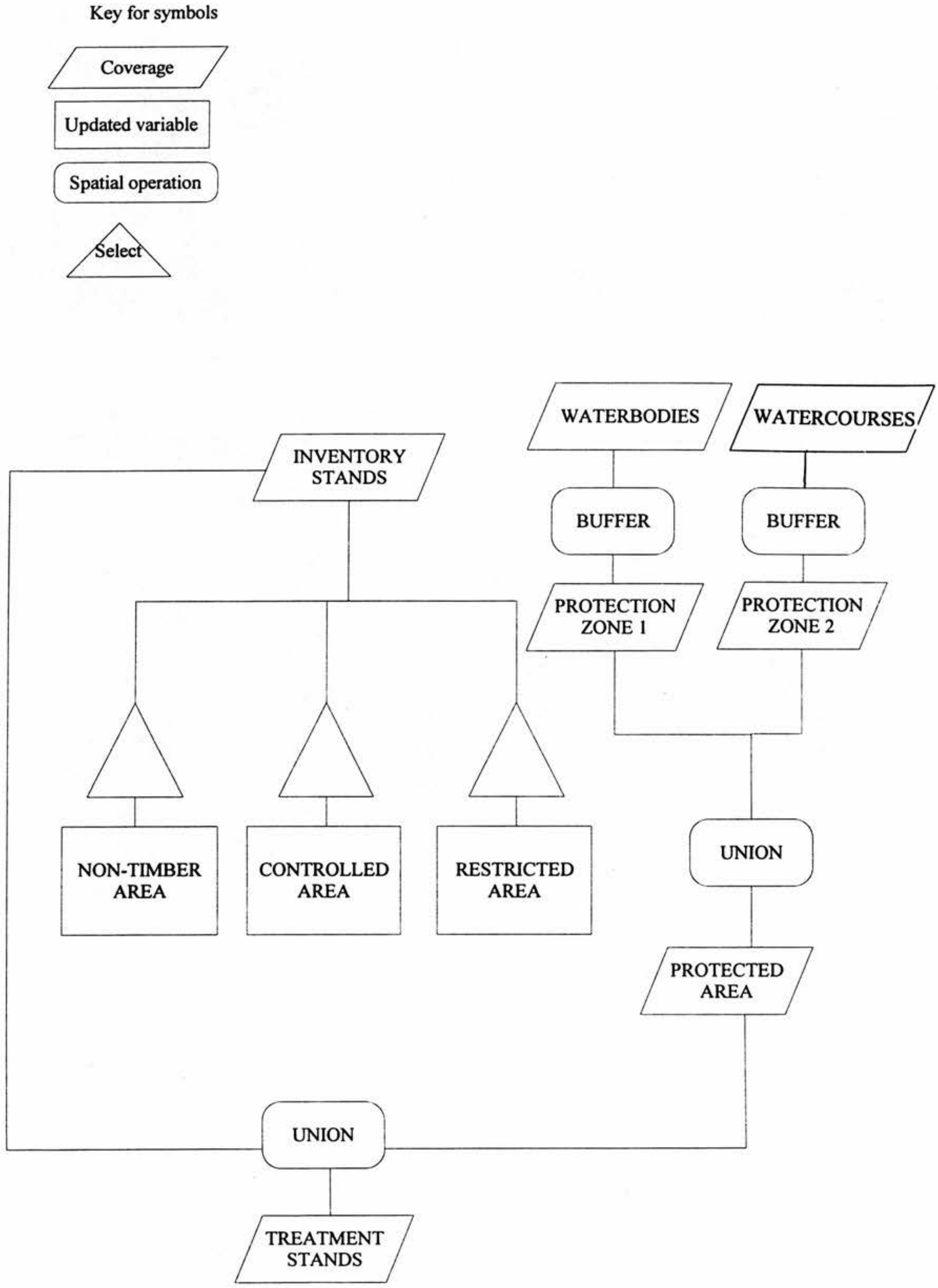

Figure 37. Cartographic model of the preparation of treatment stands.

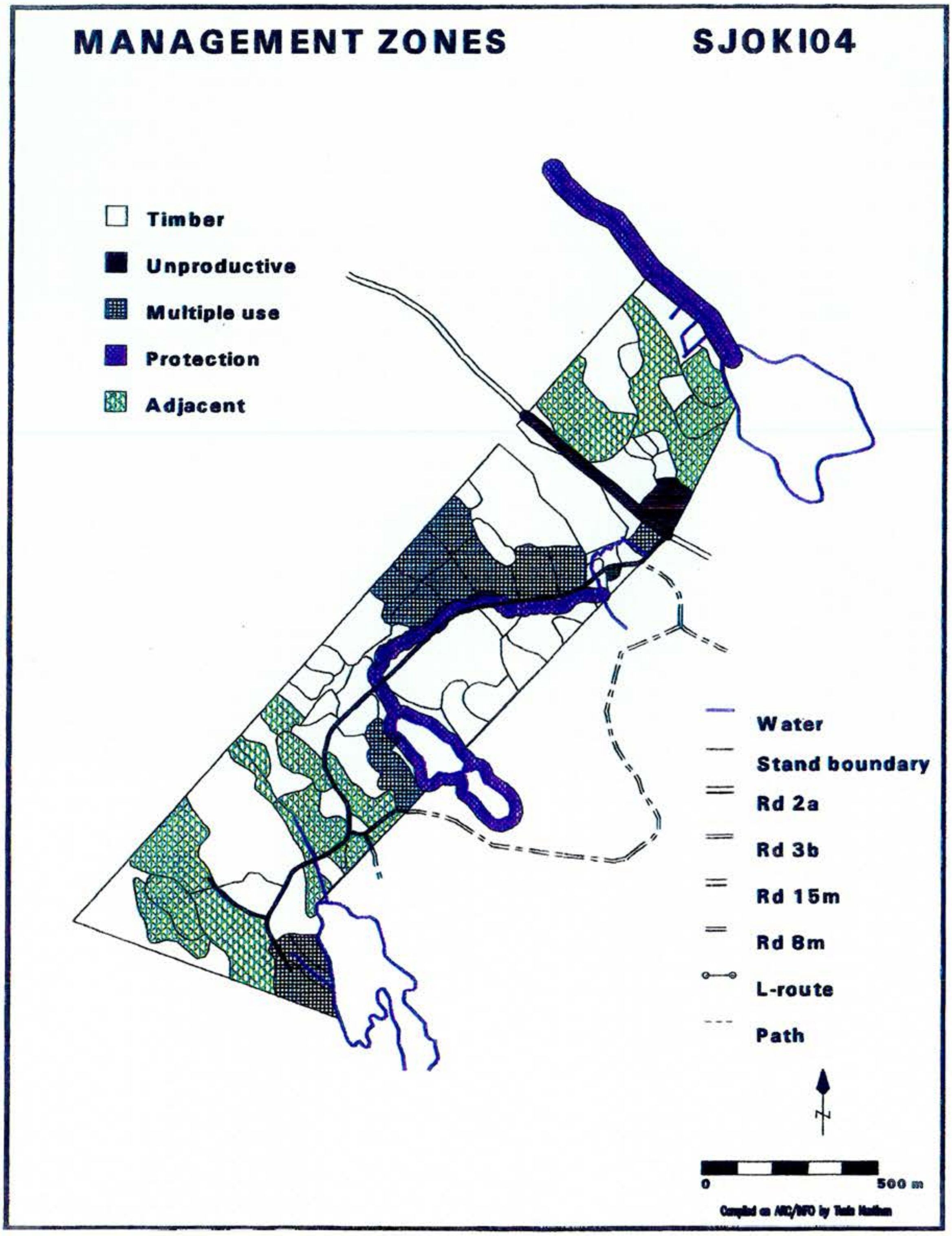

Figure 38. The map showing the zoning of treatment stands.

6.4 Analysis of production potential

The total utility from forest management is decomposed into the utility obtained from timber production and the utility obtained from multiple-use (fig. 39). The utility from timber production is decomposed into three components: short-term utility obtained from the immediate net income, long-term utility obtained from sustained timber drain, and the future utility obtained from keeping the future options (i.e. the sustainability after the planning period). The utility from multiple use is decomposed into five components: experiments, conservation, amenity, recreation, and biodiversity. Conservation is taken into account by setting aside areas from timber production or restricting timber production. In addition, costs due to modification of activities on areas outside those areas are included by modelling the actual operations and the costs related to them. Biodiversity, recreation and amenity of plans can be evaluated using summary reports for production programs.

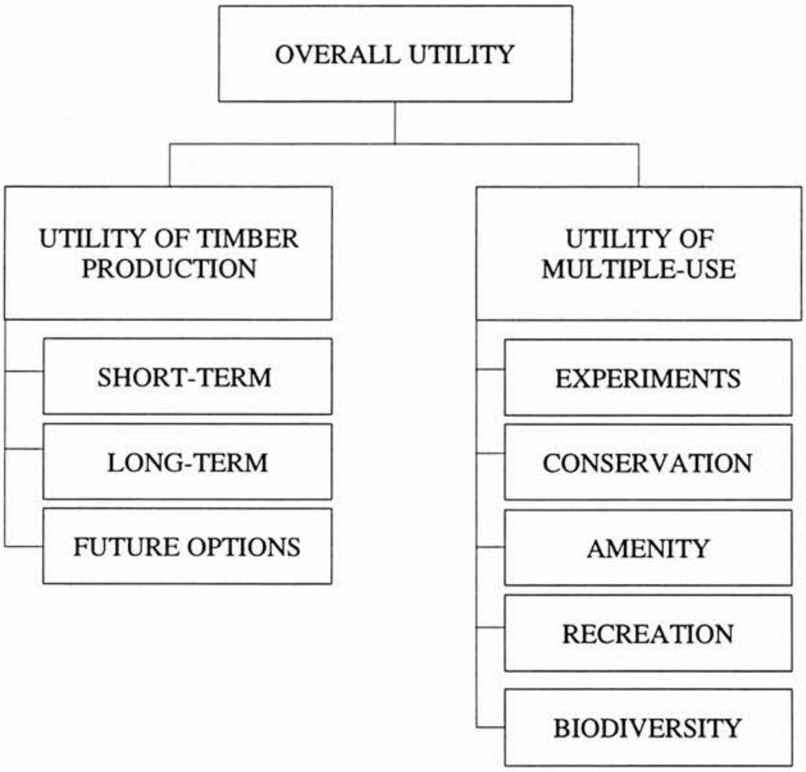

Figure 39. Decision hierarchy.

Two different problem formulations can be recognised. The first model, referred to as **Traditional**, is based on treatment units defined in the long-term plan (i.e. uncertain and average information on production possibilities). The second model (**Site-**

specific) takes into account management zones (i.e. feasible solution for a planning area but average information on production possibilities). For example, when the **Traditional** model maximises the net present value of income during the planning horizon, the formula is written as follows:

$$\text{Max } z_0 = \sum_{i=1}^{m} \sum_{j=1}^{n_i} pnv^{ij} w_{ij} \qquad (5.1)$$

where

pnv^{ij}	=	present net value of future income (FIM) of planning horizon from treatment unit *i* when managed according to management schedule *j*. Note: net income of the first planning period (*netincome.1*^{ij}) is based on current (certain) market information but net income of succeeding periods (*netincome.p*^{ij}) are based on (uncertain) estimates (e.g. trend price).
netincome.1^{ij}	=	net income (FIM) from treatment unit *i* during the first planning period when managed according to management schedule *j*
	=	*revenue.1*^{ij} - *costs.1*^{ij}
revenue.1^{ij}	=	aggregated revenues (FIM) of marketed timber assortments; revenue of a timber assortment *a* is *timber(a).1*^{ij} (m3) multiplied by current market *unitprice(a).1* (FIM/m3)
costs.1^{ij}	=	aggregated production costs (FIM) of marketed timber assortments; production costs of a timber assortment *a* is *timber(a,h,s).1*^{ij} (m3) multiplied by current market *unitcosts(a,h,s).1* (FIM/m3) for a given harvesting system *h* and a chosen sale method *s*
P	=	number of planning periods (*p*)

and other variables as in formulae (2.8)-(2.20).

In the **Site-specific** model treatment units are divided into separate "domains" based on management zones. Let D_t denote a domain of timber production (i.e. a subset of treatment units in timber production) and A_{C_i} a subset of accepted management schedules for the treatment class of treatment unit *i*. Only the treatment units of domain D_t can have management schedules that produce timber and result in revenues. The formula can be written as follows:

$$\text{Max } z_0 = \sum_{i=1}^{m} \sum_{j \in A_{C_i}}^{n_i} pnv^{ij} w_{ij} \qquad (5.2)$$

The simulated treatment schedules were used to analyse the production possibilities of the case study area under different management strategies. A management strategy may, for example, set particular management zones (such as multiple-use, protection or adjacent) aside from timber production. For each management strategy, the treatment stands are divided into given management zones according to the values of **c**-variables and those treatment schedules that are infeasible for the particular zone are excluded (rejected). The feasible schedules are then used to compute the boundaries of production possibilities by solving a series of relevant LP-problems.

Four different strategies based on different zoning (domains) were analysed (table 3). First, the strategy corresponding to the **Traditional** model i.e. without site-specific constraints - referred to as **Timber** - was analysed. Then three different production frontiers corresponding to the formulation **Site-specific** referred to as **Multiple**, **Protection**, **Landscape** were computed so that treatment stands were divided into management zones (domains) and those treatment schedules that are infeasible for the particular zone were rejected (fig. 27). In **Multiple** only those stands classified as set aside or restricted in forest inventory were excluded from timber production. In **Protection** the protection zones were set aside additionally. In **Landscape** the stands adjacent to recently cut stands were set into restricted timber production. The restrictions implemented as rejects in JLP are described in table 3 in more detail.

When all productive forest is available for timber production (**Timber** in figure 40), tightening of the end volume constraint affects the level of present net value only when end volume of over 15000 is required. Setting aside areas (**Multiple**, **Protection**, **Landscape** in figure 40) from timber production decreases the level of net present value considerably. Production possibility boundaries **Multiple** and **Protection** differ only when expectations of present net value are high and all the hectares are needed. This indicates that both the areas and the value of timber production on protection zones are small. In restricted timber production, increasing end volume requirement decreases net present value at an increasing rate, because clearcuttings cannot be applied.

Table 3. Problem formulation for the generation of production possibilities.

	Area, ha	Reject
Timber		
Multiple		
Experiment	13.4	cut
Conservation	3.1	cut
Protection		
Experiment	13.4	cut
Conservation	3.1	cut
Watercourse	4.5	clearcut
Waterbody	1.3	regeneration
Landscape		
Experiment	13.4	cut
Conservation	3.1	cut
Watercourse	4.5	clearcut
Waterbody	1.3	regeneration
Adjacent	29.1	clearcut

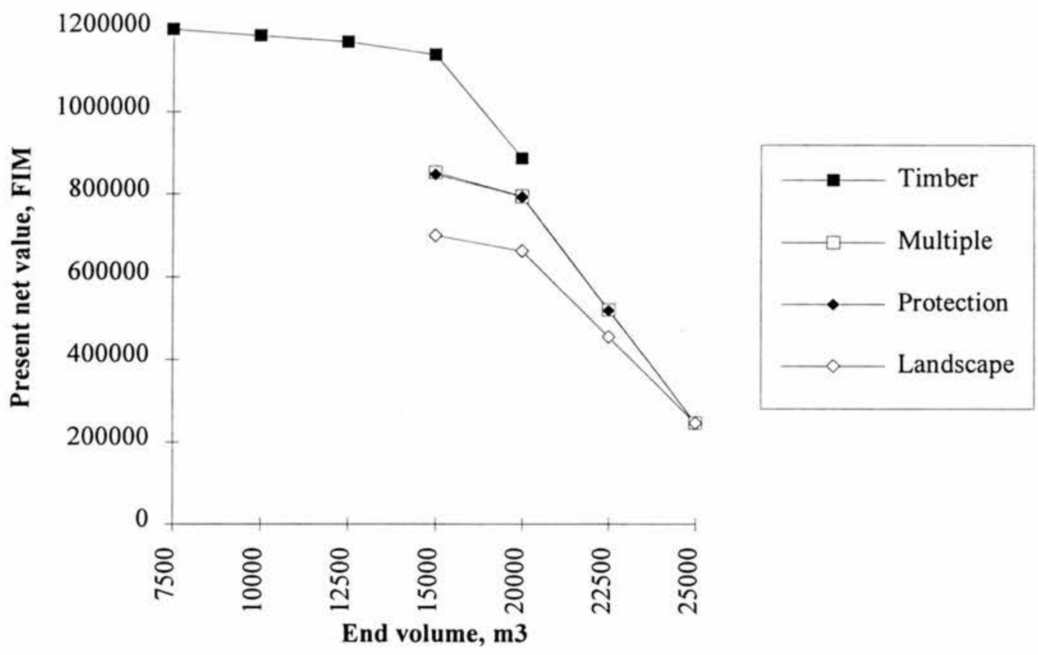

Figure 40. The production possibility boundary of the present net value (FIM) for the planning period 1989-2019 and the end volume (m3) in 2019.

6.5 Combinatorial analysis

The formulation **Site-specific** ignores changes in the areas under timber production due to the site-specific constraints set for areas under restricted timber production. For example, the layout of extraction routes may be different due to the environmental constraints and consequently the logging costs may increase. In practice, however, also the combinatorics (or interdependence of activities) should be taken into account, i.e. the costs and returns should be calculated as a function of the combination of treatments.

The third model referred to as **Combinatorial** takes the effect of synchronization of logging on logging costs into account. The linear costs and returns are replaced with combinatorial costs and returns, which are calculated as a function of logging conditions. Thus, the nonlinear relationships between inputs and outputs of production processes and interdependence of activities are implicitly defined in the structure of the model. Since neither the standard nonlinear or integer programming methods were regarded as capable of solving the combinatorial problem, a sequence of linear programs is used in this study. The efficiency of the optimization method is based on the core module, the JLP-algorithm, which utilizes the special decomposable structure of the forest planning problem.

In the **Combinatorial** model treatment stands marked for cutting are extracted into a specific domain. For example, the problem presented in **Traditional** and **Site-specific** would be defined as follows:

$$\text{Max } z_0 = \sum_{i \in D_h} \sum_{j \in A_i} pnv^{ij} w_{ij} + \sum_{i \notin D_h} \sum_{j \in A_{C_i}} pnv^{ij} w_{ij} \qquad (5.3)$$

where D_h denotes a domain of harvesting (i.e. a subset of treatment units marked for cutting) and A_i a subset of accepted management schedules for the treatment unit i.

The standard linear model defines the costs and returns of treatments as independent of the area to which the treatments are applied. In the **Combinatorial** model the linear model is replaced by the modified coefficients which take into account nonlinear and combinatorial relationships between inputs and outputs. According to the standard linear formulation the costs are independent of the area to which the treatments are applied and all the costs and returns are expressed per unit area (hectare). In the combinatorial model the calculation units are supposed to interact, and, therefore, the costs and returns are calculated as a function of the combination of treatments.

The variable part reflects the long-term plan and the fixed part can be interpreted as an adjustment of the long-term plan. In the objective function (5.3) the first part represents net income from treatment units marked (fixed) for harvesting. The estimate of net income is based on estimates for revenues and costs of marked harvesting. The estimate of revenues is based on the estimate of timber drain by timber assortments, the method of sale and the characteristics of the timber parcel relevant from the point of sale (e.g. the total amount of timber at stump or at a storage point). The estimate of costs is based on the estimate of timber drain by timber assortments and the costs of harvesting using the given method for the sale and harvesting system. The model described above integrates the short- and long-term decision models and takes into account the effect of site-specific constraints, and the non-linearity and interdependence of the calculation units.

The user interface of the JLP-package (i.e. macros written in the JLP command language) integrates effectively spatial data and economic models. The spatial models for the site-specific restrictions (e.g. zones around waterbodies) and harvesting activities (e.g. extraction) are implemented in the GIS (Nuutinen 1992) and the results of models (e.g. the codes for management zones and the totals of extraction) exported to JLP as **c**-variables. Economic models to calculate costs and returns are implemented as JLP-macros. The models are based on physical variables describing treatment schedules (**x**-variables) and treatment stands (**c**-variables), production functions for harvesting operations, and run-time parameters such as up-to-date market prices read from auxiliary files.

The combinations can be short term plans either fixed using GIS-techniques (in data preparation stage) or derived from an LP-solution. In this study, a logging plan made in 1989 and implemented in 1990 was chosen for the validation of the system. The logging unit for the first subperiod is chosen and fixed. Cutting units were created and each cutting unit given a key for its original treatment unit and the plans associated with it. The plan was stored as a timber parcel and corresponding piles were generated on a map (fig. 41). In practice forest workers collect different pulpwood assortments into stacks for extraction. Sawnwood is left as it is. For analysis purposes the stacks were stored as centroids (points) referred to later as "piles". A pile is described by its location and the amount of timber (by timber assortment) to be extracted from the surrounding terrain. Views of timber resources at different locations i.e. the growing stock of inventory and treatment stands, standing timber of each treatment alternative, and roadside timber for a particular cutting were created.

Extraction routes on the ground can be laid out in various patterns, primarily depending on the amount of timber, means of transport and terrain conditions. At present transport by tractor along parallel strip roads is used, with long and straight strip roads preferred. The goal of the design was to find the spatially feasible and economically effective layout. If there are objects on the terrain which should be avoided e.g. due to conservation requirements (e.g. buffer zones around the paths, shorelines or streams) or the difficulty of the terrain (such as a drainage network), the objects are classified into terrain obstacle classes. Side slopes, to which forest tractors are sensitive, are avoided, particularly when the tractors are loaded. The strip roads should be connected by means of cross-roads for so called loop driving. In steep slopes the road system may be laid out in a zig-zag pattern. In clearcutting the distances between strip roads are relatively short (8-12 m); in thinning this distance is about 16-24 m, to optimise efficiency of machine use. The layout of storage points and extraction routes was designed using a so called barrier background. In figure 42 a map presenting barriers such as restricted areas, protection zones, difficult terrain and steep hills is presented.

Two coverages were created for harvesting planning: extraction routes and storage points. The resultant route coverage was then combined with the terrain coverage and extraction routes were split into segments according to terrain class. A segment is described by its length, slope-code, soil type, forest type and moisture. A slope-code was derived from a look-up table as a function of the slope percentage.

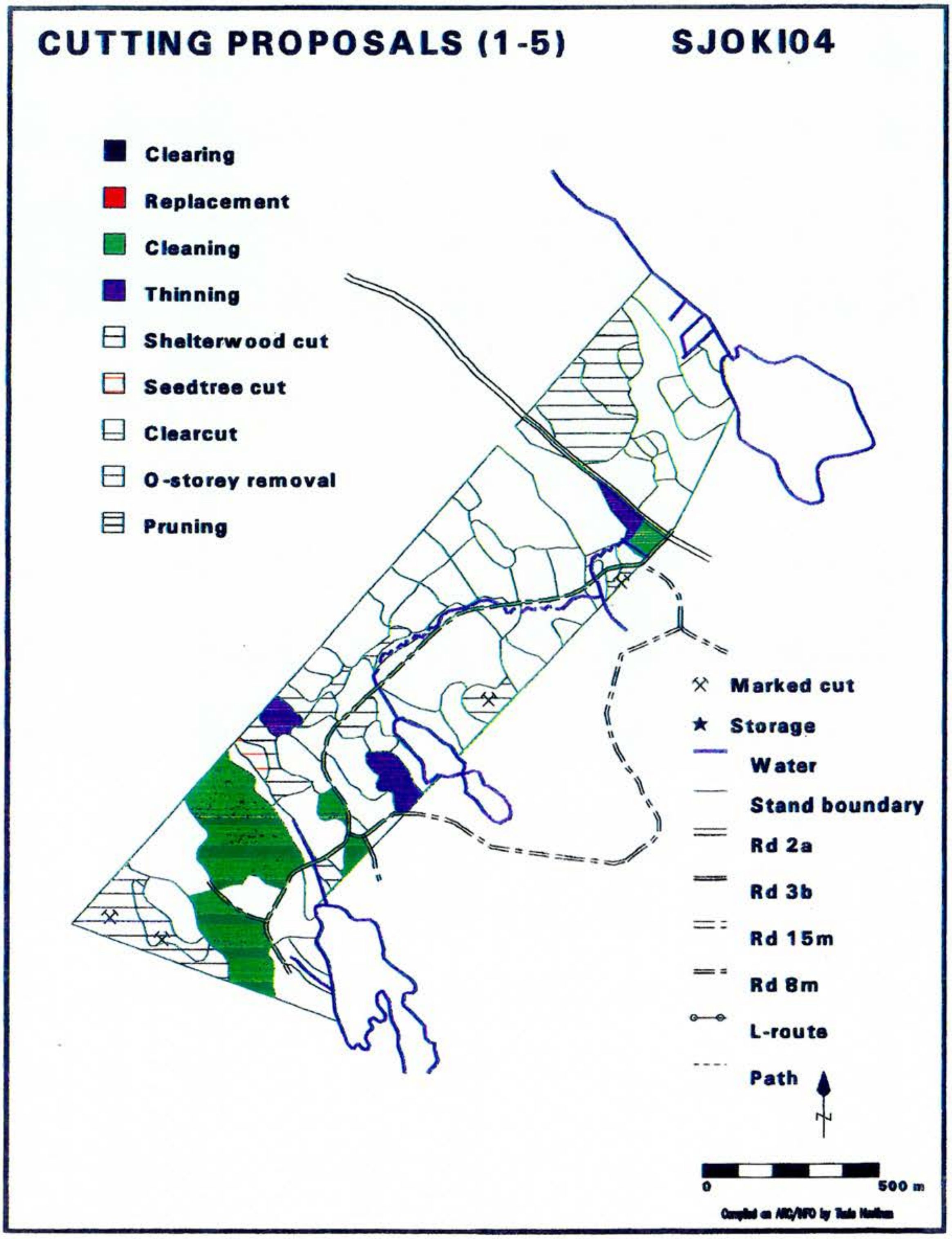

Figure 41. The map showing the treatment proposals made by the forester and the cutting stands chosen by the local forest manager.

The machine extraction process is simulated using the cutting unit coverage and off-road extraction route layout. There are two approaches to simulating the extraction process on the terrain: the simulation of forwarder round-trips on terrain or the simulation of the timber flow along the network. For the estimation of the extraction costs the ROUTE-module of ARC/INFO (v. 5) could be used. The ROUTE-module can only utilise segment variables as impedance items. The operating speed (m/min) can be computed for every segment as a function of terrain difficulty (slope and ground roughness). The travel time (min) can then be converted into price (FIM) using the machine rate (FIM/min). However, the method was not considered appropriate for this study because the actual size and location of piles over the terrain was not known and therefore the phases of the round-trip could not be separated.

In this study, therefore the ARC/INFO command ALLOCATE was used to model extraction operations and the results were used to calculate the average extraction distance, the average terrain class and the total volume of timber in storage points. The layout (fig. 43) is then used to determine the actual extraction conditions.

The treatment stands coverage was used to create calculation units for the MELA-system. The stands marked for cutting were fixed and information on restrictions and logging conditions extracted into calculation units. Each cutting stand was given the variables defining timber parcel, timber lot, cutting method, cut etc. In this study, the chosen logging system was based on manual cutting and extraction by a farm tractor. Timber could be sold standing, at stumpage or at roadside.

Table 4 shows parameters for stands 84 and 85 illustrating the effect of combinatorics on unit prices. The price correction for the size of timber parcel is measured as cubic meters (m3) of timber, the price correction for the extraction distance is measured as meters (m) and the price correction for terrain class of extraction is measured in classes. For example, if stand 85 would be cut individually, the unit price would decrease by 12 FIM due to the amount of timber harvested (44 m3 in total). If the stands are cut and timber sold independently in different years, the total price is 914 FIM less than when the timber sale and logging is synchronised.

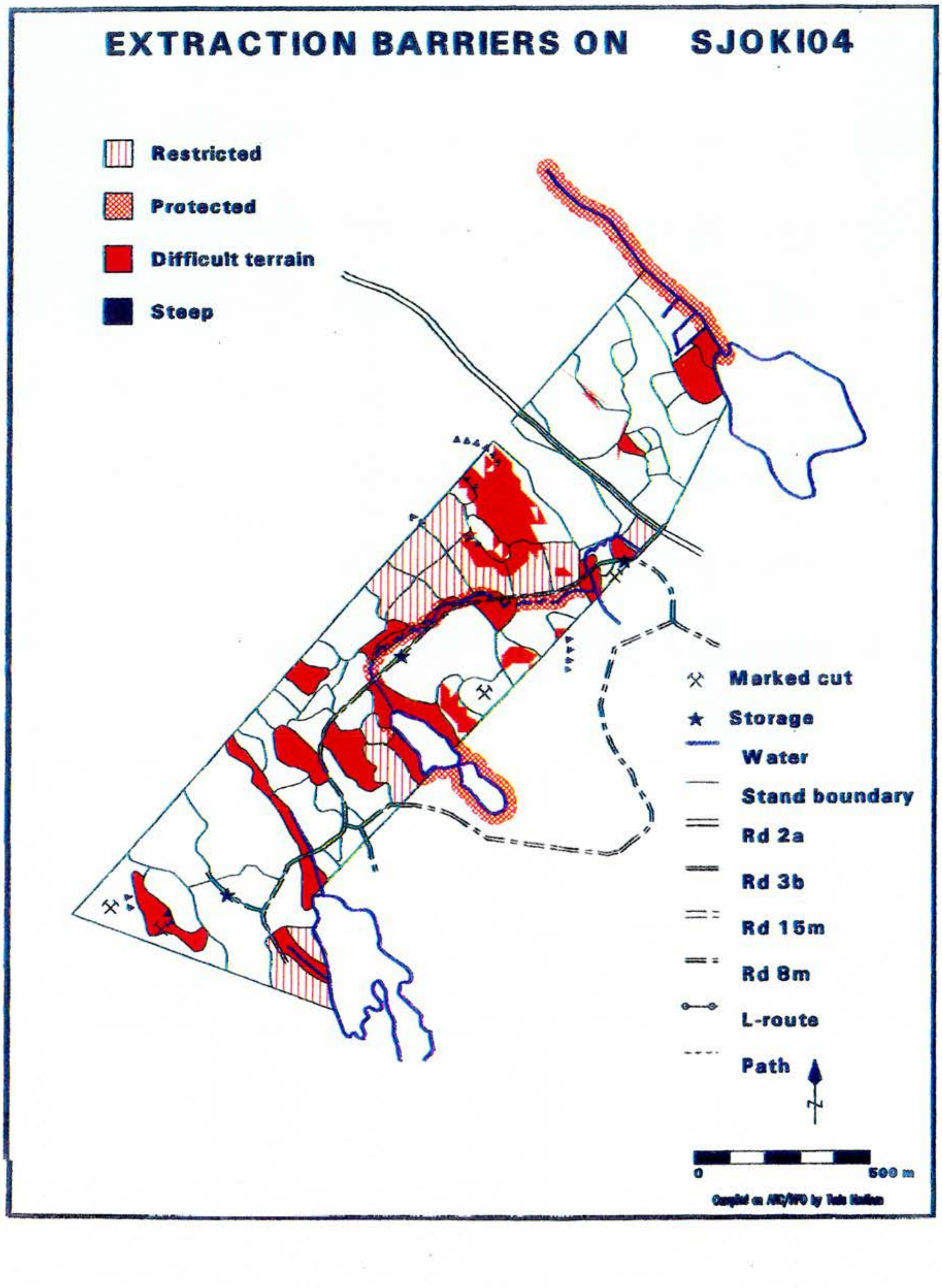

Figure 42. The map showing the extraction barriers.

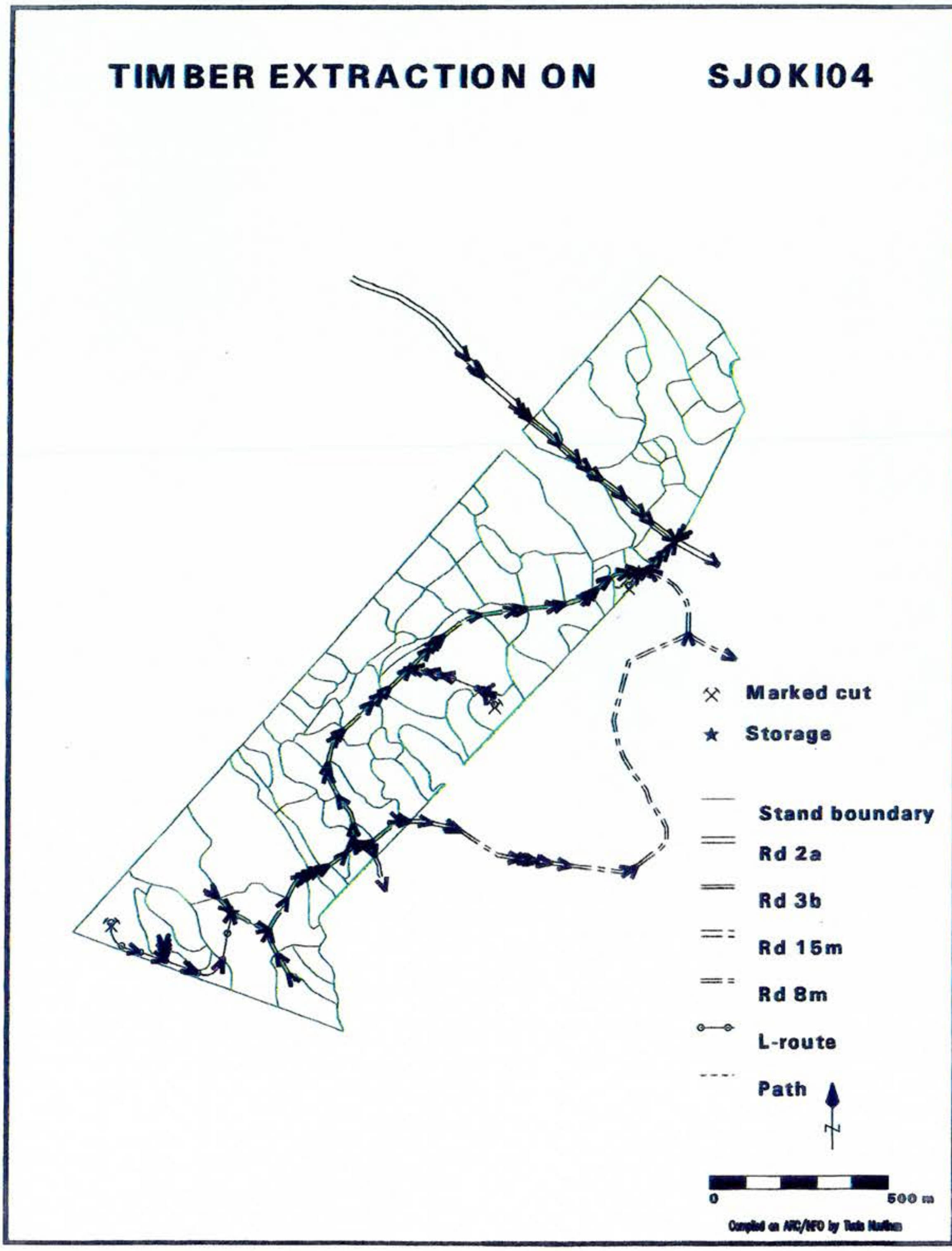

Figure 43. The map showing the extraction environment. Arrows denote the direction of movement of timber. (The number of arrows is simply a product of the drawing procedure.)

Table 4. Estimates of unit and total price for timber sale and logging.

	Stand 84	Stand 85	A. Stands 84+85 synchronised	B. Stands 84, 85 individually	Difference btw. A and B
area, hectare	3.75	1.45			
sawn log, m3	180	8.75			
pulpwood, m3	126	34.8			
distance, m	541	375	520		
terrain class	2	3	2		
correction (m3), FIM/m3	0 (306)	-12 (44)	0 (350)		
correction (m), FIM/m3	-3 (541)	0 (375)	-3 (520)		
correction (terrain), FIM/m3	0 (2)	-12 (3)	0 (2)		
price (pulpwood), FIM/m3	92	71	92		
price (sawn logs), FIM/m3	208	187	208		
price, FIM	49032	4107	54053	53139	914

6.6 Alternative plans

Three different plans were prepared. The summary of the problem formulations is presented in table 5. The decision-maker was assumed to maximise present net value of timber production so that the timber volume in 2029 would reach the level of 156 m3/ha stated in the long-term plan. For the area of 109.8 hectares the end volume would be 17129 m3. In the plan referred to as **Multiple** the annual net income should reach the level of 243000 FIM/year stated in the long-term plan. The plan **Employment** aims - instead of reaching the net income level - to employ a forest worker for 153 work days/year when management zoning is taken into account. The plan **Allowable** is aiming at the allowable annual cut 1215 m3/year stated in the long-term plan under the manpower constraint. The costs of research on areas set aside is not included in the model because research departments - not the research areas - are responsible for the management of experiments. Site-specific constraints were taken into account in all plans. The column 'reject' in table 5 shows which activities were not considered feasible for different management zones and were therefore rejected.

Table 5. Problem formulation of alternative plans.

	Area hectares	Goal PNV, FIM	Total timber 2019, m3	Net Income 1989, FIM	Manpower, days	Annual allowable cut, m3	Reject
Multiple	109.8	max	>17129	243000			
Experiment	13.4						cut
Conservation	3.1						cut
Watercourse	4.5						clearcut
Waterbody	1.3						regeneration
Adjacent	29.1						clearcut
Employment	109.8	max	>17129		<153		
Experiment	13.4						cut
Conservation	3.1						cut
Watercourse	4.5						clearcut
Waterbody	1.3						regeneration
Adjacent	29.1						clearcut
Allowable	109.8	max	>17129		<153	=1213	
Experiment	13.4						cut
Conservation	3.1						cut
Watercourse	4.5						clearcut
Waterbody	1.3						regeneration
Adjacent	29.1						clearcut

In table 6 integer solutions for alternative plans are presented. The remaining volume in 2029 is about the same in all plans even if the cut of **Allowable** in year 1989 is far less than in **Multiple** and **Employment**. As a result also the net income is only a third of **Multiple** and **Employment**. It is obvious that without the sustainable yield constraint the maximization of net present value leads into heavy cuttings at the beginning of the planning period. It also seems that the annual cuttings of one parcel would not offer work for one person.

Table 6. Information about alternative plans.

		Plan		Unit
	Multiple	Employment	Allowable	
PNV	417650	413756	325779	FIM
Total standing timber volume				
1989 before cutting	10239	10239	10239	m3
1989 after cutting	6542	6929	9252	m3
1990	6903	6888	6766	m3
2009	9272	9253	9158	m3
2019	13977	13964	13852	m3
2029	17164	17374	17155	m3
Cut 1989-1990	3995	3666	1213	m3
Net income 1989	373684	354331	118390	FIM
Men in harvesting 1989-1990	176	153	53	days

The model can assist also in the choice of sale method. Each calculation unit that belongs to a logging unit should have two options: one for delivery sale and one for stumpage sale. In this study one of the methods was chosen at a time for analysis. To analyse the effect of policy change from delivery sales into stumpage sale and giving up the permanent forest workers a possibility is to run the LP-model twice: once with stumpage sale prices and once with delivery sale prices and compare net income. When the timber parcel was sold standing the net income from sale was 183880 FIM. From roadside sale the net income was only 125060 FIM.

6.7 Sensitivity analysis

> "Risk indicates a situation in which there is more than one possible outcome from a taken choice of action. The decision maker knows these outcomes and also their probabilities." (Kilkki 1987, p. 22).

> "Uncertainty represents a state of knowledge in which the possible outcomes of the alternative choice of action are known but their probabilities are unknown" (Kilkki 1987, p. 24).

Forest planning systems try to predict the consequences of current decisions. Unfortunately the systems are usually based on deterministic models even if nature is stochastic. It is extremely difficult to estimate the future consequences of current decisions, and the possible developments arising from decisions.

The current optimal plan may become non-optimal whenever there are unpredicted changes in the decision environment. Therefore, forest planning should provide the decision maker with both the predicted outcomes of current decisions and their predicted probabilities. In addition, the system might assist in the examination of what changes are likely to occur and how they will influence the problem in general and its components in detail. The utilities of different choices of actions should be evaluated with respect to the level of certainty of the outcome. For example, it is possible to use past experience to estimate the probabilities and thus handle uncertainty as risk.

The behaviour of a model depends on the reliability of both the model and the input data. In validation the effects of observational errors of source data, errors due to interpolation or extrapolation of data, or inaccurate estimation of parameters (e.g. due to auto correlation) should be checked. A problem of using simulation models is that we cannot measure the degree of imprecision. Therefore it is important to test the sensitivity of the model to the variation in the parameter values.

The growth estimates are based on the assumption that forest development follows previously observed yield curves. However, future timber growth may be affected by ecological or technical changes - or natural disasters such as forest fire or wind throw. At a stand level the uncertainty of timber yield estimates may be an important issue and some methods to incorporate risk into planning models have been developed. Another possibility is that uncertainties may balance each other out.

The future timber market is assumed to stay stable and the price to be constant over the planning period. Since both the supply and demand are stochastic, timber price fluctuates continuously and in an unpredictable way.

In this study, the uncertainties involved with the decision making are analysed in three ways. First, the effect of uncertainties involved in yield estimates (due to inaccuracies of inventory and calculation) are examined. Second, two sets of timber prices are used. Third, the effect of interest rate is analysed.

The range of economic output measured as net income of first period varies from 109024 FIM to 117584 FIM and 97909 FIM when the random error of volume estimate varies from 15%, 20% and 25 %. The costs of inventory were added into operational costs and the corresponding random error was modelled. When inventory costs of 1 FIM/m3 were assumed to leave an error of 20 % the net present value was 304080 FIM. When inventory costs of 2 FIM/m3 were assumed to leave an error of 10 % the net present value was 275224 FIM. The effect of changes in the market policy can be tested by changing the price table used. The range of economic output measured as net income of first period varies from 121502 FIM to 115122 FIM when timber price is assumed to increase or decrease from the present. The range of economic output measured as net present value varies between 306926 FIM and 291027 FIM when the interest rate varies from 5 to 7.

In the following, the price estimation approach developed in this study is compared both with the traditional approach in which price estimates are based on the average prices of a region and with the actual prices from the statistics of the Suonenjoki research area (table 7). When assuming average pricing of timber for harvesting stands 84 and 85, the roadside value given by the system is 71582.8 FIM, logging costs 36140 FIM and the resulting stumpage value 35442 FIM. When logging conditions are taken into account in the estimation of timber price and logging costs, the roadside value given by the system is 70776.1 FIM, logging costs 39889.2 FIM and the resulting stumpage value 30886.9 FIM. (It should be noted that the above mentioned figures are based on different unit prices for each timber assortment - pine log, pine pulpwood, spruce log, spruce pulpwood, birch log and birch log - compared to the figures given in table 4 where price groups are log and pulpwood.) The difference between stumpage values of 4551.1 FIM shows the effect of synchronisation.

Table 7. A comparison of different price estimation approaches.

Variable	Average pricing	Taking logging conditions into account	Actual pricing	Unit
Roadside value	71582.8	70776.1	68050.36	FIM
Logging costs	36140	39889.2	16481.10	FIM
Stumpage value	35442	30886.9	51569.25	FIM

When the actual stumpage value (residual when extracting logging costs from the price at the roadside) is higher than the average stumpage price (price when timber is sold at the stump), the sale at the roadside is assumed to be a good choice because the timber extraction by forest owner costs less than the extraction on an average. The actual roadside value, logging costs and stumpage value in this case (stands 84 and 85) are 68050.36 FIM, 16481.10 FIM and 51569.25 FIM, respectively. The stumpage price estimate based on the actual timber volume and average unit prices would be 46203.55 FIM which is considerably lower than actual value of 51569.25 FIM. Based on that difference it looks like the choice of the roadside sale was right. The high stumpage value, however, is not due to the savings in the extraction. The main reason for the difference is that the timber parcel contained mainly good quality pine logs which got nearly 50 FIM/m3 more than average. This could not be predicted in the planning system because there are no models available in Finland to predict the quality of saw logs.

Even if the administrative costs of timber extraction are not included in the logging costs, the logging costs 16481.10 FIM exceed the difference of average roadside price and stumpage price (13494.7 FIM) which indicates that the choice was wrong. The forest company would have been ready to pay more than the stumpage value (residual) for stumpage sale because their extraction costs would have been lower. The use of the planning system might have changed the decision.

The planning system helps the decision maker to analyse the effects of changes in parameters such as timber price. In addition, the system assists when analysing the uncertainties and risks related to planning. Because the system can utilise the information on logging conditions, it can be used to assist in the choice of the timber sale method. The system should be used to examine the relative differences between alternatives presented within the system. The comparison of (absolute) values compared with the actual values show that the models should be further developed to produce more realistic estimates.

7. DISCUSSION

The aim of this chapter is to discuss the methodology developed in this study. There is a lack of methods for the integration of short-term timber sale and logging planning with tactical models (e.g. cutting budgets), and the integration of environmental and economic objectives into the same planning process. There are new requirements for inventory data but the effort of additional surveys should be minimised. Pre-harvesting inventory is being replaced with a corporate multisource GIS database. However, information may be missing, in an imperfect form, or too expensive to acquire. The important issues are: first, is it possible to replace current practice with an integrated system, and second, does the inventory data meet the requirements or do we need additional measurement. The benefits and problems are analysed, and the needs for future development and research efforts are suggested.

7.1 Applicability

A GIS (ARC/INFO), an RDBMS (Ingres), a forest simulator (MELA), and a linear programming package (JLP) have been incorporated into an integrated forest planning system.

The forest stand, hydrology, contour and forest road network maps are stored in a GIS (ARC/INFO). The description of available timber resources is stored in a relational database management system (RDBMS) integrated with a GIS.

The GIS is used to provide site-specific information on treatments stands (i.e. homogeneous units in terms of possible treatments), management zones (e.g. treatment stands next to waterbodies) and activities. The simulator is used to simulate a number of treatment alternatives (schedules) for each treatment stand. The schedules are used to analyse the production possibilities and to compile alternative plans, and the JLP-package is used to carry out the required computations.

GIS tools can be used for the design of the logging unit (i.e the layout of logging routes and storage points) so that the environmental and technical constraints are taken into account. Since the calculation of extraction distance as a shortest straight line between two points is a simplification of reality, the spatial analysis functions were used to calculate the terrain and extraction distances of calculation units. The logging unit coverages are stored as GIS coverages and statistics (such as the average extraction distance and terrain class of logging, and total volume of timber stored in a storage point) for the timber sale are calculated. These results are then used as explanatory variables for production models in JLP.

The results of multisource data analysis should be carefully validated. To validate the applicability of the model the following questions concerned with assumptions and restrictions are discussed. First, is the description of the forest accurate and appropriate enough. Second, are the decision alternatives (simulated schedules) relevant to the problems involved. Third, can the mathematical model represent the combinatorial problem.

The validation is especially important when coverages of varying resolution are overlaid. Let us first consider if the **description of the forest** is accurate and appropriate enough. The benefit of this approach is that calculation units correspond to treatments stands and therefore the proposals can be directly transferred to on-the-ground treatments. The case study shows, however, that the current inventory system fails to meet some requirements for operational planning. First, the accuracy of the timber volume estimate depends on the homogeneity of the stand and the age of the data. Pre-harvesting inventory may be necessary if field inventory is totally out-of-date. Second, a lack of digital data concerning the national conservation programme (reserved areas for wilderness, recreation and scenic purposes) will complicate the development of multiple-use restrictions. Third, the methods for recording the location and rules of site-specific restrictions - such as management prescriptions for habitats of rare species - have not been standardised. Fourth, the contours were digitised for map production not for the creation of a digital elevation model. Therefore the details needed to create an accurate DEM were missing.

Let us then consider if the **simulated schedules** are relevant to the problems involved. There is a lack of yield models for some silvicultural practices such as favoring mixed stands or uneven-aged management. Management strategies related to these goals cannot be implemented.

There are two approaches in forest planning: (1) zoning of the timber production area into restricted and non-restricted timber production areas and (2) employing multiple-use intensity as a decision variable for each hectare. If multiple-use services belong to the goals, they should somehow be included in the mathematical programming, to guarantee efficiency with respect to these services, even though numerical description may be difficult. Mathematical programming can be used to produce efficient management alternatives only if the simulator is able to deal with multiple-use production functions.

A question should concern the **reliability** of simulation models. The MELA System has been used for national and regional analysis of timber production potential based on the data of the Finnish National Forest Inventory (NFI) since the 1980s. The models are also based on the data of the NFI. The models cover the whole range of Finnish forests and they are extensively tested and evaluated.

A benefit of the MELA System is that the simulator based on individual trees provides information needed or production functions of logging operations. However, the original stand inventory data are standwise - not treewise. The treewise data was generated from the stand variables of forest inventory using theoretical stem-diameter distributions. No statistical analysis on theoretical stem-diameter distributions was made.

The third criterion of applicability is the **validity** of the mathematical models representing the combinatorial problem of short-term planning. There are some features of JLP which are particularly useful for short-term planning. First, environmental effects can be taken into account as a part of trade-off analysis to measure the costs of conservation or to measure the inoptimality loss due to an erroneous model based on production possibility boundaries. Second, economies of scale are taken into account which may be utilised in cost savings due to synchronised logging. Third, the system can be used to analyse the integer and real solutions. Fourth, uncertainty can be taken into account in sensitivity analysis.

7.2 Evaluation

Cost-benefit analysis would be required to measure the difference (benefit) in the management and decision making due to GIS. The saved costs would be the criterion of improvement. Financial evaluation of the methodology or financial appraisal of trade-offs as a whole would be difficult. Therefore different components were evaluated and some added value of using GIS in operational planning identified.

The first question was, whether it is necessary to have an up-to-date resource database, if we have a forest plan made every 10 years. It is obvious that the forest (natural processes, man-made treatments) and the decision environment (national forest policy, timber market) are constantly in a state of change. The probability of changes in silvicultural instructions and management goals is increasing the longer the time since forest inventory. The error in the production estimates (e.g. timber volume and resulting work load) decreases if up-to-date resource inventory data are available.

To maintain continuous planning the databases have to be updated both after the planning and the implementation of treatments. The benefit of a simulation application sitting on RDBMS is the ability to provide up-to-date forest descriptions. The updated database encourages one to replace pre-harvesting inventory.

The benefit of an RDBMS is the availability of standard tools for the integration of attribute data with external routines. The RDBMS-technology supports end-users by providing an easy-to-use toolbox (interactive SQL) to utilise existing databases. The tabular toolbox would provide input forms and report generators for advanced decision support systems.

The second question was, whether it is necessary to have an up-to-date resource GIS, if we have a resource database. The benefit of a GIS is the more detailed forest description and advanced spatial analysis methods needed for short-term planning. The spatial toolbox can be used to improve resource inventories, to analyse complex spatial relationships and to illustrate the results of the planning process on the map. There are two important benefits of using GIS in forest planning. First, the ability to integrate data from different sources (e.g. maps and related attribute tables) and to create new information for the description of overlapping and conflicting environmental and technical constraints, Second, the possibility of designing several layouts for actual operations and testing their spatial feasibility and economic optimality. If the site-specific constraints and factors affecting harvesting costs can be included in the planning process, the production possibilities can be estimated more accurately based on relevant data on production possibilities. Figure 40 shows an example of the magnitude of overestimate (**Timber** vs. **Landscape**) if the site-specific constraints are ignored. The production possibility boundary has shifted both to the right and down and is steeper as a function of end volume. The maximum present net value has decreased from 1.2 million FIM to 0.7 million FIM.

The integration of an RDBMS and a GIS via an operational interface such as the ARC/INFO RDBI provides users with two fully equipped toolboxes that work on real corporate databases. An additional benefit of having the RDBI is that it makes automated planning possible via the interface between the GIS with its spatial analysis toolbox and the RDBMS with its ability to handle one-to-many relationships. If the relationships between experiments and inventory stands were captured in a relationship table, the subsystems should be updated simultaneously whenever changes in the inventory stands or experiments occur. Since the relationship was captured as two separate GIS coverages, the subsystems could be used independently. An operational interface between subsystems such as an RDBMS and a GIS increases the applicability of the system: it offers a way to deal with interconnections stored in real-time information systems.

In summary, together DBMS and GIS provide better information to avoid sub-optimisation. The system does not have a direct effect via decreasing unit costs but rather by decreasing the uncertainty involved with the production coefficients.

The third question was, whether it is necessary to have planning tools, if we have an up-to-date resource database and a GIS. A task of decision analysis is to study the future production possibilities under different management strategies. For example, the separation of long-term and short-term planning may cause the violation of long-term sustainability when only short-term goals are included. Planning tools are needed to integrate data and models to produce indicators needed in decision making.

The benefits of JLP are mainly based on its efficiency and flexibility. The ability to deal with large LP-problems makes it possible to incorporate both short-term and long-term decision criteria into the same planning problem. The heuristics implemented using the JLP command language make it possible to deal with combinatorial problems. The user interface of JLP integrates spatial data and economic models effectively. The spatial synchronisation of treatments is divided into two components: the effect of sites of specific interest and the effect of plan adjustment due to the more detailed description of operations via the GIS. In addition, JLP-commands can be used to create new treatment stands or generate new treatment alternatives. Table 4 shows an example of the parameters calculated using spatial and economic models.

The system described is a step towards holistic and continuous planning where operational plans are made whenever there are changes in the forest or its environment. It makes it possible to evaluate the combination of management alternatives on an area composed of several stands with respect to decision variables. The system integrates different products and services at the different planning levels.

The user interface of JLP makes it is easy to switch between different sets of parameters or define alternative management strategies. It makes it possible to perform different kinds of sensitivity analysis when the production possibilities are known (measuring the costs of constraints, measure the costs of decreasing uncertainty via more extensive inventory, measure the effect of changing the logging system i.e. man-machine combination or route density, measure the effect of changing unit costs or prices etc.).

For example, the estimate of work load and associated costs and returns depends on the information on timber volume, cutting method, season, terrain and extraction distance. The average logging cost in the Northern Savolax and in the Northern Karelia are 73.5 FIM/m3 (50-100 FIM/m3). The effect of the choice of logging method on logging costs varies from 0 to 15 FIM/m3.

The uncertainty of yield estimates can be decreased using additional field surveys before decision making. Obviously it means increasing inventory costs. Owing to the within stand variation there would be a need for, say, 5 sample plots per stand which is about 40 min. per stand including transfer. If the average stand size was 3 hectare this would mean about 30 hectares for the 7 hours working day .

Depending on the attitude of the decision maker towards risk and uncertainty he may want to use a decision support system to avoid the utility loss due to making decisions based on erroneous data. In practice, a district manager has to choose a survey method based on accuracy requirements and available resources. Trade-off analysis can be used: the costs of data acquisition are compared against the benefits from better decisions (e.g. more reliable estimates for budgets).

The fourth question was, whether it is necessary to undertake field survey. The accuracy of timber volume estimates depends on the homogeneity of stands and the age of the data. The chosen inventory approach should depend on the variability in forest description (homogeneous timber stands are easy to describe in the database), the significance of the site, and the length of time period since the previous field survey.

Whether or not to implement a GIS depends on if GIS affects the probability of decisions when we reject unfeasible alternatives when we should or when we should not. Estimates of timber volume and logging conditions can be based on information from standard (non site-specific) timber inventory or in addition restrictions for timber production and technical barriers for machinery, transportation conditions based on spatial analysis, and market information.

7.3 Future developments

The system was designed for a non-industrial forest owner. In summary, this kind of system could be used

- to assist in forest inventory and everyday bookkeeping (management),
- to calculate up-to-date in-site stumpage value of timber based on the actual harvesting and market conditions,
- to compare net income from standing or roadside sale,
- to evaluate the combination of management alternatives economically, spatially and temporally (continuous planning) - at the same time
- to study the effect of changes in available timber resources or harvesting systems,
- to measure the effect of the modification of management due to external constraints,
- to assist in policy decisions concerning, for example,. the employment policy against timber sale policy, and
- to estimate the value of information and, thus, assisting in the choice of an inventory system.

In the future, more attention should be paid to the contents and accuracy of elevation data. Different methods for creating DEMs should be compared. The methods for recording the location and rules of site-specific restrictions - such as management prescriptions for habitats of rare species -should be standardised. A resource directory could be used to give the decision maker information on reliability of data and models.

Another possible refinement of the method concerns the capability of the system to handle constraints of spatial feasibility. In recent years the need for restricting the size of clearcutting areas has increased. In practice the restriction means either a set of constraints for the treatments of neighbouring stands or a buffer strip of standing trees between cutting units. The problem with buffer strips is that they reduce the land base and invalidate the LP solution. Therefore, methods for creating so called adjacency constraints and analysing the effect of spatial restrictions on the formulation of an LP-problem should be developed in the future. The benefit of the current system is that it is possible to use the heuristic rules in JLP to handle the adjacency constraints if the GIS-data for adjacent areas is available. A raster-based GIS could also provide a solution to adjacency problems.

GIS can also be used for the visualisation of results. It is possible to evaluate the impact of planned logging design on the scenic value by visualising the effect of tree felling on the landscape.

In this study, route simulation was not automated because the interactive approach seems to encourage managers to use their knowledge. If the changing weather conditions (e.g. soils which lose their carrying capacity when moist), market situation or conservation restrictions affect the route projection, it might be useful to design alternative route layouts. The alternative routes could then be compared using cost estimates based on actual conditions e.g. the current moisture content of the soil. Spatial sensitivity analysis capabilities to show the variation in the cutting arrangements and location of extraction routes, for example, should be further developed.

Scenario variables include, for example, the future price trend which may cause uncertainty and risk in the decision making. The same physical variable e.g. the timber volume of a management unit is a different decision variable for different management units and in different periods and may be calculated using different functions. It may be necessary to model, for example, the unit price as a function of planning periods so that the short-term price is the current market price, the medium-term price is uncertain around the trend price, and the long-term price is fuzzy around the trend price.

A solution for dealing with incomplete and unreliable information is to construct a user interface to aid in sensitivity analysis, explanation and reasoning. The decision analysis method can be easily implemented as an interactive decision support system to help the decision-maker to express the goal elements, to identify management objectives and to assign the weights of goals appropriate for the specific decision situation.

The next generation of an integrated planning system should rely on a modern client-server architecture to provide more advanced communication mechanisms between a GIS, simulation models and an LP-algorithm. The events to which the system must respond should be identified and linkages among modules automated.

A more detailed cost-benefit analysis on different data sets (case study areas) would be needed to justify software development of that scale.

Since the system is based on modular software components, it is easily tailored for different purposes. This prototype could be easily transferred to any organisation which has an RDBMS and an existing inventory database. For example, those forestry units who sell timber as co-operative units could produce a common "sale view" by combining the individual annual cutting unit views. The common "sale view" could then be used to assist in chaining the cutting units along the same route to get the forest companies to raise the unit price for timber.

The model can assist also in the choice of sale method. Each calculation unit that belongs to a logging unit should have two options: one for delivery sale and one for stumpage sale. For work planning it would be possible to build submodels for different operations and run them separately from the main models. If different sale methods were to be separate activities, the effect of setting an employment constraint could be measured using the shadow price of the constraint. This method would also be suitable for analysing the possibilities of changing the timber sale policy from delivery to stumpage sale.

Vertical i.e. hierarchical integration is excluded. It would be possible to tailor the system for industrial forest owners, who calculate the stumpage value of timber by deducting the transportation and harvesting costs from the value of product at the mill. The objective of timber purchasing companies is to minimise capital and maximise effectiveness and economic profitability. "Hot logging" (i.e. from stumpage to mill as fast as possible) has made reliable information on available timber (standing, felled, roadside) and cost components more critical.

The approach presented in this study will be utilized in the project "The production potential of the Finnish Forests in 1996-2025" (Siitonen & Nuutinen 1996). The project tries to calculate the regional and national boundaries of production possibilities between timber production and other uses of forests assuming different production technologies (such as prohibition of clear-cutting and the protection of the oldest forests). The multi-source information of the NFI at a pixel level (interpreted from Landsat information, digital maps and data in NFI files) should be useful, for example, when presenting results on large-scale maps over the whole country.

8. CONCLUSIONS

There is increasing pressure to integrate the economics of timber sale and logging planning with environmental considerations and strategic sustainability. Some forestry organisations are hoping to replace pre-harvesting inventory with a database designed for periodical inventory and long-term timber production planning to facilitate continuous (rolling) planning.

Existing forest planning systems have failed to combine the spatial and economic considerations in timber harvesting with the long-term requirements concerning timber production. Most forestry organisations have an existing mapping system or a GIS. However, there is a lack of planning methods to take advantage of GIS. As a result, sub-optimal results due to conflicting objectives have been common.

In this study, a planning system to integrate both short-term (i.e. timber harvesting) and long-term forest planning (i.e. timber production) and multiple-use and timber production planning has been outlined. The main objective of the system is to maximise achievement of management objectives (i.e. profit) within stated constraints, to rationalise and adjust the forest plan to other planning levels and to improve the plan utilisation.

The planning process of METLA has been analysed and the system requirements defined. A GIS (ARC/INFO), a forest simulator (MELA), and a linear programming package (JLP) have been incorporated into an integrated forest planning system.

This study was started on VAX/VMS operating system using Arc/Info version 5 with the Oracle database integrator. The latest parts of the study have been done on unix operating system using Arc/Info version 7.1 with the Ingres database integrator. The data transfer between different systems and the modification of self-made routines have been continuous and cumbersome.

The case study presents a combination of GIS analyses which can be used to assist in timber sale planning. In the case study, forest inventory data and GIS-analyses were used for modelling both site-specific restrictions and harvesting conditions. A new concept of treatment stand was adopted for modelling site-specific restrictions into calculation units for the MELA-simulator. The estimates of production possibilities became more accurate and treatment proposals were directly transferrable to on-the-ground treatments.

New LP-formulations were defined and implemented using JLP. JLP made it possible to solve combinatorial problems based on effectively integrated spatial and economic models. A new approach was adopted to illustrate the production possibilities under different management strategies as production possibility boundaries. These boundaries are especially useful in trade-off analyses. In addition, a new approach was developed for sensitivity analysis based on JLP command language.

The JLP software was initially developed and later further modified for this study. The author has participated in the development work by defining the software requirements and by testing the capabilities in this study.

The results were used to evaluate the adopted approach and to suggest future developments. The production possibility boundaries were used to estimate the value of GIS in taking into account the effects of site-specific constraints. The results from the combinatorial model were compared with the results of a standard model to measure the benefits of GIS in timber sale and logging planning.

The system takes into account the effect of site-specific constraints due to nature conservation, the effect of synchronization of treatments on harvesting costs and returns, and the implications of short-term plans on long-term targets, and vice versa.

The system contains elements of the integration of GIS and forest simulation data and the optimisation algorithm tailored for combinatorial problems. The tools can be used to study the effect of changes in available timber resources, environmental constraints, available logging systems, and timber sale market conditions. The combinatorial model is applicable for studies into the effect of synchronisation of treatments on costs and returns. For practical applications, however, the method should be considered a model format not a definitive model. Valuable experience has, however, been gathered for the design of new inventory and corporate databases, and for the integration of subsystems. For example, adjustment of inventory databases in respect of terrain conditions is recommended before pre-harvesting inventory can be fully replaced with a GIS. In particular, more attention should be paid to the contents and accuracy of elevation data. The methods for recording the location and rules of site-specific restrictions - such as management prescriptions for habitats of rare species -should be standardised. The next generation of an integrated planning system should rely on modern client-server architecture to provide more advanced communication mechanisms between a GIS, simulation models and an LP-algorithm.

In conclusion, it can be said that the system is a step towards continuous and holistic planning where operational plans are revised whenever there are changes in the forest or its environment.

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GLOSSARY

Accuracy

Accuracy is the magnitude of the difference between the reported value and the true value.

Activity

Activity is an action or a forest operation related to harvesting or silvicultural treatments defined as input in a prescription. In operations research, activity is a decision alternative.

Allowable cut

Allowable cut is defined as the volume, number of stems, or area cut over - either annually or periodically.

Calculation unit

Calculation unit is a unit of data processing e.g. forest inventory stand, treatment stand or cutting stand.

Cutting budget

Cutting budget is given as a list of the areas and/or volumes to be cut either annually or periodically

Cutting stand

A cutting stand is a treatment stand marked for cutting. A cutting stand may be a forest inventory stand or a part of a forest inventory stand. A cutting plan is given as a list of stands marked for cutting. Each stand has a defined cutting year, cutting method and timber volume. Cutting methods include thinning, shelterwood cutting, seedtree cutting and clear cutting. Timber volume is calculated or measured by timber assortments.

Data Base Management System (DBMS)

A Data Base Management System (DBMS) is the software to establish, update, or query a data base. The query language is a language usually provided as a part of a DBMS for easy access to data in the database. A Relational Database is a database whose records are organized into tables that can be processed by either relational algebra or relational calculus.

Decision Support System (DSS)

A Decision support system (DSS) is a computer-based information system (software) that combines models and data in an attempt to solve problems with extensive user involvement.

Digital elevation model (DEM), digital terrain model (DTM)

A DEM is digital elevation data (a set of elevation measurements for locations distributed over the land surface) and its derivatives used to analyse the topography (i.e. the surface features).

Expert System (ES)

An expert system is a computer system that captures an expert's knowledge into the knowledgebase as rules. An expert system achieves high levels of perfomance in task areas that, for human beings, require years of special education and training.

Extraction

Extraction refers to terrain or cross-country (off-road) transportation. Extraction methods are forwarding with animals or tractors, skidding with animals or tractors and extraction with cable equipment. Average extraction distance of work area is measured along the extraction route starting from the centroid of cutting stand and ending at the extraction point. An extraction point is a collection or storage point where timber is stored at the roadside after extraction. The pattern of tracks and roads for extraction are located on the map. For route projection, the information on topography, geology and soils is needed.

Felling

The felling area is a group of treatment stands marked for cutting to be worked at the same time. The felling area is divided into sections and each section is felled by one, or at most two, fellers. If possible the felling sections should be sufficiently uniform to allow a single piecework price to be set for the whole section.

Forest (inventory) stand

A forest (inventory) stand is homogeneous in terms of site and growing stock characteristics.

Forest planning

Forest planning includes long-term and short-term, strategic and operative, harvesting, timber sale and work planning.

Geographical Information System (GIS)

A GIS is a computer-assisted system for the capture, storage, analysis and display of spatial data.

Harvest scheduling

Harvesting scheduling is the application of mathematical programming techniques to determine the allowable cut and/or cutting budget over multiple rotations or cutting cycles.

Heuristics

Heuristics is the informal, judgmental knowledge of an application area that constitutes the "rules of good judgment" in the field. Heuristics also encompass the knowledge of how to solve problems efficiently and effectively, how to plan steps in solving a complex problem, how to improve preformance, and so forth.

Logging

A logging system consists of a combination of sub-operations: felling, conversion and extraction. Logging methods are whole tree, tree length, shortwood and full tree chipping methods. In the shortwood system the feller combines delimbing with crosscutting at stump. A logging plan sometimes contains the location of work sites, roads, storage points and the extraction route layout on a topographic map.

Mathematical Programming (MP)

A mathematical program is an optimization problem in which the objective and constraints are given as mathematical functions and functional relationships. Optimization is a problem-solving approach that finds the best possible solution to a problem. An objective function is a mathematical relation stating the set of goals to be optimized when solving a mathematical programming problem. A controllable variable is a variable such as quantity to produce, amounts of resources to be allocated, etc. that can be changed and manipulated by the decision maker. A constraint is a restriction or requirement on the quantity of an input used or output produced. Constraints may be defined as 1) control rows, 2) restrictions embedded in activity columns, 3) control rows to link prescriptions together to specify production relationships in some model formulations. In linear programming (LP) problems, decision variables reflect the number of acres assigned to a prescription and an associated timing choice.

Management Information System (MIS)

Management information systems (MIS) are business information systems designed to provide past, present, and future information appropriate for planning, organizing, and controlling the operations of the organization. Structured decisions are standard or repetitive decision situations for which solution techniques are already available.

Normal forest

A normal forest is a forest which has reached and maintains a structure which satisfies the objectives of management. This is the classical concept against which an actual forest may be compared, particularly as regards volume of growing stock, age- or size-class distribution, and increment.

Planning horizon

The planning horizon is the number of years in the future for which a plan or projection is made. The planning horizon is divided into several planning (cutting) periods. The planning period is a time interval, usually a decade, defined for purposes of analysis. Some harvest scheduling models use variable cutting periods. The earlier cutting periods have shorter lengths and the later periods have longer lengths. Variable cutting period lengths have the advantage of providing greater detail for the immediate future, where it is needed, without requiring lengthy calculations for the entire planning horizon.

Prescription

A prescription is a set of management practices or activities with associated standards and guidelines which is applied to specific analysis areas. Prescriptions are equivalent to management regimes. They are the combination of activities which will be implemented on an analysis area to obtain the chosen objectives. Prescriptions are identified as to which management emphasis they promote. Instructions are required especially on the sites where nature conservation is emphasized. Instructions may include adjustment to standard silvicultural operations such as exclusion of clear-cutting.

Regulated forest

A regulated forest is a forest that yields an annual or periodic crop of about equal volume, size and quality.

Scenario

A scenario is a statement of assumptions and configurations concerning the operating environment of a particular system.

Site of specific scientific interest (SSSI)

Sites of specific scientific interest include habitats of rare, sensitive or endangered species or other habitats which may have conservation value such as edge habitats and protection zones.

Software

Software is a collection of programs and routines that support the operation of the computer system. Application software is a collection of programs that can perform specific user-oriented tasks.

Sustained yield (sustainability)

Sustained yield is the yield that a forest can produce continuously at a given intensity of management, which implies at the earliest possible time a balance between increment and cutting.

Systems analysis

Systems analysis is the investigation and recording of existing systems and the conceptual design and feasibility study of new systems.

Systems design

Systems design is a specification of appropriate hardware and software components required to implement an information system.

Timber parcel

A land parcel is a forest area owned by a forest owner (a forest enterprise). A timber parcel is a parcel of planned operation, a marked area to be worked or an area where trees to be sold are marked. A large parcel of timber may be subdivided into timber lots.

Timber sale

Timber sale methods include standing sale, stumpage sale, roadside sale and delivery sale. In standing sale the trees to be sold are marked individually or the boundaries of the area to be worked are marked (a timber parcel). Each timber parcel or lot is described separately. Stumpage is the difference between delivered price and harvesting costs of forest products at the mill gate. Price appraisal consists of the following variables: timber lot, timber assortment, unit price of timber assortment in a basic parcel of timber, correction due to the size of an average tree, correction factor due to the quality of an average tree, correction due to the method and season (if birch), correction due to the size of the parcel of timber, correction due to the density of timber assortment in the parcel of timber, correction due to the extraction distance of timber assortment in the timber lot, correction due to the terrain class of timber assortment in the timber lot, correction due to the existing plan, other corrections. If delivery sale, correction due to the average size of the log, correction due to the transportation class, correction due to the season of delivery. An offer consists of the following variables: offer type (purchase or sale), name of the responsible person, company or farm, region or district, delivery site, species or timber assortment, quality (if pine or birch log then normal, very good, poor), quantity, maximum unit price or minimum unit price on the delivery site.

Treatment schedule

A schedule is a sequence of activities that prescribes the production of the output(s) under consideration. Treatments are defined as activities in a prescription and span many periods from the present to the planning horizon. All likely regimes within the limited set must be identified. The set of management regimes is limited to those most likely to be used. For example, a large number of thinning intensities (perhaps expressed as in residual basal area) and thinning strategies (expressed in the year or years in which thinning is performed) are possible.

Treatment stand

A treatment stand is a homogeneous treatment unit in terms of treatment proposals. A treatment stand may be a forest inventory stand or a part of a forest inventory stand. A treatment stand marked for cutting is referred to as a cutting stand.

User-interface

The portion of a computer system that interacts with the user, accepting commands from the computer keyboard and displaying the results generated by other portions of the computer system is referred to as the user-interface.

DATA DICTIONARY

Listing and representation method

Project Coverages

Listing	Repr. method	Details (parameters and origin)	
researcharea	poly		
parcel	poly		
parcelEXT	poly		
parcelP	poly	PARCEL-ID	
parcelC	line, point	Z	
parcelSLO	poly	SLOPE-CODE	f(*TIN)
parcelE	line, poly		
parcelH	line		
parcelL	line, poly		
parcelST	line		
parcelHY	line	WATER-TYPE	f(*L,*H,*ST)
parcelO	poly		
parcelR	line	ROAD-CLASS	
parcelS	poly	ORAKEY	
parcelWET	poly		
parcelROCK	point		
parcelTMU	poly	SOIL,HYDRO,TERRAIN, SLOPE	
parcelLB	poly	INSIDE f(*L)	
parcelSB	poly	INSIDE f(*ST,*H)	
parcelHB	poly	INSIDE f(*LB,*SB)	
parcelRB	poly	INSIDE f(*R)	
parcelPLA	poly	TREATMENTKEY, ORAKEY	
parcelREF	poly	TREATMENTKEY, distance	
parcelCUT	poly	reselect of parcelPLA	
parcelPIL	point	x,y of parcelCUT	
parcelROU	line	ROAD-CLASS	
parcelCEN	point		
parcelWA	poly		
parcelSHO	line		
parcelSTR	line		
parcelISL	poly		
parcelDRY	poly		
parcelOMA	poly		
parcelANI	poly		
parcelVEG	point		
parcelAGR	poly		
parcelCUL	poly		
parcelBLD	poly		
parcelTR	line		
parcelCB	poly		
parcelOB	poly		

LATTICE-files

SJOKI04.LAT

TINS:
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sjoki04tin

Ingres-tables

Name: current_stand
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: user table
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
arckey	float	8	no	no	
year	integer	2	no	no	
area_ha	float	4	no	no	
unit_area	float	4	no	no	
x_km	integer	2	no	no	
y_km	integer	2	no	no	
stand	integer	4	no	no	
z	integer	2	no	no	
dd	integer	2	no	no	
ownergroup	integer	1	no	no	
landcover	integer	1	no	no	
subclass	integer	1	no	no	
site	integer	1	no	no	
taxdetails	integer	1	no	no	
tax	integer	1	no	no	
hydrology	integer	1	no	no	
allow_ditching	integer	1	no	no	
urgent_regeneration	integer	2	no	no	
ditchingyear	integer	2	no	no	
fertilizingyear	integer	2	no	no	
sitetreatmentyear	integer	2	no	no	
deny_naturalregener	integer	1	no	no	
clearingyear	integer	2	no	no	
developmentclass	integer	2	no	no	
regenerationyear	integer	2	no	no	
tendingyear	integer	2	no	no	
pruningyear	integer	2	no	no	
fellingyear	integer	2	no	no	
regionalboard	integer	2	no	no	
landuse	integer	1	no	no	
number1	integer	4	no	no	
species1	integer	1	no	no	
meanage1	integer	2	no	no	
volume1	float	4	no	no	
ba1	float	4	no	no	
meand13	integer	2	no	no	
meanh1	integer	2	no	no	
logvol1	float	4	no	no	
value1	float	4	no	no	
usablevol1	float	4	no	no	
number2	integer	4	no	no	
species2	integer	1	no	no	
meanage2	integer	2	no	no	
volume2	float	4	no	no	
ba2	float	4	no	no	
meand132	integer	2	no	no	
meanh2	integer	2	no	no	
logvol2	float	4	no	no	
value2	float	4	no	no	
usablevol2	float	4	no	no	
gpine1	float	4	no	no	
gspruce1	float	4	no	no	
gsbirch	float	4	no	no	
gdbirch	float	4	no	no	
gother	float	4	no	no	

hdompine1	float	4	no	no
hdomspruce1	float	4	no	no
hdomsbirch	float	4	no	no
hdomdbirch	float	4	no	no
hdomother	float	4	no	no
netgrowth	float	4	no	no
netvaluegrowth	float	4	no	no
outturn	float	4	no	no
growth1	float	4	no	no
growth2	float	4	no	no
ditchingmethod	float	4	no	no
fertilizingmethod	float	4	no	no
sitetreatmentmethod	float	4	no	no
regenerationmethod	float	4	no	no
cuttingmethod	float	4	no	no
simulationparameter	float	4	no	no
vol11	float	4	no	no
vol12	float	4	no	no
vol21	float	4	no	no
vol22	float	4	no	no
vol31	float	4	no	no
vol32	float	4	no	no
d11	float	4	no	no
d12	float	4	no	no
d21	float	4	no	no
d22	float	4	no	no
d31	float	4	no	no
d32	float	4	no	no

Name: current_trees
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: user table
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
arckey	float	8	no	no	
numberperha	integer	4	no	no	
species	integer	2	no	no	
d13	integer	2	no	no	
h	integer	2	no	no	
g	integer	2	no	no	
d13age	integer	2	no	no	
v0	float	4	no	no	
v1	float	4	no	no	
age	integer	2	no	no	
logvol	float	4	no	no	
pulpvol	float	4	no	no	
value	float	4	no	no	
logdeduction	float	4	no	no	
storey	integer	1	no	no	
pruningheight	integer	2	no	no	
d10cm	integer	2	no	no	
u_s	float	4	no	no	
origin	integer	1	no	no	
usablevol	float	4	no	no	
id13	integer	2	no	no	
ih	integer	2	no	no	
inumber	integer	4	no	no	
tree_id	integer	2	no	no	
angle	integer	2	no	no	
distance	integer	2	no	no	

elevation	integer	2	no	no

Name: plan
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: user table
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
plan	char	20	no	no	
plandate	date		yes	no	
plancover	char	17	no	no	
relateplancover1	char	17	yes	no	
relateplancover2	char	17	yes	no	
implementationyear	integer	2	yes	no	
scenario	char	20	yes	no	
description	char	50	yes	no	

Name: treatment_stand
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: user table
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
plancover	char	17	no	no	
treatmentstand	integer	4	no	no	
x_coord	float	4	no	no	
y_coord	float	4	no	no	
area_m2	float	4	no	no	
arckey	float	8	no	no	
measurementsystem	integer	1	yes	no	
inventorydate	date		yes	no	
zone	integer	2	yes	no	
adjacency	integer	1	yes	no	
relateplancover1unit	integer	4	yes	no	
relateplancover2unit	integer	4	yes	no	
landuse	integer	2	yes	no	
multipleuse1	integer	2	yes	no	
multipleuse2	integer	2	yes	no	
multipleuse3	integer	2	yes	no	
d_distance	float	4	yes	no	
schedule	integer	2	yes	no	
cuttingyear	integer	1	yes	no	
cuttingmethod	integer	1	yes	no	
c1181	float	4	yes	no	
c1182	float	4	yes	no	
c1184	float	4	yes	no	
c1185	float	4	yes	no	
c1187	float	4	yes	no	
c1188	float	4	yes	no	
c1190	float	4	yes	no	
c1191	float	4	yes	no	
c1195	float	4	yes	no	
e_season	integer	1	yes	no	
e_distance	float	4	yes	no	
e_terrain	integer	1	yes	no	
loggingsize	float	4	yes	no	

haulageseason	integer	1	yes	no
haulageclass	integer	1	yes	no
storage	integer	4	yes	no
storagesize	float	4	yes	no
timberparcel	integer	4	yes	no
timberlot	integer	4	yes	no

Name: calculation_unit
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: user table
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
plan	char	20	no	no	
calculationunit	integer	4	no	no	
treatmentstand	integer	4	no	no	
numberofschedules	integer	2	no	no	

Name: schedule
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: user table
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
plan	char	20	no	no	
treatmentstand	integer	4	no	no	
schedule	integer	2	no	no	
x1181	float	4	no	no	
x1182	float	4	no	no	
x1184	float	4	no	no	
x1185	float	4	no	no	
x1187	float	4	no	no	
x1188	float	4	no	no	
x1190	float	4	no	no	
x1191	float	4	no	no	
x2181	float	4	no	no	
x2182	float	4	no	no	
x2184	float	4	no	no	
x2185	float	4	no	no	
x2187	float	4	no	no	
x2188	float	4	no	no	
x2190	float	4	no	no	
x2191	float	4	no	no	
x1195	float	4	no	no	
x2195	float	4	no	no	
x3195	float	4	no	no	
x4195	float	4	no	no	
x5195	float	4	no	no	
x700	float	4	no	no	
x1700	float	4	no	no	
x2700	float	4	no	no	
x3700	float	4	no	no	
x4700	float	4	no	no	
x5700	float	4	no	no	
method_1	integer	1	no	no	

method_2	integer	1	no	no
method_3	integer	1	no	no
method_4	integer	1	no	no
method_5	integer	1	no	no
pnv	float	4	no	no
x5823	float	4	no	no
x1370	float	4	no	no
x1499	float	4	no	no
x1454	float	4	no	no
x1500	float	4	no	no
x1478	float	4	no	no
mancosts	float	4	no	no
machinecosts	float	4	no	no
x1370_r	float	4	no	no
x1370_s	float	4	no	no

Name: solution
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: user table
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
plan	char	20	no	no	
calculationunit	integer	4	no	no	
treatmentstand	integer	4	no	no	
scenario	char	20	no	no	
schedule	integer	2	no	no	

Name: analysis
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: user table
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
plan	char	20	no	no	
scenario	char	20	no	no	

Name: proposal
Owner: nuutinen
Created: 16.02.1993 22:17:00
Type: view
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
plan	char	20	no	no	
scenario	char	20	no	no	
treatmentstand	integer	4	no	no	
method_1	integer	1	no	no	
x1181	float	4	no	no	
x1182	float	4	no	no	
x1184	float	4	no	no	
x1185	float	4	no	no	

x1187	float	4	no	no
x1188	float	4	no	no
x1190	float	4	no	no
x1191	float	4	no	no
x1195	float	4	no	no
x2181	float	4	no	no
x2182	float	4	no	no
x2184	float	4	no	no
x2185	float	4	no	no
x2187	float	4	no	no
x2188	float	4	no	no
x2190	float	4	no	no
x2191	float	4	no	no
x2195	float	4	no	no
volume	float	4	no	yes

Name: scenario
Owner: nuutinen
Created: 16.02.1993 22:17:00
Type: view
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
plan	char	20	no	no	
scenario	char	20	no	no	
treatmentstand	integer	4	no	no	
method_1	integer	1	no	no	
method_2	integer	1	no	no	
method_3	integer	1	no	no	
method_4	integer	1	no	no	
method_5	integer	1	no	no	
x1195	float	4	no	no	
x2195	float	4	no	no	
x3195	float	4	no	no	
x4195	float	4	no	no	
x5195	float	4	no	no	
cut	float	4	no	yes	
x1700	float	4	no	no	
x2700	float	4	no	no	
x3700	float	4	no	no	
x4700	float	4	no	no	
x5700	float	4	no	no	
pnv	float	4	no	no	
x5823	float	4	no	no	

Name: storage
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: user table
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
storage	integer	4	no	no	
x_coord	float	4	no	no	
y_coord	float	4	no	no	
owner	char	25	no	no	
description	char	25	no	no	
haulageseason	integer	1	no	no	

haulageclass	integer	1	no	no
roadclass	integer	2	no	no

Name: cutting_stand
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: user table
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
plancover	char	17	no	no	
cuttingstand	integer	4	no	no	
x_coord	float	4	no	no	
y_coord	float	4	no	no	
area_m2	float	4	no	no	
arckey	float	8	no	no	
measurementsystem	integer	1	yes	no	
inventorydate	date		yes	no	
zone	integer	2	yes	no	
adjacency	integer	1	yes	no	
relateplancover1unit	integer	4	yes	no	
relateplancover2unit	integer	4	yes	no	
landuse	integer	2	yes	no	
multipleuse1	integer	2	yes	no	
multipleuse2	integer	2	yes	no	
multipleuse3	integer	2	yes	no	
cuttingyear	integer	2	no	no	
cuttingmethod	integer	1	no	no	
c1181	float	4	no	no	
c1182	float	4	no	no	
c1184	float	4	no	no	
c1185	float	4	no	no	
c1187	float	4	no	no	
c1188	float	4	no	no	
c1190	float	4	no	no	
c1191	float	4	no	no	
c1195	float	4	no	no	
e_season	integer	1	yes	no	
e_distance	float	4	yes	no	
e_terrain	integer	1	yes	no	
loggingsize	float	4	yes	no	
haulageseason	integer	1	yes	no	
haulageclass	integer	1	yes	no	
storage	integer	4	yes	no	
storagesize	float	4	yes	no	
timberparcel	integer	4	no	no	
timberlot	integer	4	no	no	

Name: timber_lot
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: user table
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
researcharea	integer	2	no	no	
timberparcel	integer	4	no	no	
timberlot	integer	4	no	no	

cuttingmethod	integer	1	no	no	
storage	integer	4	yes	no	
e_season	integer	1	no	no	
loggingsystem	integer	1	yes	no	
mancosts	float	4	yes	no	
machinecosts	float	4	yes	no	
roadsidevalue	float	4	yes	no	

Name: timber_parcel
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: user table
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
researcharea	integer	2	no	no	
timberparcel	integer	4	no	no	
plan	char	20	no	no	

Name: timber_sale
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: user table
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
researcharea	integer	2	no	no	
forestcompany	char	20	no	no	
location	integer	1	no	no	
saledate	date		yes	no	
timberparcel	integer	4	no	no	

Name: timber_market
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: user table
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
district	integer	2	no	no	
year	integer	2	no	no	
standingmkk3_11	float	4	no	no	
roadsidemkm3_11	float	4	no	no	
firstthinningmkk3_11	float	4	no	no	
thinningmkm3_11	float	4	no	no	
regenerationmkm3_11	float	4	no	no	
loggingmkm3_11	float	4	no	no	
roadsidemkm3_12	float	4	no	no	
standingmkk3_12	float	4	no	no	
firstthinningmkk3_12	float	4	no	no	
thinningmkm3_12	float	4	no	no	
regenerationmkm3_12	float	4	no	no	
loggingmkm3_12	float	4	no	no	
roadsidemkm3_21	float	4	no	no	

standingmkk3_21	float	4	no	no
firstthinningmkk3_21	float	4	no	no
thinningmkm3_21	float	4	no	no
regenerationmkm3_21	float	4	no	no
loggingmkm3_21	float	4	no	no
roadsidemkm3_22	float	4	no	no
standingmkk3_22	float	4	no	no
firstthinningmkk3_22	float	4	no	no
thinningmkm3_22	float	4	no	no
regenerationmkm3_22	float	4	no	no
loggingmkm3_22	float	4	no	no
roadsidemkm3_31	float	4	no	no
standingmkk3_31	float	4	no	no
firstthinningmkk3_31	float	4	no	no
thinningmkm3_31	float	4	no	no
regenerationmkm3_31	float	4	no	no
loggingmkm3_31	float	4	no	no
roadsidemkm3_32	float	4	no	no
standingmkk3_32	float	4	no	no
firstthinningmkk3_32	float	4	no	no
thinningmkm3_32	float	4	no	no
regenerationmkm3_32	float	4	no	no
loggingmkm3_32	float	4	no	no

Name: felling_section
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: user table
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
researcharea	integer	2	no	no	
timberparcel	integer	4	no	no	
timberlot	integer	4	no	no	
fellingsection	integer	4	no	no	
plan	char	20	no	no	
area_m2	float	4	yes	no	
fellingyear	integer	2	no	no	
cut11	float	4	yes	no	
cut12	float	4	yes	no	
cut21	float	4	yes	no	
cut22	float	4	yes	no	
cut31	float	4	yes	no	
cut32	float	4	yes	no	
branch11	integer	1	yes	no	
branch12	integer	1	yes	no	
branch21	integer	1	yes	no	
branch22	integer	1	yes	no	
branch31	integer	1	yes	no	
branch32	integer	1	yes	no	
heightclass11	integer	1	yes	no	
heightclass12	integer	1	yes	no	
heightclass21	integer	1	yes	no	
heightclass22	integer	1	yes	no	
heightclass31	integer	1	yes	no	
heightclass32	integer	1	yes	no	
f_terrain	integer	1	yes	no	

Name: logging_system
Owner: nuutinen

Created: 08.02.1993 19:57:00
Type: user table
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
loggingsystem	integer	1	no	no	
measurementsystem	integer	1	no	no	
stripgap	integer	2	no	no	
pilesystem	integer	1	no	no	
harvestingsystem	integer	1	no	no	
feller	integer	1	no	no	
extractionmachine	integer	1	no	no	

Name: stand_inventory
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: view
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
year	integer	2	no	no	
stand	float	8	no	no	
area_ha	float	4	no	no	
volume_m3ha	float	4	no	yes	
vol11	float	4	no	no	
vol12	float	4	no	no	
vol21	float	4	no	no	
vol22	float	4	no	no	
vol31	float	4	no	no	
vol32	float	4	no	no	
standingvalue_mk	float	4	no	yes	
loggingcosts_mk	float	4	no	yes	

Name: forest_inventory
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: view
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
forestarea_ha	float	4	yes	no	
volume_m3	float	4	yes	no	

Name: marked_cutting
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: user table
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
cuttingyear	integer	2	no	no	
timberparcel	integer	4	no	no	

timberlot	integer	4	no	no	
cuttingmethod	integer	1	no	no	
storage	integer	4	no	no	
e_season	integer	1	no	no	
e_distance	float	4	no	no	
e_terrain	integer	1	no	no	
measurementsystem	integer	1	no	no	
inventorydate	date		yes	no	
cut11	float	4	no	no	
cut12	float	4	no	no	
cut21	float	4	no	no	
cut22	float	4	no	no	
cut31	float	4	no	no	
cut32	float	4	no	no	
loggingsize	float	4	no	no	

Name: stand
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: view
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq
researcharea	integer	4	no	no	
parcel	integer	4	no	no	
stand	integer	4	no	no	
substand	integer	1	no	no	
arckey	float	8	no	no	
inventorydate	date		no	no	
area	float	4	no	no	
landcover	integer	1	no	no	
subclass	integer	1	no	no	
soil	integer	1	no	no	
hydrology	integer	1	no	no	
site	integer	1	no	no	
stones	integer	1	no	no	
taxation	integer	1	no	no	
developmentclass	integer	1	no	no	
quality	integer	1	no	no	
landuse	integer	1	no	no	
sitetreatment	integer	1	no	no	
sitetreatmentyear	integer	2	no	no	
standtreatment	integer	1	no	no	
standtreatmentyear	integer	2	no	no	
sitetreatmentproposal	integer	1	no	no	
standtreatmenproposal	integer	1	no	no	
regenerationproposal	integer	1	no	no	
urgency	integer	1	no	no	
description	char	15	no	no	

Name: experiment
Owner: nuutinen
Created: 08.02.1993 19:57:00
Type: view
Version: ING6.0

Column Information:

Column Name	Type	Length	Nulls	Defaults	Key Seq

researcharea	integer	4	no	no
experiment	integer	4	no	no
sitetreatment1	integer	1	no	no
sitetreatment2	integer	1	no	no
standtreatment1	integer	1	no	no
standtreatment2	integer	1	no	no
volume	float	4	no	no
logpercentage	float	4	no	no
regeneration	integer	1	no	no
department	char	3	no	no
description	char	15	no	no

RELATE-ENVIRONMENT

RDBI

inve
experi
current
storage
timber
terrain
proposal
scenario
cutting
pile
onroute
tostorage
route50-route160
logging
centroid

SQL-MACROS

```
COPY TABLE tila0
       (vuosi = c2,
       tnro   = c4,
       omryhma= c1,
       rnro   = c4,
       pnro   = c2,
       pkoord = c5,
       ikoord = c4,
       lsumma = c4,
       korkeus= c3,
       mltk   = c2,
       mhy    = c3,
       omis   = c22,
       kalue  = c0nl) FROM 'TAUNO:sjoki041.kuv'
WITH ON_ERROR=CONTINUE, ROLLBACK=ENABLED, LOG='sjoki041.log';
COPY TABLE kasvupaikka
       (vuosi = c2,
       tnro   = c4,
       pa     = c4,
       knro   = c4,
       aknro  = c1,
       maalk_pr= c1,
       aryhma = c1,
       m_t_laji= c1,
       ojit   = c1,
       tyyppi = c1,
       kiv    = c1,
       verolk = c1,
       kasvup = c0nl)FROM 'TAUNO:sjoki042.kuv'
WITH ON_ERROR=CONTINUE, ROLLBACK=ENABLED, LOG='sjoki042.log';
COPY TABLE puustokuvio
       (vuosi = c2,
       tnro   = c4,
       pa     = c4,
       knro   = c4,
       aknro  = c1,
       kehlk  = c1,
       mlaatu = c1,
       kaytto  = c1,
       maanka = c1,
       kasajk = c2,
       puunka = c1,
       pkaajk  = c2,
       mkaehd = c1,
       pkaehd = c1,
       uudehd = c1,
       kasehd = c0nl)FROM 'TAUNO:sjoki045.kuv'
WITH ON_ERROR=CONTINUE, ROLLBACK=ENABLED, LOG='sjoki045.log';
COPY TABLE puusto0
       (tnro  = c4,
       knro   = c4,
       aknro  = c1,
       puulji = c1,
       sytapa = c1,
       rluku  = c5,
       ppa    = c2,
       klp    = c2,
       minlpm = c2,
       maxlpm = c2,
       kespit = c2,
       bioika = c3,
```

```
        dika   = c3,
        tuhot  = c0nl)FROM 'TAUNO:sjoki046.kuv'
WITH ON_ERROR=CONTINUE, ROLLBACK=ENABLED, LOG='sjoki046.log';
\p\g

INSERT INTO tila (tutkimusalue,
        tilanumero,
        palstanumero,
         arckey,
        rekisterinumero,
        aikaleima,
        p_koordinaatti,
        i_koordinaatti,
        korkeus,
        lamposumma,
        metsalautakunta,
        mhy,
        omryhma,
        kohdealue)
SELECT  3,
        tnro,
        pnro,
         float8(1000000000.0)*3 + float8(100000.0)*tnro,
        concat(shift((CHAR(rnro)),2),shift((CHAR(rnro)),2)),
        date(concat('0101',char(vuosi))),
        pkoord*100.,
        (4000000+(ikoord*100.)),
        korkeus,
        lsumma,
        mltk,
        mhy,
        omryhma,
        kalue  FROM tila0;

INSERT INTO kuvio
        (tutkimusalue,
        tilanumero,
        kuvionumero,
        alakuvionumero,
         arckey,
        aikaleima,
        pinta_ala,
        maalk_paaryhma,
        alaryhma,
        maa_turve_laji,
        ojitustilanne,
        metsatyyppi,
        kivisyys,
        veroluokka,
         kehitysluokka,
        metsikon_laatu,
        kayttomuoto,
        maankasittely,
        maan_kas_aika,
        puunkasittely,
        puun_kas_aika,
        maan_kas_ehd,
        puun_kas_ehd,
        uudistamis_ehd,
        kiireellisyys,
        kasvupaikka)
SELECT  3,
        kasvupaikka.tnro,
        kasvupaikka.knro,
        kasvupaikka.aknro,
 (float8(1000000000.0)*3 + float8(100000.0)*kasvupaikka.tnro +
```

```
  float8(10.0)*kasvupaikka.knro + float8(1.0)*kasvupaikka.aknro),
        date(concat('0101',char(kasvupaikka.vuosi))),
        float4(kasvupaikka.pa/100.),
        kasvupaikka.maalk_pr,
        kasvupaikka.aryhma,
        kasvupaikka.m_t_laji,
        kasvupaikka.ojit,
        kasvupaikka.tyyppi,
        kasvupaikka.kiv,
        kasvupaikka.verolk,
        puustokuvio.kehlk,
        puustokuvio.mlaatu,
        puustokuvio.kaytto,
        puustokuvio.maanka,
        puustokuvio.kasajk,
        puustokuvio.puunka,
        puustokuvio.pkaajk,
        puustokuvio.mkaehd,
        puustokuvio.pkaehd,
        puustokuvio.uudehd,
        puustokuvio.kasehd,
        kasvupaikka.kasvup   FROM kasvupaikka, puustokuvio
        WHERE kasvupaikka.tnro=puustokuvio.tnro
        AND kasvupaikka.knro=puustokuvio.knro
        AND kasvupaikka.aknro=puustokuvio.aknro;
INSERT  INTO puusto1(tutkimusalue,
        tilanumero,
        kuvionumero,
        alakuvionumero,
        arckey,
        osite,
        puulaji,
        syntytapa,
        runkoluku,
        pohjapinta_ala,
        keski_lpm,
        minimi_lpm,
        maximi_lpm,
        keskipituus,
        biologinen_ika,
        rinnankorkeusika,
        tuhot)
SELECT  3,
        tnro,
        knro,
        aknro,
 (float8(1000000000.0)*3 + float8(100000.0)*tnro +
  float8(10.0)*knro + float8(1.0)*aknro),
        0,
        puulji,
        sytapa,
        rluku,
        ppa,
        klp,
        minlpm,
        maxlpm,
        kespit,
        bioika,
        dika,
        tuhot FROM puusto0;
\p\g
```

VIEWS

```
CREATE VIEW STAND_INVENTORY
AS SELECT CURRENT_STAND.year as year,
        CURRENT_STAND.arckey as stand, area_ha, (volume1+volume2)  as
volume_m3ha,
        vol11, vol12, vol21, vol22, vol31, vol32,
        ((vol11*area_ha*roadsidemkm3_11 +
        vol12*area_ha*roadsidemkm3_12) +
        (vol21*area_ha*roadsidemkm3_21 +
        vol22*area_ha*roadsidemkm3_22) +
        (vol31*area_ha*roadsidemkm3_31 +
        vol32*area_ha*roadsidemkm3_32)) as standingvalue_mk,
        ((vol11*area_ha*loggingmkm3_11+vol12*area_ha*loggingmkm3_12) +
        (vol21*area_ha*loggingmkm3_21+vol22*area_ha*loggingmkm3_22) +
        (vol31*area_ha*loggingmkm3_21+vol32*area_ha*loggingmkm3_32))
         as loggingcosts_mk
        FROM CURRENT_STAND, TIMBER_MARKET
        WHERE CURRENT_STAND.year=TIMBER_MARKET.year;
CREATE VIEW FOREST_INVENTORY
AS SELECT SUM(area_ha) as forestarea_ha,
SUM((volume1+volume2)*area_ha) as volume_m3
        FROM CURRENT_STAND;

CREATE VIEW PROPOSAL
AS SELECT SOLUTION.plan as plan, SOLUTION.scenario,
        SOLUTION.treatmentstand as treatmentstand,
        method_1,
        x1181,x1182,x1184,x1185,x1187,x1188,x1190,x1191,x1195,
        x2181,x2182,x2184,x2185,x2187,x2188,x2190,x2191,x2195,
        (x1195+x2195)  as volume
        FROM ANALYSIS, PLAN, TREATMENT_STAND, SOLUTION, SCHEDULE
        WHERE
        PLAN.plan=ANALYSIS.plan AND
        TREATMENT_STAND.plancover=PLAN.plancover AND
        (SOLUTION.plan=PLAN.plan AND
        SOLUTION.scenario=PLAN.scenario AND
        TREATMENT_STAND.treatmentstand=SOLUTION.treatmentstand) AND
        (SCHEDULE.plan=SOLUTION.plan AND
        SCHEDULE.treatmentstand=SOLUTION.treatmentstand AND
        SCHEDULE.schedule=SOLUTION.schedule) and
        method_1 > 0;
CREATE VIEW SCENARIO
AS SELECT SOLUTION.plan as plan, SOLUTION.scenario,
        SOLUTION.treatmentstand as treatmentstand,
        method_1, method_2, method_3, method_4, method_5,
        x1195, x2195, x3195, x4195, x5195, (x1195+x2195) as CUT,
        x1700,x2700,x3700,x4700,x5700,pnv,x5823
        FROM ANALYSIS, PLAN, SOLUTION, SCHEDULE
        WHERE
        PLAN.plan=ANALYSIS.plan AND
        (SCHEDULE.plan=SOLUTION.plan AND
        SCHEDULE.treatmentstand=SOLUTION.treatmentstand AND
        SCHEDULE.schedule=SOLUTION.schedule) AND
        (SOLUTION.plan=PLAN.plan AND
        SOLUTION.scenario=PLAN.scenario);
\p\g
```

PROGRAMS

NALARC

```
*===================================================================
*Module        NALARC.f_program
*Header        Splits a NALLE file to ARC/INFO generate files
*Comment       NALLE files acan be split into separate layers
*
*              FORMAT OF ARC/INFO GENERATE FILES:
*              Lines:
*              User-ID
*              x,y
*              x,y
*              ...
*              END (End of line)
*              END (End of file)
*
*              Points:
*              User-ID,x,y  (User-ID=stand-ID)
*              END
*
*              Procedure:
*              ARC: GENERATE
*
*System        VAX/VMS
*Storage       GEOVAX:<TAN>
*Version
*Author        7.12.1990 Tuula A. Nuutinen
*===================================================================
*
      PROGRAM NALARC
*
*===================================================================
* Definitions
      INTEGER LFIELD, PFIELD
      INTEGER CLG
      REAL CER, LIN(300,4), POL(300)
      INTEGER LPX(300,100), LPY(300,100)
      INTEGER PRX, PRY
      INTEGER LLIMIT, ULIMIT
      CHARACTER LINE*132, HDR*3, ID*4, FILETYPE*1, TEXT*5
      CHARACTER PARAM*80
      CHARACTER*24 INFILE, OUTFILE
      CHARACTER*12 PID
      LOGICAL SPLIT, PRINT, TASO
*===================================================================
* Initialize object counter
      L=0
* Initilaize
      SPLIT=.FALSE.
      PRINT=.TRUE.
      TASO=.FALSE.

* Open files
      WRITE(6,*)'
**************************************************'
      WRITE(6,*)' *                                               *'
      WRITE(6,*)' * This program converts NALLE transfer files to ARC
      WRITE(6,*)' *                                               *'
```

```
      WRITE(6,*)' *                                                    *'
      WRITE(6,*)' *                   by Tuula A. Nuutinen            *'
      WRITE(6,*)'*****************************************************'
      WRITE(6,*)' '

*     - input file
101   CONTINUE

      CALL CRQ(' TASO transfer (Y/N)                              ? >',
     * PARAM,IST)
      IF (PARAM(1:1).EQ.'Y'.OR.PARAM(1:1).EQ.'y')TASO=.TRUE.

      CALL CRQ(' NALLE input file     (e.g. KOLInnA.VII/.PST) ? >',
     * PARAM,IST)
      INFILE=PARAM(1:CLG(PARAM))
      INUNI=1
      CALL CRQ(' Type of the input file - A(rc)/P(oint)  ? >',
     * PARAM, IST)
      FILETYPE=PARAM(1:1)
      OPEN(UNIT=INUNI,FILE=INFILE,STATUS='OLD',ERR=997)
      WRITE(6,*)' NALLE file     ',INFILE,' open ...'


111   CONTINUE
      LLIMIT=999
      ULIMIT=0
      SPLIT=.FALSE.
      CALL CRQ(' ARC/INFO output file (e.g. KOLInnR.LIN/.PNT) ? >',
     * PARAM,IST)
      OUTFILE=PARAM(1:CLG(PARAM))
      OUTUNI=2
      OPEN(UNIT=OUTUNI,FILE=OUTFILE,STATUS='NEW',ERR=997)
      WRITE(6,*)' Arc/Info file  ',OUTFILE,' open ... '
*     - output layer
      CALL CRQ(' Do you want separate layers (Y/N)       ? >',
     * PARAM,IST)
       IF (PARAM.EQ.'Y'.OR.PARAM.EQ.'y') THEN
        SPLIT=.TRUE.
        CALL CRQ(' Give the range of USER-IDs (e.g. 301 399) ? >',
     * PARAM,IST)
        LLIMIT=CER(PARAM)
        ULIMIT=CER(PARAM)
        WRITE(6,*)' Splitting into range of ',LLIMIT,ULIMIT
      END IF


* Read a record
1     READ(INUNI,100,ERR=998,END=120)LINE
100   FORMAT (A)
      IF (LINE(1:1).EQ.' ')LINE=LINE(2:)
      IF (LINE(1:3).EQ.'HDR')GOTO 1
      IF (LINE(1:3).EQ.'COO') THEN
        CALL CEI(LINE,' ',1,HDR,1,ISEP)
        IN=CER(LINE)
        IN=CER(LINE)
        ORIX=CER(LINE)
        ORIY=CER(LINE)
*-      WRITE(6,*)' * ORIGO ',ORIX,ORIY
        GOTO 1
      END IF
      IF (LINE(1:3).EQ.'EOF') GOTO 120

* Line type objects
      IF (FILETYPE.EQ.'A'.OR.FILETYPE.EQ.'a') THEN
        IF (LINE(1:3).EQ.'LIN') THEN
          L=L+1
```

```
           NP=0
           CALL CEI(LINE,' ',1,HDR,1,ISEP)
           LFIELD=CER(LINE)
           DO 10 I=1,LFIELD
             LIN(L,I)=CER(LINE)
10         CONTINUE
*    - user-ID=quality code
           IQ=LIN(L,2)
           PRINT=.TRUE.
           IF (SPLIT.AND.(IQ.LT.LLIMIT.OR.IQ.GT.ULIMIT)) THEN
*-           WRITE(6,*)IQ,' not within range'
             PRINT=.FALSE.
           END IF
           IF (PRINT) WRITE(OUTUNI,*)IQ
*    - line points
           NP=LIN(L,4)
           IP=0
11         READ(INUNI,100,ERR=998,END=120)LINE
           CALL CEI(LINE,' ',1,HDR,1,ISEP)
           PFIELD=CER(LINE)
           NPP=PFIELD/2
           DO 20 J=1,NPP
             IP=IP+1
             LPX(L,J)=CER(LINE)
             LPY(L,J)=CER(LINE)
             LPX(L,J)=ORIX+LPX(L,J)
             LPY(L,J)=ORIY+LPY(L,J)
             IF (PRINT) WRITE(OUTUNI,*)LPX(L,J),LPY(L,J)
20         CONTINUE
           IF (IP.LT.NP) THEN
*         WRITE(6,*)' ',NPP,' points (total ',IP,') of ',NP,' is read'
             GO TO 11
           END IF
           IF (PRINT) WRITE(OUTUNI,*)'END'
         IF (PRINT)WRITE(6,*)' * LINE ',L,' type ',IQ,' ',NP,' points'
           GO TO 1
          END IF
* - point type objects
       ELSE
* -     reference points
         IF (LINE(1:3).EQ.'AR1') THEN
           IQ=0
           ID='    '
           IDQ=0
           PRINT=.TRUE.
           L=L+1
           CALL CEI(LINE,' ',1,HDR,1,ISEP)
           PFIELD=CER(LINE)
           DO 30 I=1,PFIELD-1
             POL(I)=CER(LINE)
30         CONTINUE
*    - user-ID=quality code
           IQ=POL(PFIELD-2)
*    - length of character ID
           NCH=POL(PFIELD-1)
           PID=LINE
*    - If ID given
           IF (NCH.GE.1) THEN
*    - If TASO stand
             IF (TASO) THEN
*    -     If TASO ID of form New_ID#Old_ID
                IF (NCH.GT.1) THEN
                  DO 301 ICH=1,NCH
                    IF (PID(ICH:ICH).EQ.'#') THEN
                      ID=PID(1:(ICH-1))
                       IDQ=CER(ID(2:NCH))
```

```
                       GOTO 302
                     END IF
301                 CONTINUE
                    WRITE(6,*)' PROBLEMS WITH ID'
                  END IF
*    - If TASO and P,S,T, or NOT FOUND #
                 GOTO 302
*    - If NOT TASO
                ELSE
                  WRITE(6,*)' LINE ',LINE
                  CALL CEI(LINE,' ',1,ID,1,ISEP)
                  WRITE(6,*)' PID ',PID,' ID ',ID
                END IF
              END IF
              IDQ=CER(PID(2:(NCH+1)))
302           CONTINUE
              WRITE(6,*)' PID= ',PID,' ID= ',ID,' IDQ= ',IDQ
              IF (SPLIT.AND.(IQ.LT.LLIMIT.OR.IQ.GT.ULIMIT)) THEN
                WRITE(6,*)IQ,' not within range'
                PRINT=.FALSE.
              END IF
              PRX=POL(1)
              PRY=POL(2)
              PRX=ORIX+POL(1)
              PRY=ORIY+POL(2)
              IF (PRINT)WRITE(OUTUNI,*)IDQ,PRX,PRY
112           FORMAT(1X,A10,2I10)
              IF (PRINT)WRITE(6,*)' * POLYGON ',L,' IQ ',IQ,
     *         ' ID ',PID,'->',IDQ
              GO TO 1
            ELSE
              GO TO 1
            END IF
          END IF

120       CONTINUE

          WRITE(OUTUNI,*)'END'
          CLOSE(UNIT=OUTUNI)
*-        WRITE(6,*)' In file ',OUTFILE,' ',L,' objects'

* - Do you want to split another output file
          CALL CRQ(' Continue with this file (Y/N) ? >',
     *    PARAM,IST)
          IF (PARAM.EQ.'Y'.OR.PARAM.EQ.'y') THEN
             REWIND(UNIT=INUNI)
             GOTO 111
          END IF
          CALL CRQ(' Continue with another file (Y/N) ? >',
     *    PARAM,IST)
          IF (PARAM.EQ.'Y'.OR.PARAM.EQ.'y') THEN
             GOTO 101
          END IF

          GO TO 999

* Virheelliset lopetukset
997       CONTINUE
          STOP ' Opening error '
998       CONTINUE
          STOP ' Reading error'
* Lopetus
999       CONTINUE
          CLOSE(UNIT=INUNI)
          END
```

NXDBMS

```
*========================================================================
*Module        NXDBMS.f_program
*Header        Import ARC/INFO <plancover>.PAT (.NX) into DBMS
*
*Comment
*System        VAX/VMS
*Storage       GEOVAX:<TAN>
*Version
*Author        23.6.1992 Tuula A. Nuutinen
*Changes       9.7.1992
*              Read in modified .nx from .PAT
*Bug
*========================================================================
*
       PROGRAM NXDBMS
*
* Input channels
* Sy|tt|tiedoston laitekoodit
       INTEGER        NXUNIT
        PARAMETER        (NXUNIT =  8)

* Output channels
* Tulostiedostojen laitekoodit
       INTEGER        SQLUNIT, LOGUNIT
       PARAMETER      (SQLUNIT  = 17)
       PARAMETER      (LOGUNIT =  4)

* Input line
* Tietue
       CHARACTER      LINE*132

* Planned treatmentunit cover
* Suunniteltu kasittelykuviointi
       CHARACTER      TREATMENT_COVER*17

* Treatment unit ID
* Kasittely-yksik|n numero
       INTEGER        TREATMENT_STAND

* Reference  point
* Referenssipiste
       REAL*8         XCOORD, YCOORD

* Area
* Pinta-ala
       REAL*8         AREA

* Stand ID
* Metsik|n tunniste
       REAL*8         STAND_ARCKEY

* Inside zone code (landuse codes of FFRI/92)
* Vyohyke (maankayttoluokka METLA/92)
       INTEGER        ZONE

* Adjacency code (1=neigbouring <2 m stand)
* Naapuruus (1=alle 2 m taimikon naapurissa)
       INTEGER        ADJACENCY

* Distance to nearest road
* Etaisyys lahimpaan tiehen
       REAL           D_DISTANCE
```

```
* Chosen schedule
* Valittu vaihtoehto
       INTEGER        SCHEDULE

* Extraction season
* Juonto kausi
       INTEGER        E_SEASON

* Extraction distance
* Juonto matka
       REAL           E_DISTANCE

* Extraction terrain
* Juonto maasto
       INTEGER        E_TERRAIN

* Size of logging
* Hakkuun koko
       REAL           LOGGINGSIZE

* Storage-id
* Varasto
       INTEGER        STORAGE

* Size of storage/logging
* Varastolla olevan puutavaran maara
       REAL           STORAGESIZE

* Timberparcel-id
* Leimikko
       INTEGER        TIMBERPARCEL

* Timberlot-id
* Lohko
       INTEGER        TIMBERLOT

       INTEGER        CLG
*======================================================================
* Open the files
       OPEN(NXUNIT,STATUS='OLD')
       OPEN(SQLUNIT,STATUS='NEW',FORM='FORMATTED',
     *  CARRIAGECONTROL='LIST')
       OPEN(LOGUNIT,STATUS='NEW',FORM='FORMATTED')


       READ(NXUNIT,100,END=900) LINE
100    FORMAT(A)
       CALL CEI(LINE,' ',1,TREATMENT_COVER,1,ISEP)
       WRITE(SQLUNIT,171)TREATMENT_COVER(1:CLG(TREATMENT_COVER))
171    FORMAT(' DELETE FROM TREATMENT_STAND WHERE PLANCOVER=''',A,
     *     ''';')

       ICU=0
1      CONTINUE
       READ(NXUNIT,*,END=900)TREATMENT_STAND,
     *   XCOORD, YCOORD, AREA, STAND_ARCKEY, ZONE, ADJACENCY,
     * D_DISTANCE, SCHEDULE, E_SEASON, E_DISTANCE, E_TERRAIN,
     * LOGGINGSIZE, STORAGE, STORAGESIZE, TIMBERPARCEL,TIMBERLOT
       ICU=ICU+1
       WRITE(SQLUNIT,172)TREATMENT_COVER(1:CLG(TREATMENT_COVER)),
     *  FLOAT(TREATMENT_STAND), XCOORD, YCOORD, AREA,
     *  STAND_ARCKEY, ZONE, ADJACENCY,
     * D_DISTANCE, SCHEDULE, E_SEASON, E_DISTANCE, E_TERRAIN,
     * LOGGINGSIZE, STORAGE, STORAGESIZE, TIMBERPARCEL, TIMBERLOT
172    FORMAT(' INSERT INTO TREATMENT_STAND( ',/
     *  'PLANCOVER,TREATMENTSTAND,X_COORD,Y_COORD,AREA_M2,ARCKEY,'/
```

```
     *   'ZONE,ADJACENCY,D_DISTANCE,SCHEDULE,E_SEASON,E_DISTANCE,'/
     *   'E_TERRAIN,LOGGINGSIZE,STORAGE,STORAGESIZE,TIMBERPARCEL,'/
     *   'TIMBERLOT) VALUES(',/
     *    ' ''',A,''',',F5.0,3(',',F12.3),/
     *    ',',F13.0,2(',',I2),',',F12.3,',',I3,',',I2,',',F12.3,/
     *    ',',I3,',',F12.3,',',I5,',',F12.3,2(',',I5),');')
        GOTO 1

* - Write log for summary
900     CONTINUE
*IF INGRES
        WRITE(SQLUNIT,*)'\g'
*END IF
        WRITE(LOGUNIT,*)' '
        WRITE(LOGUNIT,*)' TOTAL of ',ICU,' treatment stands read'
        GOTO 999

* - Error messages
990     WRITE(LOGUNIT,*)' Error in opening the file '
        GOTO 999
999     CONTINUE
        END
```

DBMSVES

```
*=====================================================================
*Module          DBMS.pfo_program
*Header          Creates an input file (.VES) for MELA simulator
*                Muodostaa MELAn syottotiedoston .VES
*Comment         Only those stands accepted in MELA where
*                landcover 1-3 and at least one description tree
*System          VAX/VMS
*Storage
*Version
*Author          30.11.1990 Tuula A. Nuutinen
*Changes         29.12.1992
*                MELASTAND(7)=TREATMENT_STAND*1000
*                7.10.1992
*                Area in a table KUVIO already in hectares
*                /10000. removed
*                9.7.1992
*                Reads NS, JLPKEY, DBMS()
*                Stands without trees are rejected.
*                New TREATMENT_STAND index format.
*                ARCKEY in english.
*                TREATMENT_STAND key stored as MELASTAND(1)&(7).
*Bug             Has not been tested after 9.7. change!!!
*                MAXGIS should be JLP MAXNC1-(number of keys+number of
STAND())
*=====================================================================
*
       PROGRAM DBMSVES
*
*=====================================================================
       INCLUDE 'dbms.inc'
*                    Database dictionary
*                    Taulukot, joihin haetaan tila-, metsikk|- ja
*                    puustotietoja MELAn .VES-tiedoston muodos-
*                    tamiseksi
       INCLUDE 'ves.inc'
*                           MELA dictionary
*                           MELAn .VES-tiedoston kuvaus

*IF ORACLE
*- EXEC SQL BEGIN DECLARE SECTION
*- CHARACTER*20 UID
*- CHARACTER*20 PWD
*- EXEC SQL END DECLARE SECTION
*END IF

       REAL TREEGROUP(MAXMELATREEVARS,MAXSAMPLESIZE)
*                           Description trees per inventory tree
*                           Metsik|n yhden puuositteen kaikki puut
       REAL MELATREES(MAXMELATREEVARS,MAXINVTREES*MAXSAMPLESIZE)
*                           Description trees of a stand
*                           Metsik|n kaikkien puuositteiden kaikki
puut

* Input channels
* Sy|tt|tiedoston laitekoodit
       INTEGER         NXUNIT
        PARAMETER         (NXUNIT =  8)
       PARAMETER       (NEW_NXUNIT = 81)

* Output channels
* Tulostiedostojen laitekoodit
       INTEGER         VESUNIT, TOIUNIT, LOGUNIT
       PARAMETER       (VESUNIT =  9)
```

```
       PARAMETER     (TOIUNIT = 13)
      PARAMETER     (LOGUNIT =  4)

* Treatment unit ID
* Kasittely-yksik|n numero
      INTEGER        TREATMENT_STAND

* Planning year
* Suunnitelmavuosi
      INTEGER        TREATMENT_YEAR

* Stand ID
* Metsik|n tunniste
      REAL*8         STAND_ARCKEY

* Stand inventory  year
* Inventointivuosi
      INTEGER        INVENTORY_YEAR

* Area
* Pinta-ala
      REAL*8         AREA

* Reference  point
* Referenssipiste
      REAL*8         XCOORD, YCOORD

* C-variables for JLP from GIS
* JLPn C-muuttujat PATIsta
      PARAMETER      (MAXGIS = 30)
      PARAMETER      (MAXDBMS = 17)
      REAL           GIS(MAXGIS)
      INTEGER        DBMS(MAXDBMS)
*     0       = No value from GIS

* Number of schedules
* Simuloitujen vaihtoehtojen lukumaara
      INTEGER NS


* JLP calculation unit ID in file TREATMENT_COVER.NX
* JLP laskentayksikon numero tiedostossa TREATMENT_COVER.NX
      INTEGER        JLPKEY

* MELA calculation unit ID in file TREATMENT_COVER.NX
* MELA laskentayksikon numero tiedostossa TREATMENT_COVER.NX
      INTEGER        MELAKEY

* Farm ID
* Tilan tunniste
      REAL*8         FARM_ARCKEY


* Unread tratment units found in the .NX file
* Onko k{sittely-yksik|it{ viel{ lukematta .NX-tiedostossa
      LOGICAL        TREATUNIT_FOUND
      LOGICAL        FARM_FOUND, STAND_FOUND, TREE_FOUND


*=================================================================
* BEGIN  * main program
* BEGIN  * p{{ohjelma

      EXEC SQL INCLUDE SQLCA
      EXEC SQL WHENEVER SQLERROR GOTO 999
```

```
        EXEC SQL WHENEVER SQLWARNING CONTINUE

*IF ORACLE
*- UID='TAN'
*- PWD='JOENSUU'
*- EXEC SQL CONNECT :UID IDENTIFIED BY :PWD
*ELSE IF INGRES
        EXEC SQL CONNECT PATI
*END IF

* Open files
* Avataan tiedostot
*     MELA input file .VES
*     MELAn sy|tt|tiedosto .VES
        OPEN(VESUNIT,STATUS='NEW',FORM='UNFORMATTED')
*     MELA instruction file .TOI
*     MELAn ohjausparametritiedosto .TOI
        OPEN(TOIUNIT,STATUS='NEW',FORM='UNFORMATTED')
*     Log
*     Log
        OPEN(LOGUNIT,STATUS='NEW',FORM='FORMATTED')

*     index file
*     indeksitiedosto
        OPEN(NXUNIT,STATUS='OLD',FORM='FORMATTED',
     1       CARRIAGECONTROL='LIST')
        OPEN(NEW_NXUNIT,STATUS='NEW',FORM='FORMATTED',
     1       CARRIAGECONTROL='LIST')

         TREATUNIT_FOUND      = .TRUE.
        FARM_ARCKEY          = 0.
        MELAKEY    = 0

        DO WHILE (TREATUNIT_FOUND)

*          Read the next treatment unit
*          Luetaan seuraava k{sittely-yksikk|

           READ(NXUNIT,*,END=801)NS,
     *     JLPKEY,TREATMENT_STAND,
     *     TREATMENT_YEAR,
     *     STAND_ARCKEY,
     *      INVENTORY_YEAR,
     *      AREA, XCOORD, YCOORD,
     *      (GIS(ICVAR),ICVAR=1,MAXGIS),
     *      (DBMS(ICVAR),ICVAR=1,MAXDBMS)
           GO TO 802
801        TREATUNIT_FOUND = .FALSE.
802        CONTINUE

           IF (TREATUNIT_FOUND) THEN
*              A treatment unit found
*               L|ydettiin k{sittely-yksikk|

              IF ((AINT (STAND_ARCKEY / 100000)).NE.
     1             (AINT (FARM_ARCKEY  / 100000))    ) THEN
*                A new farm
*                 Tila vaihtui, luetaan uuden tilan tiedot
                FARM_ARCKEY = AINT(STAND_ARCKEY/100000) * 100000
                 CALL READ_FARM(FARM_ARCKEY, FARM, FARM_FOUND)
                IF (.NOT.FARM_FOUND) THEN
*IF ENGLISH
                    WRITE(6,*) 'Farm not found for ',FARM_ARCKEY
*ELSE IF FINNISH
*-                  WRITE(6,*) 'EI L\YDETTY TILAA ',FARM_ARCKEY,
*-     1                             ' ARCKEY:LLA.'
```

```
*END IF
                     FARM_FOUND = .FALSE.
                   GOTO 999
                 ENDIF
             ENDIF

             IF (FARM_FOUND) THEN
*            Read stand data for treatment unit
*             Luetaan k{sittely-yksik|n metsikk|tiedot
                CALL READ_STAND(STAND_ARCKEY, STAND, STAND_FOUND)

               IF (.NOT.STAND_FOUND) THEN
*IF ENGLISH
                   WRITE(6,*) 'Stand not found for ',STAND_ARCKEY
*ELSE IF FINNISH
*-                 WRITE(6,*) 'EI L\YDETTY METSIKK\[ ',STAND_ARCKEY,
*-     1                                 ' ARCKEY:LLA.'
*END IF
                   GOTO 999

               ELSE
*                 Stand data found
*                   L|ydettiin metsikk|tiedot
                   IF ( (STAND(3).LT.1.0) .OR. (STAND(3).GT.3.0) )
     1              THEN
*                   Not forest
*                      Ei mets{maata.
                       CONTINUE
                    ELSE

                    IF (AREA.NE.0)STAND(2)=AREA

                    WRITE(logunit,*)
*IF ENGLISH
                    WRITE(logunit,*) 'Treatment unit : ',
     1                                TREATMENT_STAND,
     2                          '    Arckey : ', STAND_ARCKEY
*ELSE IF FINNISH
*-                  WRITE(logunit,*) 'K{sittely-yksikk| : ',
*-     1                                TREATMENT_STAND, '     ',
*-     2                             '   Arckey : ', STAND_ARCKEY
*END IF
                    write(logunit,*) (stand(i),i=1,5)
                    write(logunit,*) (stand(i),i=6,10)
                    write(logunit,*) (stand(i),i=11,15)
                    write(logunit,*) (stand(i),i=16,20)
                    write(logunit,*)


*                   Create a MELA stand
*                      Luodaan MELA-metsikk|

                      CALL MAKE_MELASTAND(FARM,STAND,
     1                                 TREATMENT_STAND,MELASTAND)
                      DO 301 I=1,MAXINVTREES*MAXSAMPLESIZE
                         DO 302 J=1,MAXMELATREEVARS
                            MELATREES(J,I)=0.
302                      CONTINUE
301                   CONTINUE

                      IT=0
                       TREE_FOUND = .TRUE.

                       DO WHILE (TREE_FOUND)
                          CALL
      READ_TREE(STAND_ARCKEY,TREE,TREE_FOUND)
```

```
                                 IF (TREE_FOUND) THEN
                                    IT = IT +1
*IF ENGLISH
                                  WRITE(logunit,*) '     ',IT,'. inv.tree'
*ELSE IF FINNISH
*-                                WRITE(logunit,*) '     ',IT,'. puuosite'
*END IF
                                   write(logunit,*) (tree(i),i=1,5)
                                   write(logunit,*) (tree(i),i=6,10)
                                   write(logunit,*) (tree(i),i=11,11)

*                                 Generate description trees
*                                    Muodost. puusositetta kuvaava puujoukko
                                    CALL SAMPLE_MELATREES(MELASTAND,
     1                                                   TREE,
     2                                                   MAXSAMPLESIZE,
     3                                                   TREEGROUP)

                                    DO 401 ITT=1,MAXSAMPLESIZE
                                       ITI=(IT-1)*MAXSAMPLESIZE+ITT
                                       MELATREES(1,ITI)=TREEGROUP(1,ITT)
                                       MELATREES(2,ITI)=TREEGROUP(2,ITT)
                                       MELATREES(3,ITI)=TREEGROUP(3,ITT)
                                       MELATREES(4,ITI)=TREEGROUP(4,ITT)
                                       MELATREES(5,ITI)=TREEGROUP(5,ITT)
                                       MELATREES(6,ITI)=TREEGROUP(6,ITT)
                                       MELATREES(7,ITI)=TREEGROUP(7,ITT)
                                       MELATREES(8,ITI)=TREEGROUP(8,ITT)
                                       MELATREES(9,ITI)=TREEGROUP(9,ITT)
                                       MELATREES(10,ITI)=TREEGROUP(10,ITT)
401                                 CONTINUE
                                  END IF
                               END DO
*                                    /* TREE_FOUND */

                              DO 501 I=1,MAXMELATREEVARS
                                 MELATREE(I)=0.
501                           CONTINUE


*                          Write a MELA stand record
*                            Kirjoitetaan MELASTAND

*                          No MELA-record for stands without trees
*                          Ei MELA-tietuetta puuttomille kuvioille

                              NOOFMELATREES=IT*MAXSAMPLESIZE
                              IF (NOOFMELATREES.GT.0) THEN
                               MELAKEY=MELAKEY+1
                               MELASTAND(1)=MELAKEY
*cha TREATMENT_STAND*1000 for MONSU
                               MELASTAND(7)=TREATMENT_STAND*1000.
                               WRITE(6,*)' * ',MELASTAND(1),' - ',
     *                                             MELASTAND(7)
                                 CALL XREC(MELASTAND)
*                              Description trees exist
*                                 Metsik|ss{ on puita
                                 DO 502 J=1,NOOFMELATREES
                                    DO 503 I=1,MAXMELATREEVARS
                                       MELATREE(I)=MELATREES(I,J)
503                                 CONTINUE
                                    CALL XRECA(MELATREE)
502                              CONTINUE
*                              Write on disk
*                                Kirjoitetaan levylle
```

```
                          CALL XRECW
*                           Muodostetaan MELAn ohjausparametritiedosto
*                        CALL EHDOT HERE
*                          CALL EHDOT T[H[N

*                        Muokataan/taydennetaan .NX
*                        Modify/complete .NX

                 WRITE(NEW_NXUNIT,*)NS,MELAKEY,
     *          TREATMENT_STAND, TREATMENT_YEAR,
     *            STAND_ARCKEY, INVENTORY_YEAR,
     *          AREA, XCOORD, YCOORD,
     *          (GIS(ICVAR),ICVAR=1,MAXGIS),
     *          (NINT(STAND(INX)),INX=3,20)
                         ELSE
*IF ENGLISH
                         WRITE(logunit,*) ' ** REJECTED - no trees ** '
*ELSE IF FINNISH
*                        WRITE(logunit,*) ' ** HYLATTY - ei puita **'
*END IF
                            END IF

                         END IF
*                            /* Forest land or not   */
*                            /* Onko mets{maa vai ei */

                    END IF
*                        /* STAND_FOUND */

               END IF

*                   /* FARM_FOUND */

          END IF
*                /* TREATUNIT_FOUND */

          END DO
*                /* TREATUNIT_FOUND */


*         Commit
*IF ORACLE
*- EXEC SQL COMMIT WORK RELEASE
*ELSE IF INGRES
          EXEC SQL COMMIT
*END IF

*IF ENGLISH
          WRITE(6,*)' Total of ',MELAKEY
          STOP 'MELA input files created'
*ELSE IF FINNISH
*-        STOP 'Tiedostot muodostettu'
*END IF

* - Error message
999       CONTINUE
*IF ORACLE
*- EXEC SQL ROLLBACK WORK RELEASE
*ELSE IF INGRES
          EXEC SQL ROLLBACK
*END IF
*IF ENGLISH
          STOP 'MELA input files NOT created'
*ELSE IF FINNISH
*-        STOP 'Tiedostojen muodostaminen ei onnistunut'
*END IF
```

```
      END
```

READ_FARM

```
*=========================================================================
*Module       READ_FARM subroutine
*Header         Reads a record from a table PARCEL according to ARCKEY
*             Luetaan PATI-tietokannan TILA-taulusta ARCKEY:n
mukainen tila.
*Comment
*
*System       VAX/VMS
*Storage
*Version
*Author       30.11.1990 Tuula A. Nuutinen
*=========================================================================
*
      SUBROUTINE READ_FARM(ARCKEY,FARM,FARM_FOUND)

*Input
*     REAL          ARCKEY

*Output
      REAL          FARM(*)
      LOGICAL       FARM_FOUND
      EXEC SQL INCLUDE SQLCA
*     Farm table
*      TILA-taulun monikko
*IF ORACLE
*-EXEC SQL BEGIN DECLARE SECTION
*-   REAL f_researcharea, f_farm, f_parcel, f_arckey
*-   CHARACTER*5 f_registernumber
*-   REAL f_inventorydate
*-   REAL f_y
*-   REAL f_x
*-   REAL f_z
*-   REAL f_dd
*-   REAL f_regionalboard
*-   REAL f_localboard
*-   REAL f_ownergroup
*-   CHARACTER*22 f_description
*-   REAL*8 ARCKEY
*-EXEC SQL END DECLARE SECTION
*ELSE IF INGRES
      EXEC SQL BEGIN DECLARE SECTION
         EXEC SQL INCLUDE 'patitila.dcl'
         REAL*8 ARCKEY
      EXEC SQL END DECLARE SECTION
*END IF

*     Cursor for FARM
*     Kursori TILA-taulun monikon (tilan) hakemiseksi
*IF ORACLE
*-EXEC SQL DECLARE FARM_CURSOR CURSOR FOR
*-     *             SELECT researcharea, farm, parcel, arckey,
*-     *             registernumber,
*-     *             TO_NUMBER(TO_CHAR(inventorydate,'YY')),
*-     *             y,
*-     *             x,
*-     *             z,
*-     *             dd,
*-     *             regionalboard,
*-     *             localboard,
*-     *             ownergroup,
*-     *             description
```

```
*-      *       FROM PARCEL F
*-      *       WHERE F.arckey = :ARCKEY
*ELSE IF INGRES
        EXEC SQL DECLARE TILA_CURSOR CURSOR FOR
     *          SELECT tutkimusalue,tilanumero,palstanumero, arckey,
     *                   rekisterinumero,
     *                   aikaleima,
     *                   p_koordinaatti,
     *                   i_koordinaatti,korkeus,lamposumma,
     *                   metsalautakunta, mhy, omryhma, kohdealue
     *            FROM TILA T
     *            WHERE T.arckey = :ARCKEY
*END IF
*=====================================================================
        EXEC SQL WHENEVER SQLERROR GO TO 999

*IF ORACLE
*-      EXEC SQL OPEN FARM_CURSOR
*ELSE IF INGRES
        EXEC SQL OPEN TILA_CURSOR
*END IF
*       Retrieve a farm
*       Haetaan tila
*IF ORACLE
*- EXEC SQL FETCH FARM_CURSOR INTO :f_researcharea,
*-      *          :f_farm, :f_parcel, :arckey,
*-      *          :f_registernumber, :f_inventorydate, :f_y,
*-      *          :f_x, :f_z, :f_dd, :f_regionalboard,
*-      *          :f_localboard, :f_ownergroup, :f_description
*ELSE IF INGRES
        EXEC SQL FETCH TILA_CURSOR INTO :TILA_REC
*END IF

*IF ORACLE
*- IF (SQLCDE.EQ.1403) THEN
*ELSE IF INGRES
        IF (SQLCOD.EQ.100) THEN
*END IF
*           Farm not found
*           Tilaa ei ollut
            FARM_FOUND = .FALSE.
        ELSE
*           Farm found
*           L|ydettiin tila
            FARM_FOUND = .TRUE.

*IF ORACLE
*-    FARM(1)     = f_regionalboard
*-    FARM(2)     = f_ownergroup
*-    FARM(3)     = f_dd
*-    FARM(4)     = f_z
*-    FARM(5)     = f_y
*-    FARM(6)     = f_x
*ELSE IF INGRES
            FARM(1)     = TILA_REC.metsalautakunta
            FARM(2)     = TILA_REC.omryhma
            FARM(3)     = TILA_REC.lamposumma
            FARM(4)     = TILA_REC.korkeus
            FARM(5)     = TILA_REC.p_koordinaatti
            FARM(6)     = TILA_REC.i_koordinaatti
*END IF
        END IF

         GO TO 1000

999     CONTINUE
```

```
*       Error in reading
*       Lukemisessa tapahtui jokin virhe

*IF ORACLE
*- 1000EXEC SQL CLOSE FARM_CURSOR
*ELSE IF INGRES
1000    EXEC SQL CLOSE TILA_CURSOR
*END IF
        END
```

READ_STAND

```
*======================================================================
*Module         READ_STAND subroutine
*Header         Reads a record from a table STAND according to ARCKEY
*               Luetaan PATI-tietokannan KUVIO-taulusta ARCKEY:n
mukainen kuvio.
*Comment
*
*System         VAX/VMS
*Storage
*Version
*Author         30.11.1990 Tuula A. Nuutinen
*Changes        Aki Nalli
*
*Note           Inventointivuosi pit{{ olla 1900-luvulla.
*======================================================================
        SUBROUTINE READ_STAND(ARCKEY, STAND, STAND_FOUND)

*Input
*       REAL            ARCKEY

*Output
        REAL            STAND(*)
        LOGICAL         STAND_FOUND

        EXEC SQL INCLUDE SQLCA

*       Stand table
*       Kuvio-taulun monikko
*IF ORACLE
*-EXEC SQL BEGIN DECLARE SECTION
*-    REAL s_researcharea
*-    REAL      s_farm
*-    REAL s_stand
*-    REAL s_substand
*-    REAL s_arckey
*-    REAL s_inventorydate
*-    REAL s_area
*-    REAL s_landcover
*-    REAL s_subclass
*-    REAL s_soil
*-    REAL s_hydrology
*-    REAL s_site
*-    REAL s_stones
*-    REAL s_taxation
*-    REAL s_developmentclass
*-    REAL s_quality
*-    REAL s_landuse
*-    REAL s_sitetreatment
*-    REAL s_sitetreatmentyear
*-    REAL s_standtreatment
*-    REAL s_standtreatmentyear
*-    REAL s_sitetreatmentproposal
*-    REAL s_standtreatmentproposal
```

```
*-   REAL s_regenerationproposal
*-   REAL s_urgency
*-   CHARACTER*15 s_description
*-   REAL*8 ARCKEY
*-EXEC SQL END DECLARE SECTION
*ELSE IF INGRES
       EXEC SQL BEGIN DECLARE SECTION
          EXEC SQL INCLUDE 'patikuvio.dcl'
          REAL*8 ARCKEY
       EXEC SQL END DECLARE SECTION
*END IF

*      Cursor for STAND
*      Kursori KUVIO-taulun monikon (kuvion) hakemiseksi
*IF ORACLE
*- EXEC SQL DECLARE STAND_CURSOR CURSOR FOR
*-     *       SELECT researcharea, farm, stand, substand,

*-     *              arckey,
*-     *              TO_NUMBER(TO_CHAR(inventorydate,'YY')),

*-     *              area,
*-     *              landcover,
*-     *              subclass,
*-     *              soil,
*-     *              hydrology,
*-     *              site,
*-     *              stones,
*-     *              taxation,
*-     *               developmentclass,
*-     *              quality,
*-     *              landuse,
*-     *              sitetreatment,
*-     *              sitetreatmentyear,
*-     *              standtreatment,
*-     *              standtreatmentyear,
*-     *              sitetreatmentproposal,
*-     *              standtreatmentproposal,
*-     *              regenerationproposal,
*-     *              urgency,
*-     *              description
*-     *  FROM STAND S
*-     *  WHERE S.arckey = :ARCKEY
*-     *  ORDER BY S.arckey
*ELSE IF INGRES
       EXEC SQL DECLARE KUVIO_CURSOR CURSOR FOR
     *         SELECT tutkimusalue, tilanumero, kuvionumero,
     *                alakuvionumero, arckey,
     *                DATE_PART('year',aikaleima),
     *                pinta_ala, maalk_paaryhma, alaryhma,
     *                maa_turve_laji, ojitustilanne, metsatyyppi,
     *                kivisyys, veroluokka, kehitysluokka,
     *                metsikon_laatu, kayttomuoto, maankasittely,
     *                maan_kas_aika, puunkasittely, puun_kas_aika,
     *                maan_kas_ehd, puun_kas_ehd, uudistamis_ehd,
     *                kiireellisyys, kasvupaikka
     *          FROM KUVIO K
     *          WHERE K.arckey = :ARCKEY
     *        ORDER BY K.arckey
*======================================================================
       EXEC SQL WHENEVER SQLERROR GO TO 999

*IF ORACLE
*- EXEC SQL OPEN STAND_CURSOR
*ELSE IF INGRES
       EXEC SQL OPEN KUVIO_CURSOR
```

```
*END IF
*       Retrieve a stand
*       Haetaan kuvio
*IF ORACLE
*- EXEC SQL FETCH STAND_CURSOR INTO :s_researcharea,
*-      *               :s_farm, :s_stand, :s_substand,
*-      *               :s_arckey,
*-      *               :s_inventorydate,
*-      *               :s_area, :s_landcover, :s_subclass,

*-      *               :s_soil, :s_hydrology, :s_site,

*-      *               :s_stones, :s_taxation, :s_developmentclass,

*-      *               :s_quality, :s_landuse,
*-      *               :s_sitetreatment, :s_sitetreatmentyear,
*-      *               :s_standtreatment, s_standtreatmentyear,
*-      *               :s_sitetreatmentproposal,
*-      *               :s_standtreatmentproposal,
*-      *               :s_regenerationproposal,
*-      *               :s_urgency,
*-      *               :s_description
*ELSE IF INGRES
        EXEC SQL FETCH KUVIO_CURSOR INTO :KUVIO_REC
*END IF

*IF ORACLE
*- IF (SQLCDE.EQ.1403) THEN
*ELSE IF INGRES
        IF (SQLCOD.EQ.100) THEN
*END IF
*          Stand not found
*          Kuviota ei ollut
            STAND_FOUND = .FALSE.
         ELSE
*          Stand found
*           L|ydettiin kuvio
            STAND_FOUND = .TRUE.

*IF ORACLE
*-    STAND(1)     = s_inventorydate
*-    STAND(2)     = s_area
*-    STAND(3)     = s_landcover
*-    STAND(4)     = s_subclass
*-    STAND(5)     = s_soil
*-    STAND(6)     = s_hydrology
*-    STAND(7)     = s_site
*-    STAND(8)     = s_stones
*-    STAND(9)     = s_taxation
*-    STAND(10)    = s_developmentclass
*-    STAND(11)    = s_quality
*-    STAND(12)    = s_landuse
*-    STAND(13)    = s_sitetreatment
*-    STAND(14)    = s_sitetreatmentyear
*-    STAND(15)    = s_standtreatment
*-    STAND(16)    = s_standtreatmentyear
*-    STAND(17)    = s_sitetreatmentproposal
*-    STAND(18)    = s_standtreatmentproposal
*-    STAND(19)    = s_regenerationproposal
*-    STAND(20)    = s_urgency
*ELSE IF INGRES
           STAND(1)     = KUVIO_REC.aikaleima-1900
           STAND(2)     = KUVIO_REC.pinta_ala
           STAND(3)     = KUVIO_REC.maalk_paaryhma
           STAND(4)     = KUVIO_REC.alaryhma
           STAND(5)     = KUVIO_REC.maa_turve_laji
```

```
            STAND(6)     = KUVIO_REC.ojitustilanne
            STAND(7)     = KUVIO_REC.metsatyyppi
            STAND(8)     = KUVIO_REC.kivisyys
            STAND(9)     = KUVIO_REC.veroluokka
            STAND(10)    = KUVIO_REC.kehitysluokka
            STAND(11)    = KUVIO_REC.metsikon_laatu
            STAND(12)    = KUVIO_REC.kayttomuoto
            STAND(13)    = KUVIO_REC.maankasittely
            STAND(14)    = KUVIO_REC.maan_kas_aika
            STAND(15)    = KUVIO_REC.puunkasittely
            STAND(16)    = KUVIO_REC.puun_kas_aika
            STAND(17)    = KUVIO_REC.maan_kas_ehd
            STAND(18)    = KUVIO_REC.puun_kas_ehd
            STAND(19)    = KUVIO_REC.uudistamis_ehd
            STAND(20)    = KUVIO_REC.kiireellisyys
*END IF
      END IF

      GO TO 1000

999   CONTINUE
*     Error in reading
*     Lukemisessa tapahtui jokin virhe

*IF ORACLE
*-1000 EXEC SQL CLOSE STAND_CURSOR
*ELSE IF INGRES
1000  EXEC SQL CLOSE KUVIO_CURSOR
*END IF
      END
```

READ_TREE

```
*======================================================================
*Module        READ_TREE subroutine
*Header        Reads a record from a table TREES according to ARCKEY
*              Luetaan PATI-tietokannan PUUSTO-taulusta ARCKEY:n
mukainen
*              puutietue
*Comment
*
*System        VAX/VMS
*Storage
*Version
*Author        30.11.1990 Tuula A. Nuutinen
*======================================================================
      SUBROUTINE READ_TREE(ARCKEY, TREE, TREE_FOUND)

*Input
*     REAL           ARCKEY

*Output
      REAL           TREE(*)
      LOGICAL        TREE_FOUND

      LOGICAL CLOSED
      EXEC SQL INCLUDE SQLCA

*     Trees table
*     Puusto-taulun monikko
*IF ORACLE
*- EXEC SQL BEGIN DECLARE SECTION
*-    REAL              t_researcharea
*-    REAL              t_farm
*-    REAL              t_stand
```

```
*-   REAL           t_substand
*-   REAL           t_arckey
*-   REAL           t_tree
*-   REAL           t_species
*-   REAL           t_origin
*-   REAL           t_numberperha
*-   REAL           t_baperha
*-   REAL           t_meand13
*-   REAL           t_mind13
*-   REAL           t_maxd13
*-   REAL           t_meanheight
*-   REAL           t_bioage
*-   REAL           t_d13age
*-   REAL           t_damage
*-   REAL*8 ARCKEY
*- EXEC SQL END DECLARE SECTION
*ELSE IF INGRES
        EXEC SQL BEGIN DECLARE SECTION
          EXEC SQL INCLUDE 'patipuusto.dcl'
          REAL*8 ARCKEY
        EXEC SQL END DECLARE SECTION
*END IF


        DATA CLOSED/.TRUE./

*       Cursor for TREES
*       Kursori PUUSTO-taulun monikon (puutietueen) hakemiseksi
*IF ORACLE
*- EXEC SQL DECLARE TREE_CURSOR CURSOR FOR
*-      *              SELECT researcharea, farm, stand, substand,
*-      *              arckey,
*-      *              tree,
*-      *              species, origin, numberperha, baperha,
*-      *              meand13, mind13, maxd13, meanheight,
*-      *              bioage, d13age, damage
*-      *          FROM TREES T
*-      *          WHERE T.arckey = :ARCKEY
*-      *          ORDER BY T.arckey, T.tree
*ELSE IF INGRES
        EXEC SQL DECLARE PUUSTO_CURSOR CURSOR FOR
     *          SELECT tutkimusalue, tilanumero, kuvionumero,
     *                  alakuvionumero, arckey, osite, puulaji,
     *                 syntytapa, runkoluku, pohjapinta_ala,
     *                  keski_lpm, minimi_lpm, maximi_lpm,
     *                  keskipituus, biologinen_ika,
     *                 rinnankorkeusika, tuhot
     *            FROM PUUSTO P
     *            WHERE P.arckey = :ARCKEY
     *            ORDER BY P.arckey, P.osite
*END IF
*=====================================================================
        EXEC SQL WHENEVER SQLERROR GO TO 999

        IF (CLOSED) THEN
*IF ORACLE
*-    EXEC SQL OPEN TREE_CURSOR
*ELSE IF INGRES
           EXEC SQL OPEN PUUSTO_CURSOR
*END IF
           CLOSED=.FALSE.
        END IF

*       Retrieve a tree
*       Haetaan puu
*IF ORACLE
```

```
*-EXEC SQL FETCH TREE_CURSOR INTO :t_researcharea,
*-      *              :t_farm, :t_stand, :t_substand,
*-      *              :t_arckey,
*-      *              :t_tree,
*-      *              :t_species, :t_origin, :t_numberperha,
:t_baperha,
*-      *              :t_meand13, :t_mind13, :t_maxd13, :t_meanheight,

*-      *              :t_bioage, :t_d13age, :t_damage
*ELSE IF INGRES
       EXEC SQL FETCH PUUSTO_CURSOR INTO :PUUSTO_REC
*END IF

*IF ORACLE
*- IF (SQLCDE.EQ.1403) THEN
*ELSE IF INGRES
       IF (SQLCOD.EQ.100) THEN
*END IF

*IF ORACLE
*-   EXEC SQL CLOSE TREE_CURSOR
*ELSE IF INGRES
          EXEC SQL CLOSE PUUSTO_CURSOR
*END IF
           TREE_FOUND = .FALSE.
          CLOSED=.TRUE.
       ELSE
*         A tree found
*         L|ydettiin puu
          TREE_FOUND = .TRUE.

*IF ORACLE
*-   TREE(1)     = t_species
*-   TREE(2)     = t_origin
*-   TREE(3)     = t_numberperha
*-   TREE(4)     = t_baperha
*-   TREE(5)     = t_meand13
*-   TREE(6)     = t_mind13
*-   TREE(7)     = t_maxd13
*-   TREE(8)     = t_meanheight
*-   TREE(9)     = t_bioage
*-   TREE(10)    = t_d13age
*-   TREE(11)    = t_damage
*ELSE IF INGRES
          TREE(1)      = PUUSTO_REC.puulaji
          TREE(2)      = PUUSTO_REC.syntytapa
          TREE(3)      = PUUSTO_REC.runkoluku
          TREE(4)      = PUUSTO_REC.pohjapinta_ala
          TREE(5)      = PUUSTO_REC.keski_lpm
          TREE(6)      = PUUSTO_REC.minimi_lpm
          TREE(7)      = PUUSTO_REC.maximi_lpm
          TREE(8)      = PUUSTO_REC.keskipituus
          TREE(9)      = PUUSTO_REC.biologinen_ika
          TREE(10)     = PUUSTO_REC.rinnankorkeusika
          TREE(11)     = PUUSTO_REC.tuhot
*END IF
       END IF

        RETURN

999    CONTINUE
*      Error in reading
*       Lukemisessa tapahtui jokin virhe

       END
```

VESDBMS

```
*=====================================================================
*Module         VESDBMS.f_program
*Header         Writes a .VES (.PAI format) into an SQL-query
*               Kirjoittaa .VES (.PAI muodossa) SQL-kyselyksi
*System
*Storage
*Version
*Author         8.3.1991       Tuula A. Nuutinen, METLA/JOE
*Changes        12.6.1991 ARCKEY / Tuula A. Nuutinen, METLA/JOE
*Comment        The tables have to be created before nn_PAI.SQL
*               can be loaded
*               Taulut on luotava ennen kuin nn_PAI.SQL
*               voidaan lukea tietokantaan
*Bug            Error in reading sample plots => CURRENT_STAND error
*=====================================================================
*
      PROGRAM VESDBMS
*
* Input channels
* Syottotiedostojen laitekoodit
      INTEGER        NXUNIT, PAIUNIT
      PARAMETER      (NXUNIT = 8)
      PARAMETER      (PAIUNIT = 16)


* Output channels
* Tulostiedostojen laitekoodit
      INTEGER        SQLUNIT, LOGUNIT
      PARAMETER      (SQLUNIT = 17)
      PARAMETER      (LOGUNIT = 4)

* Key table
      PARAMETER      (MAXML=1000)
      PARAMETER      (MAXGIS=30)
      INTEGER        NS
      INTEGER        MELAKEY(MAXML)
      INTEGER        TREATMENT_UNIT
      INTEGER        TREATMENT_YEAR
      REAL*8         STAND_ARCKEY
      INTEGER        INVENTORY_YEAR
      REAL*8         AREA
      REAL*8         XCOORD, YCOORD
      INTEGER        CVAR(MAXGIS)
      INTEGER        STAND(20)
      REAL*8         ARCKEY(MAXML)

* .PAI record
      PARAMETER      (LOGD=18)
*                    Minimum diameter for saw logs
      DIMENSION      X(10000)
      REAL           CURRENT_STAND(70)
      REAL           CURRENT_TREES(26,100)
      INTEGER        NUMBER(6)
      REAL           DSUM(6)
      REAL           TIMBER(6)
      REAL           STEM_SIZE(6)
*=====================================================================
=
* Open the files
      OPEN(NXUNIT,STATUS='OLD')
      OPEN(PAIUNIT,STATUS='OLD',FORM='UNFORMATTED')
      OPEN(SQLUNIT,STATUS='NEW',FORM='FORMATTED',
```

```
     *  CARRIAGECONTROL='LIST')
        OPEN(LOGUNIT,STATUS='NEW',FORM='FORMATTED')

* Read the keys from the index file into key tables
        ICU=0
1       CONTINUE
        ICU=ICU+1
        READ(NXUNIT,*,END=11)NS, MELAKEY(ICU),
     *  TREATMENT_UNIT, TREATMENT_YEAR,
     *  STAND_ARCKEY, INVENTORY_YEAR,
     *  AREA, XCOORD, YCOORD,
     *  (CVAR(ICVAR),ICVAR=1,MAXGIS),
     *  (STAND(IMMY),IMMY=3,20)

        ARCKEY(MELAKEY(ICU))=STAND_ARCKEY
*-      WRITE(LOGUNIT,*)' Read a record ',ICU,' for ',
*-      *  MELAKEY(ICU),ARCKEY(MELAKEY(ICU))
        GOTO 1
11      CONTINUE
*-      WRITE(LOGUNIT,*)'Total number of units ',ICU-1
*-      DO 121 IMU=1,ICU-1
*-        WRITE(LOGUNIT,*)'Keys ',IMU,MELAKEY(IMU),ARCKEY(MELAKEY(IMU))
*-121   CONTINUE

* Read the corresponding .PAI calculation unit
        IMU=0
10      CONTINUE
        IMU=IMU+1
        READ(PAIUNIT,END=20,ERR=33)IX,(X(I),I=1,IX)

* Initialize
        DO 1772 ITI=1,6
          NUMBER(ITI)=0
          DSUM(ITI)=0.
          TIMBER(ITI)=0.
          STEM_SIZE(ITI)=0.
1772    CONTINUE
        DO 1773 ITI=1,70
          CURRENT_STAND(ITI)=0.
1773    CONTINUE
        DO 1774 ITI=1,26
          DO 1775 ISI=1,100
          CURRENT_TREES(ITI,ISI)=0.
1775      CONTINUE
1774    CONTINUE

* Move the pointer to the calculation unit
        NA=1
        NT=X(NA)
        NK=X(NA+1)
        NA=NA+1
        NAP=NA+NK+1
        NR=X(NAP)
        IC=X(NA+1)
        WRITE(LOGUNIT,*)'* Reading PAI for ',MELAKEY(IMU),' MELA ',IC

* Move the pointer to sample plot data
        NA=NA+NAP-1
* ... if no sample plots
        IF(NR.LT.1) GO TO 40
        DO 50 I=1,NR
          NKK=X(NAP+1)


* Delete previous records
*-      WRITE(LOGUNIT,*)' DELETE records for MELA ',ic,' ',ARCKEY(IC)
```

```
        WRITE(SQLUNIT,71)ARCKEY(IC)
71      FORMAT(' DELETE FROM CURRENT_STAND WHERE ARCKEY = ',
     *  F14.0,';')
*-      WRITE(SQLUNIT,72)ARCKEY(IC)
*-72    FORMAT(' DELETE FROM CURRENT_TREES WHERE ARCKEY = ',
*-      *  F14.0,';')

*Cha 9.6.1992 Added timber assortement values
*-      WRITE(SQLUNIT,171)ARCKEY(IC),
*-      *  (X(NA+K),K=2,71)
        DO 1771 K=2,71
          CURRENT_STAND(K)=X(NA+K)
1771    CONTINUE


*
* Move the pointer to the TREE data
          NAPP=NAP+1+NKK+1
          NP=X(NAPP)
          NPP=X(NAPP+1)
* ... if no trees
          IF(NP.LT.1) GO TO 50
*-        WRITE(LOGUNIT,*)' Write ',NP,' trees for ',ARCKEY(IC)
          NAPP=NAPP+1
          DO 60 J=1,NP
            DO 601 N=1,NPP
               CURRENT_TREES(N,J)=X(NAPP+N)
601         CONTINUE
            IF (CURRENT_TREES(2,J).EQ.1.) THEN
                 IF (CURRENT_TREES(3,J).GT.LOGD) THEN
                   NUMBER(1)=NUMBER(1)+1
                   DSUM(1)=DSUM(1)+CURRENT_TREES(3,J)
                 ELSE
                   NUMBER(2)=NUMBER(2)+1
                   DSUM(2)=DSUM(2)+CURRENT_TREES(3,J)
                 END IF
                 TIMBER(1)=TIMBER(1)+
     *                       (CURRENT_TREES(1,J)*CURRENT_TREES(10,J))
                 TIMBER(2)=TIMBER(2)+
     *                       (CURRENT_TREES(1,J)*CURRENT_TREES(11,J))
                ELSE
                  IF (CURRENT_TREES(2,J).EQ.2.) THEN
                   IF (CURRENT_TREES(3,J).GT.LOGD) THEN
                     NUMBER(3)=NUMBER(3)+1
                     DSUM(3)=DSUM(3)+CURRENT_TREES(3,J)
                   ELSE
                     NUMBER(4)=NUMBER(4)+1
                     DSUM(4)=DSUM(4)+CURRENT_TREES(3,J)
                   END IF
                   TIMBER(3)=TIMBER(3)+
     *                       (CURRENT_TREES(1,J)*CURRENT_TREES(10,J))
                   TIMBER(4)=TIMBER(4)+
     *                       (CURRENT_TREES(1,J)*CURRENT_TREES(11,J))
                 ELSE
                   IF (CURRENT_TREES(3,J).GT.LOGD) THEN
                     NUMBER(5)=NUMBER(5)+1
                     DSUM(5)=DSUM(5)+CURRENT_TREES(3,J)
                   ELSE
                     NUMBER(6)=NUMBER(6)+1
                     DSUM(6)=DSUM(6)+CURRENT_TREES(3,J)
                   END IF
                   TIMBER(5)=TIMBER(5)+
     *                       (CURRENT_TREES(1,J)*CURRENT_TREES(10,J))
                   TIMBER(6)=TIMBER(6)+
     *                       (CURRENT_TREES(1,J)*CURRENT_TREES(11,J))
                 END IF
```

```
              END IF

*-            WRITE(SQLUNIT,161)ARCKEY(IC),
*-      *      (X(NAPP+N),N=1,NPP)
*-           WRITE(SQLUNIT,161)ARCKEY(IC),
*-      *         (CURRENT_TREES(N,J),N=1,NPP)
161         FORMAT(' INSERT INTO CURRENT_TREES VALUES(',/
     *         ' ',F14.0,',',/
     *   5(' ',F7.2,','),/
     *   5(' ',F7.2,','),/
     *   5(' ',F7.2,','),/
     *   5(' ',F7.2,','),/
     *   5(' ',F7.2,','),F7.2,');')
            NAPP=NAPP+NPP
60          CONTINUE
            DO 606 ITI=1,6
              IF (NUMBER(ITI).GT.0)STEM_SIZE(ITI)=DSUM(ITI)/NUMBER(ITI)
606         CONTINUE


            NAP=NAP+2+(NP*NPP)

          WRITE(SQLUNIT,171)ARCKEY(IC),
     *   (CURRENT_STAND(K),K=2,71),(TIMBER(ITI),ITI=1,6),
     *   (STEM_SIZE(ISI),ISI=1,6)
171       FORMAT(' INSERT INTO CURRENT_STAND VALUES(',/
     *       ' ',F14.0,',',/
     *   5(' ',F7.2,',')/
     *   5(' ',F7.2,',')/
     *   5(' ',F7.2,',')/
     *   5(' ',F7.2,',')/
     *   5(' ',F7.2,',')/
     *   5(' ',F7.2,',')/
     *   5(' ',F7.2,',')/
     *   2(' ',F7.2,','),F10.2,',',2(F7.2,',')/
     *   5(' ',F7.2,',')/
     *   2(' ',F7.2,','),F10.2,',',2(F7.2,',')/
     *   5(' ',F7.2,',')/
     *   5(' ',F7.2,',')/
     *   5(' ',F7.2,',')/
     *   5(' ',F7.2,',')/
     *   5(' ',F7.2,',')/
     *   6(' ',F7.2,','),F7.2,');')

50        CONTINUE

40        CONTINUE

* Return to read
*IF INGRES
           WRITE(SQLUNIT,*)'\g'
*END IF
          GO TO 10
*
33        CONTINUE
          STOP
20        CONTINUE

          END
```

ADDNS

```
*=====================================================================
*Module         ADDNS.f_program
*Header         Adds number of schedules into INDEX-file from .CDA for
JLP
*
*System
*Storage
*Version
*Author         8.6.1992      Tuula A. Nuutinen, METLA/JOE
*Changes
*Comment
*=====================================================================
*
       PROGRAM ADDNS
*
* Input channels
* Syottotiedostojen laitekoodit
       INTEGER        NXUNIT, NEW_NXUNIT, CDAUNIT
       PARAMETER      (NXUNIT = 8)
       PARAMETER      (CDAUNIT = 20)

* Output channels
* Tulostiedostojen laitekoodit
       PARAMETER      (NEW_NXUNIT = 81)

* Key table see JLP.PAR
*needs:
*end:
       PARAMETER      (MAXML=1000)
       PARAMETER      (MAXGIS=30)
       INTEGER        OLD_NS
       INTEGER        NS
       INTEGER        MELAKEY(MAXML)
       INTEGER        TREATMENT_UNIT
       INTEGER        TREATMENT_YEAR
       REAL*8         STAND_ARCKEY
       INTEGER        INVENTORY_YEAR
       REAL*8         AREA
       REAL*8         XCOORD, YCOORD
       INTEGER        CVAR(MAXGIS)
       INTEGER        STAND(20)
       REAL*8         ARCKEY(MAXML)
*=====================================================================
* Open the files
       OPEN(NXUNIT,STATUS='OLD')
       OPEN(CDAUNIT,STATUS='OLD')
       OPEN(NEW_NXUNIT,STATUS='NEW',FORM='FORMATTED',
     *  CARRIAGECONTROL='LIST')

* Read the index records from an old INDEX and number of schedules
from .CDA
* and write both into a new INDEX
       ICU=0
1      CONTINUE
       ICU=ICU+1
       READ(NXUNIT,*,END=12)OLD_NS,MELAKEY(ICU),
     *  TREATMENT_UNIT, TREATMENT_YEAR,
     *  STAND_ARCKEY, INVENTORY_YEAR,
     *  AREA, XCOORD, YCOORD,
     *  (CVAR(ICVAR),ICVAR=1,MAXGIS),
     *  (STAND(IMMY),IMMY=3,20)
       ARCKEY(MELAKEY(ICU))=STAND_ARCKEY
       READ(CDAUNIT,*,END=11)NS
       WRITE(NEW_NXUNIT,*)NS, MELAKEY(ICU),
```

```
     *  TREATMENT_UNIT, TREATMENT_YEAR,
     *  STAND_ARCKEY, INVENTORY_YEAR,
     *  AREA, XCOORD, YCOORD,
     *  (CVAR(ICVAR),ICVAR=1,MAXGIS),
     *  (STAND(IMMY),IMMY=3,20)

        WRITE(6,*)' * ',MELAKEY(ICU),' <> ',NS
        GOTO 1
11      CONTINUE
        WRITE(6,*)' Error in .CDA in a record ',ICU,' for ',
     *  MELAKEY(ICU),ARCKEY(MELAKEY(ICU))
        STOP
12      CONTINUE
        WRITE(6,*)'Total number of units ',ICU-1
        STOP
        END
```

CDADBMS

```
*==================================================================
*Module         CDADBMS.f_program
*Header         Reading JLP write/* .CDA
*Comment
*System         VAX/VMS
*Storage        GEOVAX:<TAN>
*Version
*Author         20.6.1992 Tuula A. Nuutinen
*Changes
*Bug            STAND(20) should be included from DBMS.INC
*               JMAKE should be used to include JLP.PAR definitions
*==================================================================
*
       PROGRAM CDADBMS
*
*Parameters see JLP.PAR and JMAKE
*needs:
*end:
       PARAMETER (MAXML=1000)
*              max. number of calculation units
       PARAMETER (MAXNC1=100)
*              max. number of c-variables
*      PARAMETER (LVARNA=32)
*              length of character variables used for variable names
*      PARAMETER (LLINE=130)
*              length of command line in a .SAV
*      PARAMETER (LHDR=5)
*              length of command names
       PARAMETER (MAXGIS=30)
*              max. number of GIS-variables

*Assign the I/O-channels
       INTEGER SAVUNIT, CDAUNIT
       INTEGER LOGUNIT, SQLUNIT
       PARAMETER (SAVUNIT=9)
       PARAMETER (CDAUNIT=20)
       PARAMETER (LOGUNIT=4)
       PARAMETER (SQLUNIT=17)

*Definitions
       CHARACTER*130 LINE
       CHARACTER*5   HDR
       CHARACTER*10  OWNHDR
       CHARACTER*32  CNAME(MAXNC1)
       CHARACTER*20  PLAN
       INTEGER       CLG

       REAL          C(MAXNC1)
       INTEGER       MV(MAXML)

       PARAMETER      (MAXC_RDBMS=2)
       CHARACTER*32  C_COLUMNS(MAXC_RDBMS)
       REAL          C_RDBMS(MAXC_RDBMS)
       INTEGER       COUT(MAXC_RDBMS)

       DATA C_COLUMNS /'coverkey','ns'/
*==================================================================
       OPEN(SAVUNIT,STATUS='OLD',ACCESS='SEQUENTIAL',
     *  FORM='FORMATTED',ERR=990,IOSTAT=IER)
       OPEN(CDAUNIT,STATUS='OLD',ACCESS='SEQUENTIAL',
     *  FORM='FORMATTED',ERR=990,IOSTAT=IER)
       OPEN(SQLUNIT,STATUS='NEW',FORM='FORMATTED',
     *  CARRIAGECONTROL='LIST')
       OPEN(LOGUNIT,STATUS='NEW',FORM='FORMATTED')
```

```
* - Initialize
        PLAN=' '
        ISNS=0
        DO 10 IOUT=1,MAXC_RDBMS
          COUT(IOUT)=0
          C_RDBMS(IOUT)=0
10      CONTINUE


* - Read header
100     FORMAT (A)
101     CONTINUE
        READ(SAVUNIT,100,ERR=991,END=110)LINE
        CALL CEI(LINE,' ',1,HDR,1,ISEP)
        IF (HDR(1:1).EQ.'*'.OR.HDR(1:1).EQ.';'.OR.HDR(1:1).EQ.'!')
     *  GOTO 101

*       - Find plan
        IF (HDR(1:5).EQ.'title') THEN
           CALL CEI(LINE,' ',1,OWNHDR,1,ISEP)
          IF (OWNHDR(1:5).EQ.'plan') THEN
           CALL CEI(LINE,' ',1,PLAN,1,ISEP)
           END IF
          WRITE(LOGUNIT,*)' Plan ',PLAN
          GOTO 101
        END IF

*       - Save the list of output c-variables
        IF (HDR(1:5).EQ.'keepc')THEN
          NC=0
          DO 201 IC=1,MAXNC1
            CALL CEI(LINE,',',1,CNAME(IC),1,ISEP)
            IF (CNAME(IC)(1:1).EQ.' ')GOTO 203
            IF (CNAME(IC)(1:1).EQ.'>') THEN
              READ(SAVUNIT,100,ERR=991,END=110)LINE
              CALL CEI(LINE,',',1,CNAME(IC),1,ISEP)
            END IF
            NC=NC+1
            IF (CNAME(IC)(1:2).EQ.'ns')ISNS=IC
            DO 202 IOUT=1,MAXC_RDBMS
              IF (CNAME(IC).EQ.C_COLUMNS(IOUT)) COUT(IOUT)=IC
202         CONTINUE
201       CONTINUE
203       CONTINUE
          GOTO 101
        END IF

*       - skip x-variables
        IF (HDR(1:5).EQ.'keepx')GOTO 101

*       - skip otherwise
        GOTO 101

110     CONTINUE

* - Write log for C_COLUMNS
        WRITE(LOGUNIT,*)' C_RDBMS variables '
        DO 120 IOUT=1,MAXC_RDBMS
         WRITE(LOGUNIT,*)C_COLUMNS(IOUT),CNAME(COUT(IOUT))
120     CONTINUE

* - Write sql to clear rows
        WRITE(SQLUNIT,171)PLAN(1:CLG(PLAN))
171     FORMAT(' DELETE FROM CALCULATION_UNIT WHERE PLAN=''',A,''' ;')
```

```
      WRITE(SQLUNIT,172)PLAN(1:CLG(PLAN))
172   FORMAT(' DELETE FROM SOLUTION WHERE PLAN=''',A,''' ;')

* - Read c-variables and write sql to insert
      ICC=0
501   CONTINUE
      READ(CDAUNIT,*,END=900,ERR=995)(C(IC),IC=1,NC)
      ICC=ICC+1
      MV(ICC)=C(ISNS)
      DO 502 IOUT=1,MAXC_RDBMS
       C_RDBMS(IOUT)=C(COUT(IOUT))
502   CONTINUE
      WRITE(LOGUNIT,*)' Read a record ',ICC,' for ',
     *  C_RDBMS(2),C_RDBMS(1)
      WRITE(SQLUNIT,173)PLAN(1:CLG(PLAN)),FLOAT(ICC),
     *  (C_RDBMS(IOUT),IOUT=1,MAXC_RDBMS)
173   FORMAT(' INSERT INTO CALCULATION_UNIT VALUES(',/
     *  ' ''',A,''',',F5.0,<MAXC_RDBMS>(',',F5.0),');')
      GOTO 501

* - Write log for summary
900   CONTINUE
*IF INGRES
       WRITE(SQLUNIT,*)'\g'
*END IF
      WRITE(LOGUNIT,*)' '
      WRITE(LOGUNIT,*)' TOTAL of ',ICC,' calculation units read'
      GOTO 999

* - Error messages
990   WRITE(LOGUNIT,*)' Error in opening the file ',IER
      GOTO 999
991   WRITE(LOGUNIT,*)' Error in reading definitions file'
      GOTO 999
995   WRITE(LOGUNIT,*)' Error in reading C-variables'
      GOTO 999
999   CONTINUE
      END
```

XDADBMS

```
*=====================================================================
*Module       XDADBMS.f_program
*Header       Reading JLP write/* .XDA
*Comment
*System       VAX/VMS
*Storage      GEOVAX:<TAN>
*Version
*Author       20.6.1992 Tuula A. Nuutinen
*Changes      7.7.1992 TABLE-name and COLUMNS read from a definition
file
*Comment      Edit .DEF file for new SCHEDULE-tables and run XDADBMS
*Bug          STAND(20) should be included from DBMS.INC
*             JMAKE should be used to include JLP.PAR definitions
*=====================================================================
*
      PROGRAM XDADBMS
*
*Parameters see JLP.PAR and JMAKE
*needs:
*end:
      PARAMETER (MAXML=1000)
*             max. number of calculation units
      PARAMETER (MAXNC1=500)
*             max. number of c-variables
      PARAMETER (MAXNX=1000)
```

```
*             max. number of x-variables
*       PARAMETER (LVARNA=32)
*             length of character variables used for variable names
*       PARAMETER (LLINE=130)
*             length of command line in a .SAV
*       PARAMETER (LHDR=5)
*             length of command names
        PARAMETER (MAXGIS=30)
*             max. number of GIS-variables

*Assign the I/O-channels
        INTEGER DEFUNIT, SAVUNIT, CDAUNIT, XDAUNIT
        INTEGER LOGUNIT, SQLUNIT
        PARAMETER (DEFUNIT=7)
        PARAMETER (SAVUNIT=9)
        PARAMETER (CDAUNIT=20)
        PARAMETER (XDAUNIT=21)
        PARAMETER (LOGUNIT=4)
        PARAMETER (SQLUNIT=17)

*Definitions
        CHARACTER*130 LINE
        CHARACTER*5   HDR
        CHARACTER*10  OWNHDR
        CHARACTER*32  CNAME(MAXNC1)
        CHARACTER*32  XNAME(MAXNX)
        CHARACTER*32  XTABLE
        CHARACTER*32  CONST
        CHARACTER*20  PLAN
        INTEGER       CLG
        REAL          CER

        REAL          C(MAXNC1)
        REAL          X(MAXNX)
        INTEGER       MV(MAXML)

        PARAMETER     (MAXC_RDBMS=2)
        CHARACTER*32  C_COLUMNS(MAXC_RDBMS)
        REAL          C_RDBMS(MAXC_RDBMS)
        INTEGER       COUT(MAXC_RDBMS)

        PARAMETER     (MAXX_RDBMS=1000)
        CHARACTER*32  X_COLUMNS(MAXX_RDBMS)
        REAL          X_RDBMS(MAXX_RDBMS)
        INTEGER       XOUT(MAXX_RDBMS)

*======================================================================
        OPEN(DEFUNIT,STATUS='OLD',ACCESS='SEQUENTIAL',
     *   FORM='FORMATTED',ERR=990,IOSTAT=IER)
        OPEN(SAVUNIT,STATUS='OLD',ACCESS='SEQUENTIAL',
     *   FORM='FORMATTED',ERR=990,IOSTAT=IER)
        OPEN(CDAUNIT,STATUS='OLD',ACCESS='SEQUENTIAL',
     *   FORM='FORMATTED',ERR=990,IOSTAT=IER)
        OPEN(XDAUNIT,STATUS='OLD',ACCESS='SEQUENTIAL',
     *   FORM='FORMATTED',ERR=990,IOSTAT=IER)
        OPEN(SQLUNIT,STATUS='NEW',FORM='FORMATTED',
     *   CARRIAGECONTROL='LIST')
        OPEN(LOGUNIT,STATUS='NEW',FORM='FORMATTED')


* - Initialize
        PLAN=' '
        ISNS=0
        DO 10 IOUT=1,MAXX_RDBMS
          XOUT(IOUT)=0
          X_RDBMS(IOUT)=0
```

```
10      CONTINUE

* - Read output variable-listS
1       CONTINUE
        READ(DEFUNIT,100,ERR=991,END=11)LINE
        CALL CEI(LINE,' ',1,HDR,1,ISEP)
        IF (HDR(1:1).EQ.'*'.OR.HDR(1:1).EQ.';'.OR.HDR(1:1).EQ.'!')
     *  GOTO 11

* - x-table
        IF (HDR(1:5).EQ.'xtabl') THEN
          CALL CEI(LINE,'.',1,XTABLE,1,ISEP)
          WRITE(LOGUNIT,*)' X-table ',XTABLE
          GOTO 1
        END IF

* - x-variables
        IF (HDR(1:5).EQ.'xcolu')THEN
          NXX=0
          DO 31 IX=1,MAXNX
            CALL CEI(LINE,',',1,X_COLUMNS(IX),1,ISEP)
            IF (X_COLUMNS(IX)(1:1).EQ.' ')GOTO 33
            IF (X_COLUMNS(IX)(1:1).EQ.'>') THEN
              READ(DEFUNIT,100,ERR=991,END=11)LINE
              CALL CEI(LINE,',',1,X_COLUMNS(IX),1,ISEP)
            END IF
            NXX=NXX+1
31        CONTINUE
33        CONTINUE
          GOTO 1
        END IF

* - c-variables
        IF (HDR(1:5).EQ.'ccolu')THEN
          NCC=0
          DO 21 IC=1,MAXNC1
            CALL CEI(LINE,',',1,C_COLUMNS(IC),1,ISEP)
            IF (C_COLUMNS(IC)(1:1).EQ.' ')GOTO 23
            IF (C_COLUMNS(IC)(1:1).EQ.'>') THEN
              READ(DEFUNIT,100,ERR=991,END=11)LINE
              CALL CEI(LINE,',',1,C_COLUMNS(IC),1,ISEP)
            END IF
            NCC=NCC+1
21        CONTINUE
23        CONTINUE
          GOTO 1
        END IF

*       - skip otherwise
        GOTO 1

11      CONTINUE


* - Read header
100     FORMAT (A)
101     CONTINUE
        READ(SAVUNIT,100,ERR=991,END=110)LINE
        CALL CEI(LINE,' ',1,HDR,1,ISEP)
        IF (HDR(1:1).EQ.'*'.OR.HDR(1:1).EQ.';'.OR.HDR(1:1).EQ.'!')
     *  GOTO 101

* - Find PLAN
         IF (HDR(1:5).EQ.'title') THEN
           CALL CEI(LINE,' ',1,OWNHDR,1,ISEP)
           IF (OWNHDR(1:5).EQ.'plan') THEN
```

```
            CALL CEI(LINE,' ',1,PLAN,1,ISEP)
          END IF
          WRITE(LOGUNIT,*)' Plan ',PLAN
          GOTO 101
        END IF

* - Find periods
       IF (HDR(1:5).EQ.'const') THEN
         GOTO 101
       END IF

* - Find the location of 'ns'
       IF (HDR(1:5).EQ.'keepc')THEN
         NC=0
         DO 201 IC=1,MAXNC1
           CALL CEI(LINE,',',1,CNAME(IC),1,ISEP)
           IF (CNAME(IC)(1:1).EQ.' ')GOTO 203
           IF (CNAME(IC)(1:1).EQ.'>') THEN
             READ(SAVUNIT,100,ERR=991,END=110)LINE
             CALL CEI(LINE,',',1,CNAME(IC),1,ISEP)
           END IF
           NC=NC+1
           IF (CNAME(IC)(1:2).EQ.'ns')ISNS=IC
           DO 202 IOUT=1,NCC
             IF (CNAME(IC).EQ.C_COLUMNS(IOUT)) COUT(IOUT)=IC
202        CONTINUE
201      CONTINUE
203      CONTINUE
         GOTO 101
       END IF

* - Save the list of output x-variables
       IF (HDR(1:5).EQ.'keepx')THEN
         NX=0
         DO 301 IX=1,MAXNX
           CALL CEI(LINE,',',1,XNAME(IX),1,ISEP)
           IF (XNAME(IX)(1:1).EQ.' ')GOTO 303
           IF (XNAME(IX)(1:1).EQ.'>') THEN
             READ(SAVUNIT,100,ERR=991,END=110)LINE
             CALL CEI(LINE,',',1,XNAME(IX),1,ISEP)
           END IF
           NX=NX+1
           DO 302 IOUT=1,NXX
             IF (XNAME(IX).EQ.X_COLUMNS(IOUT)) XOUT(IOUT)=IX
302        CONTINUE
301      CONTINUE
303      CONTINUE
         GOTO 101
       END IF

*      - skip otherwise
       GOTO 101

110    CONTINUE

* - Write log for X_COLUMNS
       WRITE(LOGUNIT,*)' X_RDBMS variables '
       DO 120 IOUT=1,NXX
        WRITE(LOGUNIT,*)X_COLUMNS(IOUT),XNAME(XOUT(IOUT))
120    CONTINUE

* - Write sql to clear rows
       WRITE(SQLUNIT,171)XTABLE(1:CLG(XTABLE)),PLAN(1:CLG(PLAN))
171    FORMAT(' DELETE FROM ',A,' WHERE PLAN=''',A,
     *  ''';')
```

```
*- Read schedules
       ICC=0
       ICX=0
501    CONTINUE
       READ(CDAUNIT,*,END=900,ERR=995)(C(IC),IC=1,NC)
       ICC=ICC+1
       MV(ICC)=C(ISNS)
       DO 502 IOUT=1,NCC
         C_RDBMS(IOUT)=C(COUT(IOUT))
502    CONTINUE
       IXX=0
       DO 601 IS=1,MV(ICC)
         READ(XDAUNIT,*,END=996,ERR=996)(X(IX),IX=1,NX)
         IXX=IXX+1
         DO 602 IOUT=1,NXX
           X_RDBMS(IOUT)=X(XOUT(IOUT))
602      CONTINUE
       NOROWS=NXX/5
       NOCOLS=JMOD(NXX,5)
       IF (NOCOLS.EQ.0) THEN
       WRITE(SQLUNIT,172)XTABLE(1:CLG(XTABLE)),PLAN(1:CLG(PLAN)),
     *  C_RDBMS(1),FLOAT(IXX),
     *  (X_RDBMS(IOUT),IOUT=1,NXX)
172    FORMAT(' INSERT INTO ',A,' VALUES(',/
     *  ' ''',A,''' ',2(',',F5.0),/
     *   <NOROWS>(5('  ,',F10.2)/),');')
       ELSE
       IF (NOROWS.EQ.0) THEN
       WRITE(SQLUNIT,173)XTABLE(1:CLG(XTABLE)),PLAN(1:CLG(PLAN)),
     *  C_RDBMS(1),FLOAT(IXX),
     *  (X_RDBMS(IOUT),IOUT=1,NXX)
173    FORMAT(' INSERT INTO ',A,' VALUES(',/
     *  ' ''',A,''' ',2(','F5.0),/
     *   <NOCOLS>(',',F10.2),');')
       ELSE
       WRITE(SQLUNIT,174)XTABLE(1:CLG(XTABLE)),PLAN(1:CLG(PLAN)),
     *  C_RDBMS(1),FLOAT(IXX),
     *  (X_RDBMS(IOUT),IOUT=1,NXX)
174    FORMAT(' INSERT INTO ',A,' VALUES(',/
     *  ' ''',A,'''',2(',',F5.0),/
     *   <NOROWS>(5(',',F10.2)/),
     *   <NOCOLS>(',',F10.2),');')
       END IF
       END IF
601    CONTINUE
       WRITE(LOGUNIT,*)' Read ',IXX,' schedules for ',ICC
       ICX=ICX+IXX
*IF INGRES
        WRITE(SQLUNIT,*)'\g'
*END IF

       GOTO 501

900    CONTINUE
       WRITE(LOGUNIT,*)' '
       WRITE(LOGUNIT,*)' TOTAL of ',ICC,' units ',ICX,' schedules '
       GOTO 999

990    WRITE(LOGUNIT,*)' Error in opening the file ',IER
       GOTO 999
991    WRITE(LOGUNIT,*)' Error in reading definitions file'
       GOTO 999
995    WRITE(LOGUNIT,*)' Error in reading C-variables'
       GOTO 999
996    WRITE(LOGUNIT,*)' Error in reading X-variables'
       GOTO 999
```

```
999    CONTINUE
       END
```

SVSDBMS

```
*=====================================================================
*Module         SVSDBMS.f_program
*Header         Reading JLP .SVS
*
*Comment
*System         VAX/VMS
*Storage        GEOVAX:<TAN>
*Version
*Author         20.6.1992 Tuula A. Nuutinen
*Changes
*Bug            Reads only integer solutions
*               JMAKE should be used to include JLP.PAR definitions
*=====================================================================
*
       PROGRAM SVSDBMS
*
*Parameters see JLP.PAR and JMAKE
*needs:
*end:
       PARAMETER (MAXML=1000)
*              max. number of calculation units
       PARAMETER (MAXNC1=100)
*              max. number of c-variables

*Assign the I/O-channels
       INTEGER SAVUNIT, CDAUNIT, SVSUNIT
       INTEGER LOGUNIT, SQLUNIT
       PARAMETER (SAVUNIT=9)
       PARAMETER (CDAUNIT=20)
       PARAMETER (SVSUNIT=22)
        PARAMETER (RATUNIT=23)
       PARAMETER (LOGUNIT=4)
       PARAMETER (SQLUNIT=17)

* Definitions
       CHARACTER*130 LINE
       CHARACTER*80  TITLE
       CHARACTER*5   HDR
       CHARACTER*10  OWNHDR
       CHARACTER*24  FIGURE
       CHARACTER*32  CNAME(MAXNC1)
       CHARACTER*20  PLAN
       CHARACTER*20  SCENARIO
       INTEGER       CLG
       REAL          CER

       REAL          C(MAXNC1)
       INTEGER       MV(MAXML)

       PARAMETER      (MAXC_RDBMS=2)
       CHARACTER*32  C_COLUMNS(MAXC_RDBMS)
       REAL          C_RDBMS(MAXC_RDBMS)
       INTEGER       COUT(MAXC_RDBMS)

       DATA C_COLUMNS /'coverkey','ns'/
*=====================================================================
       OPEN(SAVUNIT,STATUS='OLD',ACCESS='SEQUENTIAL',
     *  FORM='FORMATTED',ERR=990,IOSTAT=IER)
       OPEN(CDAUNIT,STATUS='OLD',ACCESS='SEQUENTIAL',
```

```
     *  FORM='FORMATTED',ERR=990,IOSTAT=IER)
        OPEN(SVSUNIT,STATUS='OLD',ACCESS='SEQUENTIAL',
     *  FORM='FORMATTED',ERR=990,IOSTAT=IER)
        OPEN(SQLUNIT,STATUS='NEW',FORM='FORMATTED',
     *  CARRIAGECONTROL='LIST')
         OPEN(RATUNIT,STATUS='NEW',FORM='FORMATTED')
        OPEN(LOGUNIT,STATUS='NEW',FORM='FORMATTED')


* - Initialize
        PLAN=' '
        SCENARIO=' '
        ISNS=0
        DO 10 IOUT=1,MAXC_RDBMS
          COUT(IOUT)=0
          C_RDBMS(IOUT)=0
10      CONTINUE


*- Read header
100     FORMAT (A)
101     CONTINUE
        READ(SAVUNIT,100,ERR=991,END=110)LINE
        CALL CEI(LINE,' ',1,HDR,1,ISEP)
        IF (HDR(1:1).EQ.'*'.OR.HDR(1:1).EQ.';'.OR.HDR(1:1).EQ.'!')
     *  GOTO 101

*       - Find PLAN
         IF (HDR(1:5).EQ.'title') THEN
           CALL CEI(LINE,' ',1,OWNHDR,1,ISEP)
           IF (OWNHDR(1:5).EQ.'plan') THEN
            CALL CEI(LINE,' ',1,PLAN,1,ISEP)
            WRITE(LOGUNIT,*)' Plan ',PLAN
           END IF
         GOTO 101
         END IF



*       - Save the list of output c-variables
        IF (HDR(1:5).EQ.'keepc')THEN
          NC=0
          DO 201 IC=1,MAXNC1
            CALL CEI(LINE,',',1,CNAME(IC),1,ISEP)
            IF (CNAME(IC)(1:1).EQ.' ')GOTO 203
            IF (CNAME(IC)(1:1).EQ.'>') THEN
              READ(SAVUNIT,100,ERR=991,END=110)LINE
              CALL CEI(LINE,',',1,CNAME(IC),1,ISEP)
            END IF
            NC=NC+1
            IF (CNAME(IC)(1:2).EQ.'ns')ISNS=IC
            DO 202 IOUT=1,MAXC_RDBMS
              IF (CNAME(IC).EQ.C_COLUMNS(IOUT)) COUT(IOUT)=IC
202        CONTINUE
201       CONTINUE
203       CONTINUE
          GOTO 101
        END IF

*       - skip x-variables
        IF (HDR(1:5).EQ.'keepx')GOTO 101

*       - skip otherwise
        GOTO 101

110     CONTINUE
```

```
*- Read scenario from solution file .SVS
        READ(SVSUNIT,100,ERR=994,END=994)LINE
        READ(SVSUNIT,100,ERR=994,END=994)TITLE
        CALL CEI(TITLE,' ',1,SCENARIO,1,ISEP)
        WRITE(LOGUNIT,*)' Scenario ',SCENARIO
        REWIND(SVSUNIT)


* - Write log for C_COLUMNS
       WRITE(LOGUNIT,*)' C_RDBMS variables '
       DO 120 IOUT=1,MAXC_RDBMS
        WRITE(LOGUNIT,*)C_COLUMNS(IOUT),CNAME(COUT(IOUT))
120    CONTINUE

* - Write sql to clear rows
       WRITE(SQLUNIT,171)PLAN(1:CLG(PLAN)),
     *   SCENARIO(1:CLG(SCENARIO))
171    FORMAT(' DELETE FROM SOLUTION ',
     *  ' WHERE PLAN=''',A,''' AND SCENARIO=''',A,''' ;')

*- Read integer solution and write sql to update
*      - Skip over header until 'unit'
        READ(SVSUNIT,100,ERR=994,END=994)LINE
        READ(SVSUNIT,100,ERR=994,END=994)TITLE
       WRITE(RATUNIT,*)TITLE

401    CONTINUE
       READ(SVSUNIT,100,ERR=994,END=994)LINE
       CALL CEI(LINE,' ',1,HDR,1,ISEP)
       IF (HDR(1:4).EQ.'unit')GOTO 402
       GOTO 401

402    CONTINUE
       READ(SVSUNIT,100,ERR=994,END=994)LINE
       IF (LINE(1:1).EQ.'>')GOTO 900
4021   CONTINUE
       ICI=CER(LINE)
       VALUE=CER(LINE)
       ICS1=CER(LINE)
       PROS1=CER(LINE)
       IF (LINE(1:1).NE.' ') THEN
         ICS2=CER(LINE)
         PROS2=CER(LINE)
       ELSE
         ICS2=0
         PROS2=0
       END IF
       ICS=ICS1
       PROS=PROS1
       IF (PROS2.GT.PROS1) THEN
         ICS=ICS2
         PROS=PROS2
       END IF
       READ(CDAUNIT,*,END=995,ERR=995)(C(IC),IC=1,NC)
       ICC=ICC+1
       MV(ICC)=C(ISNS)
       DO 403 IOUT=1,MAXC_RDBMS
        C_RDBMS(IOUT)=C(COUT(IOUT))
403    END DO
       WRITE(LOGUNIT,*)' Read a record ',ICC,' for ',ICI,C_RDBMS(1)
       WRITE(SQLUNIT,172)PLAN(1:CLG(PLAN)),FLOAT(ICC),C_RDBMS(1),
     *   SCENARIO(1:CLG(SCENARIO)),FLOAT(ICS)
172    FORMAT(' INSERT INTO SOLUTION VALUES(' ,/
     *  ' ''',A,''' ',2(',',F5.0),', ''',A,''',',F5.0,');')
       WRITE(RATUNIT,173)NINT(C_RDBMS(1)),ICS
```

```
173     FORMAT(2I5)
        GOTO 402

* - Write log for summary
900     CONTINUE
*IF INGRES
         WRITE(SQLUNIT,*)'\g'
*END IF
        WRITE(LOGUNIT,*)' '
        WRITE(LOGUNIT,*)' TOTAL of ',ICC,' calculation units read'
        GOTO 999

* - Error messages
990     WRITE(LOGUNIT,*)' Error in opening the file ',IER
        GOTO 999
991     WRITE(LOGUNIT,*)' Error in reading definitions file'
        GOTO 999
994     WRITE(LOGUNIT,*)' Error in reading solution'
        GOTO 999
995     WRITE(LOGUNIT,*)' Error in reading C-variables'
        GOTO 999
999     CONTINUE
        END
```

MELA INPUT DATA AND PARAMETERS

MELA input variables

```
        REAL MELASTAND(MAXMELASTANDVARS)
*       1       Calculation unit ID
*       2       Starting year (4 digits)
*       3       Area, ha
*       4       Area, ha
*       5       Y, km (universal coordinate system)
*       6       X, km (universal coordinate system)
*       7       Stand ID
*       8       Height above sea level, m
*       9       Mean annual temperature sum, dd (4 digits)
*       10      Ownergroup
*               0 private
*               1 company
*               2 state
*               3 town
*               4 community
*       11      Landcover
*               1 productive forest land - high prod. y.
*               2 productive forest land - low prod. y.
*               3 unproductive forest land - e.g. swamp, rocks,
dunes
*               4 unproductive forest land - e.g. roads, rides,
stacking areas etc.
*               5 agricultural land
*               6 built land
*               7 infrastructure
*               8 lake
*               9 sea
*       12      Subclass
*               1 firm mineral soils
*               2 spruce peatland
*               3 pine peatland
*               4 "neva"
*               5 "letto"
*       13      Site
*               1 OMaT
*               2 OMT
*               3 MT
*               4 VT
*               5 CT
*               6 ClT
*               7 unproductive forest land - e.g. swamp, rocks, sand
dunes
*               8 unproductive forest land - timberline
*       14      Taxation correction
*               0 no change
*               1 stone content - high
*               2 peat-covered
*               3 raw-humus covered
*               4 close to waterfront
*       15      Taxation
*               1 IA
*               2 IB
*               3 II
*               4 III
*               5 IV
*               6 productive forest land - low prod. y.
*               7 unproductive forest land - e.g. swamp, rocks, sand
dunes
```

```
*       16      Hydrology
*               0 unditched firm mineral soils
*               1 ditched firm mineral soils
*               2 unditched peatland
*               3 ditched peatland
*               4 changing peatland
*               5 changed peatland
*       17      Allow ditching
*               0 yes
*               1 no
*       18      Requirement for regeneration
*               0 none
*               1 over-mature
*               2 wrong tree species
*               3 poor technical quality
*               4 over stocked
*               5 neglected
*               6 not fully stocked (naturally regenerated)

*               7 not fully stocked (artificially regenerated)

*               8 damaged (rotten etc.)
*               9 unproductive
*       19      Last ditching, year
*       20      Last fertilizing, year
*       21      Last sitetreatment, year
*       22      Allow natural regeneration
*               0 yes
*               1 no
*       23      Last clearing, year
*       24      Development/management stage (not in use)
*       25      Last regeneration, year
*       26      Last tending, year
*       27      Last pruning, year
*       28      Last cutting, year
*       29      Regional board (1..19)
*       30      Landuse
*       31      Last cutting, method
*               1 thinning/BA
*               2 clearcutting
*               3 thinning/number per ha
*               4 felling of overstorey
*               5 seed tree cutting
*               6 shelter tree cutting
*
        REAL MELATREE(MAXMELATREEVARS)
*
*       1       Number per ha
*       2       Tree species
*               1 pine (??)
*               2 spruce (??)
*               3 silver birch (??)
*               4 downy birch (??)
*               5 European aspen (??)
*               6 alder (??)
*               7 other softwood (??)
*               8 other hardwood (??)
*       3       dbh, cm
*       4       Height, m
*       5       dbh age, year
*       6       Biological age, year
*       7       Logdecrease
*       8       Pruning year
*       9       Age of reaching dbh 10 cm
*       10      Mode of regeneration
*               0 natural
```

```
*            1 direct sowing
*            2 planting
*            3 replacement of losses
*      11    tree ID
*      12    degrees from origin
*      13    distance from origin
*      14    elevation from origin
*
```

SHORT.PAR

```
1 2 5 11 21 31
1 0 0 0 0 2 0 0 0 0
31 50 0 0 1000 0 1 200 0 0 500 21 0 0 151 0 0
*VOLUME_CORRECTION by FBD
*TASO_TILAVUUS
* 0 .85248 .85248 .85248 .85248
* 1 .91169 .91169 .91169 .91169
* 2 .92236 .92236 .92236 .92236
* 3 .95698 .95698 .95698 .95698
* 4 .96756 .96756 .96756 .96756
* 5 .99120 .99120 .99120 .99120
* 6 .97848 .97848 .97848 .97848
* 7 .97493 .97493 .97493 .97493
* 8 .96055 .96055 .96055 .96055
* 9 .97197 .97197 .97197 .97197
*TVS
* 11 1 3
* 11 7 7
* 11 18 21
* 11 23 23
* 11 25 29
* 11 63 63
* 11 66 70
TVT
          001  002  004 -008  015  029  030  035  090
     100  181 -195  260  265  270  286 -290  340  350
     365  370  401 -405  474  499  501 -510  537  550
    -555  681 -700  800  803  808  823 900
*
* ROADSIDE PRICE
* ==============
*
* Price along roadside by tree species (8, NFI7) and assortement (log,
* pulpwood) starting from the year TIME. Note: time does not work yet.
* TIME 0 will mean 'always'.
* TIME, pine, spruce, s.birch, d.birch, softw., hardw., o.softw.,
o.hardw. (log)
* pine, spruce, s.birch, d.birch, softw., hardw., o.softw., o.hardw.
(pulp)
*
* Tienvarsihinnat puulajeittain (8, VMI7) ja puutavaralajeittain
(tukki,
* kuitu) ajankohdasta AIKA l{htien. Ajalla on varattu paikka, mutta se
EI
* TOIMI VIEL[.
* 0 tulee tarkoittamaan 'aina'. J{rjestys on seuraava:
* aika, m{, ku, rk, hk, ha, le, mha, mle (tukkirivi)
*       m{, ku, rk, hk, ha, le, mha, mle (kuiturivi)
*
* Price along roadside 1989 JUUKA
* Tienvarsihinnat 1989 JUUKA
TIENVARSIHINNAT
 0. 241.50 192.00 254.00 254.00 152.00 152.00 165.00 152.00
    165.00 188.00 152.00 152.00 152.00 152.00 165.00 152.00
* Price along roadside 1989 SUONENJOKI
```

```
* Tienvarsihinnat 1989 SUONENJOKI
* Price along roadside 1992 LIEKSA
* Tienvarsihinnat 1992 LIEKSA
*
* The size correction:              0 = no correction
*                                   1 = ARSU-correction
* Tienvarsihinnan j{reyskorjaus:0 = annetut hinnat ilman korjausta
*                                   1 = ARSU-korjaus
*
TH-J[REYSKORJAUS 0
*
*
* STUMPAGE PRICE
* ==============
*
* Stumpage price 1989 JUUKA
* Kantohinnat 1989 JUUKA
KANTOHINNAT
 0. 195.50 143.00 207.00 207.00 70.00 70.00 83.00 70.00
    83.00 99.00 70.00 70.00 70.00 70.00 83.00 70.00
* Stumpage price 1989 SUONENJOKI
* Kantohinnat 1989 SUONENJOKI
* Stumpage price 1992 LIEKSA
* Kantohinnat 1992 LIEKSA
*
* PRICE CORRECTIONS
* =================
*
* A typical logging unit:
* Size of log 0.401-0.500 m3/stem
* Size of logging 301-500 m3
* Average extraxtion distance 301-400 m
* Density 61-100 m3/ha
* Terrain I-II
*
* Perusleimikko:
* J{reys (tukkipuurunkolajeilla k{ytt|osan keskij{reys) 0.401-0.500
m3/runko
* Leimikon koko 301-500 m3
* Mets{kuljetusmatka (Leimikon keskim{{r{inen) 301-400 m
* Tiheys (Leimikosta hakattava puum{{r{) 61-100 m3/ha
* Maasto (Mets{traktorin ohjemaksujen maastoluokka) I-II
*
* ROADSIDE PRICE:
* ---------------
* The size of log, m3/jm
* Tukin yksikk|kuutioluokka, m3/jm
* -0.035 0.036-0.040 0.041-0.045 0.046-0.050 0.051-0.055 0.056
* The price correction, mk/m3
* Tukin yksikk|hinnan korjaus j{reyden mukaan, mk/m3
* M{: -6,-4,0,+4,+6,+8
* Ku: -3,-2,0,+2,+3,+4
* Ko: -8,-5,0,+5,+8,+12
*
* The proportion of good quality pine logs, %
* Laatutyvien osuus m{ntytukkien "kuutiom{{r{st{", %
* 0,5,10,15,20,30,...
* The price correction, mk/m3
* M{ntytukkien laatukorjaus, mk/m3
* -30,-25,-20,-15,10,0,...
*
* The top diameter, cm
* Latval{pimittaluokka, cm
* -19,21-27,29-
* The max diameter of dry branch
* Laatutyvien kuivan oksan enimm{isl{pimitat luokittain
```

```
* 10,15,25
*
* STUMPAGE PRICE:
* ---------------
* Size of log, m3/stem
* J{reys, m3/runko
* -0.300  0.301-0.400 0.401-0.500 0.501-0.600 0.601-
* Price correction, mk/m3
* Yksikk|hinnan korjaus, mk/m3
* M{+Ko: -4,-2,0,+2,+4
* Ku   : -8,-4,0,+3,+6
*
* Size of pulpwood, cm
* Keskim{{r{inen d1.3, cm
* -7 9 11 13 15 17 19-
* Price correction, mk/m3
* Kuitupuun yksikk|hinnan korjaus d1.3:n mukaan, mk/m3
* M{+Ko: -25,-15,-5,0,+5,+10,+15
* Ku   : -30,-20,-10,0,+10,+20,+30
*
* Size of logging unit, m3
* Leimikon koko, m3
* -30 31-100 101-300 301-500 501-1000 1001-
* Price correction, mk/m3
* Yksikk|hinnan korjaus leimikon koon mukaan, mk/m3
* -20,-12,-4,0,+2,+5
*
* Extraction distance, m
* Mets{kuljetusmatka, m
* -100 101-300 301-400 401-600 -600 (kutakin alkavaa 200 m matkaa
kohti)
* Price correction, mk/m3
* Yksikk|hinnan korjaus mets{kuljetusmatkan mukaan, mk/m3
* +4,+3,0,-3,-3
*
* Density, m3/ha
* Tiheys, m3/ha
* -30 31-60 61-100 101-150 151-
* Price correction
* Yksikk|hinnan korjaus tiheyden mukaan, mk/m3
* -8,-3,0,+3,+5
*
* Terrain class
* Maastoluokka
* I II III IV
* Price correction
* Yksikk|hinnan korjaus maastoluokan mukaan
* 0,0,+6,+12
*
* The size of logging unit
* Leimikon koko, m (tiheys v{h. 100 m3/ha ja maastoluokka v{h II)
* 200-500  500-
* Correction due to season
* Korjuun menetelm{- ja kausilis{
* +10,+13
```

SHORT.TPD

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
                  SHORT TERM .TPD 5.3.1991 TAN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

C THINNING STEM LEVEL (FIRST THINNING)
C HARVENNUS RUNKOLUKUOHJETASOLLE (ENSIHARVENNUS)
C                  KEY
C                  TULKINTA-AVAIN
C
```

```
c                 1. calculation unit
c.................laskentayksikk|, josta alkaen rivi on voimassa
c                 number of row elements
c cc..............rivill{ seuraavien alkioiden m{{r{
c c               permanent prescription
c c  cc...........tietueen pysyvyys
c c  c            name of change
c c  c  ccc.......muutoksen nimi
c c  c  c         row type
c c  c  c   cc....tietuelaji (1...7...n)
c c  c  c   c              row data
c c  c  c   c    ccccccccc tietueen varsinaiset tiedot
c c  c  c   c    c
c                          years and length of period     row type 1
c                          muutosvuodet ja toistumisväli   tietuelaji 1
0  9 1. 10. 1.   1. 4. 8. 16. 26. 10.
c                          minimum gap between changes    row type 2
c                          lyhimm{t sallitut toteutusv{lit tietuelaji 2
0  9 1. 10. 2.   10. 10. 10. 10. 10. 10.
c                          alternative change             row type 3
c                          muutoksen vaihtoehtoisuus      tietuelaji 3
0  4 1. 10. 3.   1.0
c                          similar changes                row type 4
c                          samanluonteiset muutokset      tietuelaji 4
0  9 1. 10. 4.   15. 20. 25. 28. 29. 50.
c                          allowed predecessors           row type 5
c                          sallitut edelt{j{t             tietuelaji 5
0  6 1. 10. 5.   70. 71. 99.
c                          probability of results         row type 6
c                          toteutustodenn{k|isyys         tietuelaji 6
0  5 1. 10. 6.   1.0 1.0
c                          minimum gap between changes
c                          in other branches              row type 7
c                          lyhimm{t sallitut toteuttamisv{lit
c                          rinnakkaisissa haaroissa       tietuelaji 7
0  4 1. 10. 7.    0.
c                          elements of change             row type 7+1
c                          alkeismuutosm{{rittely         tietuelaji
7+1
0 16 1. 10. 8.   2.0 1.  3.0 1.0 0.0 800. 800. 8.0 12. 0.6 1500. 1.0
0.50

C THINNING BA-LEVEL
C HARVENNUS POHJAPINTA-ALAOHJETASOLLE
0  9 1. 15. 1.   1. 4. 8. 16. 26. 10.
0  9 1. 15. 2.   10. 10. 10. 10. 10. 10.
0  4 1. 15. 3.   1.0
0  9 1. 15. 4.   10. 20. 25. 28. 29. 30.
0  6 1. 15. 5.   70. 71. 99.
0  5 1. 15. 6.   1.0 1.0
0  4 1. 15. 7.    0.
0 16 1. 15. 8.   2.0 1.  1.0 1.0 0.0 4.0 2.0 10. 1.5 .85 1.5 .900 0.35
C 0 16 1. 15. 8.   2.0 1.  1.0 1.0 0.0 5.0 6.0 10. 1.0 .85 1.0 .925
0.40

C THINNING 30 % BA
C                (NOT IN USE)
C HARVENNUS 30 % POHJAPINTA-ALASTA
C                (EI K[YT\SS[ NYT)
0  4 1. 20. 1.   0.
0  5 1. 20. 2.   10. 10.
0  4 1. 20. 3.   1.
0  9 1. 20. 4.   10. 15. 25. 28. 29. 30.
0  6 1. 20. 5.   70. 71. 99.
0  5 1. 20. 6.   1.0 1.0
0  4 1. 20. 7.    0.
```

```
0 16 1. 20. 8.   2. 1.  1. 0. .3 3. 6. 10. 1.0 .6 .8 1.0 0.40

C REMOVAL OF HOLDOVER
C YLISPUIDEN POISTO
0  9 1. 25. 1.   1. 4. 8. 16. 26. 10.
0  9 1. 25. 2.   10. 10. 10. 10. 10. 10.
0  4 1. 25. 3.   0.
0  6 1. 25. 4.   15. 20. 30.
0  6 1. 25. 5.   70. 71. 99.
0  5 1. 25. 6.   1.0 1.0
0  4 1. 25. 7.   0.
0 16 1. 25. 8.   2. 1.  4. 0. 1. 0.5 2.0 .70 .85 .6 8.0 .8 0.

C SEED TREE CUTTING
C SIEMENPUUHAKKUU
0  9 1. 28. 1.   1. 4. 8. 16. 26. 10.
0  9 1. 28. 2.   10. 10. 10. 10. 10. 10.
0  4 1. 28. 3.   1.
0  9 1. 28. 4.   10. 15. 20. 25. 29. 30.
0  6 1. 28. 5.   70. 71. 99.
0  5 1. 28. 6.   1.0 1.0
0  4 1. 28. 7.   0.
0 16 1. 28. 8.   2. 1.  5. 0. 1. 100. 100. .9 .9 .7 1.5 1.0 0.

C SHELTERWOOD CUTTING
C SUOJUSPUUHAKKUU
0  9 1. 29. 1.   1. 4. 8. 16. 26. 10.
0  9 1. 29. 2.   10. 10. 10. 10. 10. 10.
0  4 1. 29. 3.   1.
0  9 1. 29. 4.   10. 15. 20. 25. 28. 30.
0  6 1. 29. 5.   70. 71. 99.
0  5 1. 29. 6.   1.0 1.0
0  4 1. 29. 7.   0.
0 16 1. 29. 8.   2. 1.  6. 0. 1. 100. 100. .9 .9 .7 1.3 1.0 0.

C CLEARCUTTING
C AVOHAKKUU
0  9 1. 30. 1.   1. 4. 8. 16. 26. 10.
0  9 1. 30. 2.   10. 10. 10. 10. 10. 10.
0  4 1. 30. 3.   1.
0  9 1. 30. 4.   10. 15. 20. 25. 28. 29.
0  6 1. 30. 5.   70. 71. 99.
0  5 1. 30. 6.   1.0 1.0
0  4 1. 30. 7.   0.
0 16 1. 30. 8.   2. 1.  2. 0. 1. 0. 0. .9 .90 .5 2.0 1.15 0.

C CLEARING
C UUDISTUSALAN RAIVAUS
0  9 1. 35. 1.   1. 4. 8. 16. 26. 10.
0  9 1. 35. 2.   10. 10. 10. 10. 10. 10.
0  4 1. 35. 3.    0.
0  4 1. 35. 4.    0.
0  9 1. 35. 5.   28. 29. 30. 70. 71. 99.
0  4 1. 35. 6.    1.
0  4 1. 35. 7.   0.
0  9 1. 35. 8.    5. 1.  0. 1. 1. 6.

C SOIL CULTIVATION
C MAANPINNAN K[SITTELY
0  9 1. 36. 1.   1. 4. 8. 16. 26. 10.
0  9 1. 36. 2.   10. 10. 10. 10. 10. 10.
0  4 1. 36. 3.    0.
0  4 1. 36. 4.    0.
0  8 1. 36. 5.   28. 29. 30. 35. 99.
0  4 1. 36. 6.    1.
0  4 1. 36. 7.   0.
```

```
0  9 1. 36. 8.    6. 1.  0. 1. 1. 4.

C PINE PLANTING
C M[NNYN VILJELY
0  9 1. 41. 1.   1. 4. 8. 16. 26. 10.
0  9 1. 41. 2.   10. 10. 10. 10. 10. 10.
0  4 1. 41. 3.   1.0
0  5 1. 41. 4.   42. 43.
0  7 1. 41. 5.   30. 35. 36. 99.
0  5 1. 41. 6.   1.0 1.0
0  4 1. 41. 7.   0.
0 15 1. 41. 8.   4.0 1.  0.0 0.0 3.0 1.0 0.0 2.0 0.1 0.0 3.0 5.0

C SPRUCE PLANTING
C KUUSEN VILJELY
0  9 1. 42. 1.   1. 4. 8. 16. 26. 10.
0  9 1. 42. 2.   10. 10. 10. 10. 10. 10.
0  4 1. 42. 3.   1.0
0  5 1. 42. 4.   41. 43.
0  7 1. 42. 5.   30. 35. 36. 99.
0  5 1. 42. 6.   1.0 1.0
0  4 1. 42. 7.   0.
0 15 1. 42. 8.   4.0 1.  0.0 0.0 3.0 2.0 0.0 2.0 0.2 0.0 1.0 3.0

C BIRCH PLANTING
C KOIVUN VILJELY
0  9 1. 43. 1.   1. 4. 8. 16. 26. 10.
0  9 1. 43. 2.   10. 10. 10. 10. 10. 10.
0  4 1. 43. 3.   1.0
0  5 1. 43. 4.   41. 42.
0  7 1. 43. 5.   30. 35. 36. 99.
0  5 1. 43. 6.   1.0 1.0
0  4 1. 43. 7.   0.
0 15 1. 43. 8.   4.0 1.  0.0 0.0 3.0 3.0 0.0 2.0 0.4 0.0 1.0 2.0

C COMPLEMENTARY PLANTING
C T[YDENNYSVILJELY
0  9 1. 45. 1.   1. 4. 8. 16. 26. 10.
0  9 1. 45. 2.   10. 10. 10. 10. 10. 10.
0  4 1. 45. 3.   0.0
0  4 1. 45. 4.    0.
0  8 1. 45. 5.   25. 41. 42. 43. 99.
0  5 1. 45. 6.   1.0 1.0
0  4 1. 45. 7.   0.
0 15 1. 45. 8.   4.0 1.  3.0 0.8 5.0 0.0 0.0 3.0 0.2 0.0 1.0 5.0

C TENDING
C TAIMIKONHOITO
0  9 1. 50. 1.   1. 4. 8. 16. 26. 10.
0  9 1. 50. 2.   10. 10. 10. 10. 10. 10.
0  4 1. 50. 3.   0.
0  4 1. 50. 4.   10.
0  7 1. 50. 5.   25. 70. 71. 99.
0  5 1. 50. 6.   1.0 1.0
0  4 1. 50. 7.   0.
0 14 1. 50. 8.   3. 1.  0.0 1.0 0.95 0.85 0.0 7.7 100. 0.15 9.0

C PINE PRUNING (NOT IN USE)
C M[NNYN KARSINTA (EI NYT KäYTöSSä)
0  9 1. 60. 1.   0.
0  9 1. 60. 2.   30.
0  4 1. 60. 3.   0.
0  4 1. 60. 4.   0.
0  8 1. 60. 5.  10. 15. 20. 50. 99.
0  4 1. 60. 6.   1.
0  4 1. 60. 7.   0.
```

```
0 10 1. 60. 8.   9.  1.  0.0  1.0  6.0  12.  0.0

C DITCHING (NOT IN USE)
C UUDISOJITUS (EI NYT KäYTöSSä)
0  4 1. 70. 1.   0.
0  4 1. 70. 2.  20.
0  4 1. 70. 3.   1.
0  4 1. 70. 4.  0.
0  4 1. 70. 5.  99.
0  5 1. 70. 6.   1.0 1.0
0  4 1. 70. 7.   0.
0  7 1. 70. 8.   7.  1.  1.  1.

C COMPLEMENTARY DITCHING (NOT IN USE)
C UUSINTAOJITUS (EI NYT KäYTöSSä)
0  4 1. 71. 1.   0.
0  4 1. 71. 2.  30.
0  4 1. 71. 3.   0.
0  4 1. 71. 4.  0.
0  5 1. 71. 5.  70.,99.
0  4 1. 71. 6.   1.
0  4 1. 71. 7.   0.
0  7 1. 71. 8.   7.  1.  2.  1.

C FERTILIZATION (NOT IN USE)
C LANNOITUS (EI NYT KäYTöSSä)
0  4 1. 80. 1.   0.
0  4 1. 80. 2.  10.
0  4 1. 80. 3.   1.
0  4 1. 80. 4.   0.
0  8 1. 80. 5.  15. 20. 70.  71. 99.
0  5 1. 80. 6.   1.0 1.0
0  4 1. 80. 7.   0.
0 13 1. 80. 8.   8.  1.  1.0  0.0  0.5  1.5  0.6  1.5  0.6  1.2

C NATURAL PROCESSES
C KEHITTYMINEN/LUONNONPROSESSIT
0  5 1. 99. 1.   1. 1.
0  5 1. 99. 2.   1. 1.
0  4 1. 99. 3.   0.
0  4 1. 99. 4.   0.
0 21 1. 99. 5.   10. 15. 20. 25. 28. 29. 35. 36. 41. 42. 43. 45. 50.
60. 70. 71. 80. 99.
0  5 1. 99. 6.   1.0 1.0
0  4 1. 99. 7.   .0
0  12 1. 99. 8.   1. 1.  1. 5. 100.0  1.  1.  1.  1.
```

GROWTH.PAR

```
1 3
0 0 0 0 0 0 0 0 1.0 0
3 50 0 0 1000 0 1 1 0 0 0 0 0 0 0 0
```

GROWTH.TPD

```
C  pelkk{ kasvatus ilman toimenpiteit{

0  5 1. 99. 1.   1. 1.
0  5 1. 99. 2.   1. 1.
0  4 1. 99. 3.   0.
0  4 1. 99. 4.   0.
0  4 1. 99. 5.   99.
0  5 1. 99. 6.   1.0 1.0
0  4 1. 99. 7.   .0
0  10 1. 99. 8.   1. 1.  1. 5. 30.0  1. 1.
```

AML-MACROS

STANDARD.AML - index a coverage for NXDBMS (standard)

```
&ARGS INDEX
&DATA ARC INFO
ARC
SELECT %INDEX%.PAT
OUTPUT INDEX.LIS INIT
CALC $COMMA-SWITCH = -1
RES STAND-ID > 0
FORMAT $NUM1,2,I
CALCULATE $NUM1 = 0
DISP [QUOTE %INDEX%] PRINT
SORT ARCKEY
DISP %INDEX%-ID, X-COORD, Y-COORD, AREA, ARCKEY, ~
INSIDE, ADJACENT, $NUM1, $NUM1, ~
$NUM1, $NUM1, $NUM1, $NUM1, $NUM1, $NUM1, $NUM1, $NUM1 PRINT
SORT %INDEX%#
OUTPUT arcnsp
CALC $COMMA-SWITCH = 0
Q STOP
&END
QUIT
&RETURN
```

MODIFIED.AML - index a coverage for NXDBMS (modified)

```
&ARGS INDEX
&DATA ARC INFO
ARC
SELECT %INDEX%.PAT
OUTPUT INDEX.LIS INIT
CALC $COMMA-SWITCH = -1
RES STAND-ID > 0
FORMAT $NUM1,2,I
CALCULATE $NUM1 = 0
DISP [QUOTE %INDEX%] PRINT
SORT ARCKEY
DISP %INDEX%-ID, X-COORD, Y-COORD, AREA, ARCKEY, ~
INSIDE, ADJACENT, D_DISTANCE, SCHEDULE, ~
E_SEASON, E_DISTANCE, E_TERRAIN, LOGGINGSIZE, ~
STORAGE, STORAGESIZE, TIMBERPARCEL, TIMBERLOT PRINT
SORT %INDEX%#
OUTPUT arcnsp
CALC $COMMA-SWITCH = 0
Q STOP
&END
QUIT
&RETURN
```

INDEX.SQL - index treatmentstand for DBMSVES

THEME.AML - draws a thematic map (2-D)

```
Usage: THEME <parcel> <shade_cover> <box_cover!#>
<INVE!PROPOSAL!SCENARIO>
       <item> {lut!#} {key!#} {title}  {scale}
Bug:   for plan themes SCENARIO has to be executed before THEME
```

SHORT.AML - draws a short-term planning environment

```
Usage: SHORT <parcel> <box_cover!#> {scale}
```

PLAN.AML - draws a plan coverage with restricted areas
Usage: PLAN <parcel> <plan_cover> <box_cover!#> {scale}

```
/*=====================================================================
/* Module      PLAN.AML
/* Header      AML-macro to define a plan and a plan coverage
/* Author      19.6.1992 Tuula Nuutinen, METLA/JOE
/* Note        PLAN has to be in the subdirectory ARCPLOT of &ATOOL-
path
/*             &ATOOL <path...path>
/*             e.g. Arc: &ATOOL [TAN.ATOOL]
/*                    Arcplot: COMMANDS
/*                    will show [TAN.ATOOL.ARCPLOT]PLAN.AML
/*             LOGIN has to be given before
/* Usage:      Arcplot: PLAN <parcel> <plan_cover> <box_cover> {scale}
/* Examples:   Arcplot: PLAN SJOKI04 SJOKI04PLA SJOKI04CUT
/*             Arcplot: INVE
/*             Arcplot: EXPERI
/*             Arcplot: TIMBER
/*             Arcplot: STORAGE
/*             Arcplot: SAVE SJOKI04PRO SJOKI04PRO
/* Bug         If schedules of inventory stands were stored,
/*             SCHEDULE should be defined to DBMSEXECUTE schedules
/*             for pointed stands on ARCKEY
/*=====================================================================
&args .PARCEL .PLANCOVER  BCOVER SCALE
&if [null %.PARCEL%] or [null %.PLANCOVER%] or [null %BCOVER%] &then
  &return &warning Usage: PLAN <parcel> <plan_cover> <box_cover|#>
{scale}
&if not [null %SCALE%] &then
   mapscale %SCALE%
&if %BCOVER% ne # &then
  &do
  mapex %BCOVER%
  clipmapex on
  &end
&run $AMLHOME/arcplot/%.LANGUAGE%_template
/* WATERCOURSES
&if [exists %.PARCEL%hb -polygon] &then
  &do
  reselect %.PARCEL%hb poly inside > 1
  polygonshade %.PARCEL%hb 88
  linesymbol 1
  linecolor 1
  polys %.PARCEL%hb
  clearselect
  &end
/* UNPRODUCTIVE
&if [exists %.PARCEL%rb -polygon] &then
  &do
  reselect %.PARCEL%rb poly inside > 1
  polygonshade %.PARCEL%rb 1
  clearselect
  linesymbol 1
  linecolor 1
  polys %.PARCEL%rb
  &end
/*reselect %.PARCEL%s poly orakey > 0
reselect %.PARCEL%s poly ^inve where landcover >= 4
reselect %.PARCEL%s poly dbikey > 0
/*reselect %.PARCEL%s poly ^inve where maaluokka >= 4
polygonshade %.PARCEL%s 1
clearselect
/* LANDUSE RESTRICTIONS
```

```
/*reselect %.PLANCOVER% poly orakey > 0
reselect %.PLANCOVER% poly ^inve where landuse > 1
reselect %.PLANCOVER% poly dbikey > 0
/*reselect %.PLANCOVER% poly ^inve where kayttomuoto > 1
polygonshade %.PLANCOVER% 61
clearselect
/* ADJACENCY RESTRICTIONS
reselect %.PLANCOVER% poly ^current where meanh1 < 2
aselect %.PLANCOVER% poly adjacent 10
nselect %.PLANCOVER% poly
aselect %.PLANCOVER% poly ^current where meanh1 < 2
nselect %.PLANCOVER% poly
polygonshade %.PLANCOVER% 83
clearselect
/* STANDS
linesymbol 1
linecolor 1
polys %.PLANCOVER%
/* LEGEND
linesymbol 1
linecolor 1
textsymbol 85
textfont 94023
textsize 0.15
keybox 0.15 0.15
keyseparation 0.15 0.2
keyposition 5.45 8.6
keyshade $AMLHOME/key/%.LANGUAGE%_restri.key
keyposition 5.45 6.5
keyline $AMLHOME/key/%.LANGUAGE%_stand.key nobox
/*
textsymbol 85
move 0.75 9.15
textfont 94023
textsize 0.25
&if %.LANGUAGE% ne sf &then
  text 'MANAGEMENT ZONES '
&else
  text 'SUUNNITTELUN ALUEJAOT '
move 5.35 9.15
text [translate %.PARCEL%]
textfont 1
textsymbol 1
```

SAVE.AML - inserts a plan into RDBMS table
  -> ADJACENT.AML - finds adjacent stands

```
Usage: SAVE <plan> <plan_cover>
/*=================================================================
/* Module      SAVE.AML
/* Header      AML-macro to save a plan as TREATMENT_STAND
/* Author      19.6.1992 Tuula Nuutinen, METLA/JOE
/* Note        SAVE has to be in the subdirectory ARCPLOT of &ATOOL-
path
/*             &ATOOL <path...path>
/*             e.g. Arc: &ATOOL [TAN.ATOOL]
/*                  Arcplot: COMMANDS
/*                  will show [TAN.ATOOL.ARCPLOT]SAVE.AML
/*             LOGIN has to be given before
/* Usage:      Arcplot: SAVE <plan> <plancover>
/* Examples:   Arcplot: SAVE SJOKI04PRO SJOKI04PRO
/*=================================================================
&args .PLAN .PLANCOVER
&if [null %.PLAN%] or [null %.PLANCOVER%] &then
  &return &warning Usage: SAVE <plan> <plan_cover>
dbmsexecute %.DBMS% select PLAN, PLANCOVER from PLAN where ~
```

```
PLAN=[quote %.PLAN%]
dbmsexecute %.DBMS% delete from PLAN where ~
PLAN=[quote %.PLAN%] and  PLANCOVER=[quote %.PLANCOVER%]
DBMSEXECUTE %.DBMS% INSERT INTO PLAN(PLAN,PLANCOVER) VALUES ~
([quote %.PLAN%], [quote %.PLANCOVER%])
ADJACENT
INDEXITEM %.PLANCOVER%.PAT DBIKEY
&return
```

ADJACENT.AML

```
reselect %.PLANCOVER% poly ^current where meanh1 < 2
aselect %.PLANCOVER% poly adjacent 10
nselect %.PLANCOVER% poly
aselect %.PLANCOVER% poly ^current where meanh1 < 2
nselect %.PLANCOVER% poly
calc %.PLANCOVER% poly adjacent = 1
quit
&return
```

SCENARIO.AML - displays a scenario
Usage: SCENARIO <plan> <scenario>
Bug should define RELATES for plan at the same time

TIMBER.AML - displays roadside storage, marked stand, current stand
Usage: TIMBER <parcel>
Bug: If TIMBER on national level, marked forest, inventory forest

BARRIER.AML - draws barriers
Usage: BARRIER <parcel> <box!#> {scale}

FELL.AML - used by FELL.COM to output piles
Extracts TIMBER_PILES or CUTTING_STANDS into <parcel>pil

PILES.AML - used by FELL.COM to create a pile coverage
Creates <parcel>pil -coverage

EXTRACT.AML - draws extraction environment
Usage: EXTRACT <parcel> <box_cover!#> {scale}

ROUTE.AML - displays a route
Usage: ROUTE <parcel>

STORAGE.AML - displays a roadside storage
Usage: STORAGE

SALE.AML - draws a sale environment
Usage: SALE <area> <parcel> <box_cover!#> {scale}
Bug: should summarize on district level

JLP-MACROS

IN.JLP

```
*!=====================================================================
*!  Module       <session>.jlp
*!  Header       JLP macro for running a session
*!  System
*!  Author       30.12.1992 Tuula Nuutinen, METLA/JOE
*!  Storage
*!  Note       PROJECT assigned in optimize
*!  Usage:
*!======================================================================
*
incl APPLICATION/*import-mela:*end
end
```

BOUNDARY.JLP

```
*!=====================================================================
*!  Module       <session>.jlp
*!  Header       JLP macro for running a session
*!  System
*!  Author       30.12.1992 Tuula Nuutinen, METLA/JOE
*!  Storage
*!  Note       PROJECT assigned in optimize
*!  Usage:
*!          check HARVEST.JLP search .log session-parameters
*!          edit SJOKI04PLA.SAV title
*!======================================================================
*
incl APPLICATION/*restrict:*end
incl PROBLEM/*session:*end
incl PROBLEM/*scenario1:*end
incl APPLICATION/*report:*end
end
```

SOLVE.JLP

```
*!=====================================================================
*!  Module       <session>.jlp
*!  Header       JLP macro for running a session
*!  System
*!  Author       30.12.1992 Tuula Nuutinen, METLA/JOE
*!  Storage
*!  Note       PROJECT assigned in optimize
*!  Usage:
*! 1) check session-parameters in PROBLEM
*! 2) check title in INTERNAL before unsave
*!======================================================================
*
incl APPLICATION/*unsave:*end
incl PROBLEM/*session:*end
incl LPPROBLEM/*problem:*end
incl APPLICATION/*report:*end
incl APPLICATION/*solution:*end
*system svsdbms export PROJECT PRESCRIPTIONS SCENARIO
*system svsdbms import  PROJECT PRESCRIPTIONS SCENARIO
end
```

PROBLEM.JLP

```
*!=====================================================================
```

```
*!  Module       <problem>.jlp
*!  Header       JLP macro for decision problem
*!  System
*!  Author       30.12.1992 Tuula Nuutinen, METLA/JOE
*!  Storage
*!  Note:
*!  Usage:
*!
*!  jlp> incl <problem>.jlp/*session:*end         !Defines session
parameters
*!  jlp> incl <problem>.jlp/*scenario1:*end       !Solves scenario1
*!
*!======================================================================
*
*
*=======
*session
*=======
*
*
* - loggingsystem
*       0 manual felling, farm tractor, 3m pulpwood (DEFAULT)
*       1 manual felling, forwarder, 5m pulpwood
*
* - measurementpoint
*       0 roadside (DEFAULT)
*       1 standing
*
* - salepoint
*       0 roadside (DEFAULT)
*       1 standing
*
* - attitude
*       0 neutral (DEFAULT)
*       1 optimist
*       2 pessimist
*
* - uncertainty
*       0 not included (DEFAULT)
*       1 included
*
* - fieldsurvey
*       0 no (DEFAULT)
*       1 yes
*
const no,yes=0,1
outl 1
printl 1
outf HISTORY
const standard,modified=0,1
const mode=1
const year=1992
const manual, mechanized=0,1
const loggingsystem=0
const cc_routedensity=20
const t_routedensity=30
const roadside,standing=0,1
const measurementpoint=0
const salepoint=0
const neutral,optimist,pessimist=0,1,2
const attitude=2
const uncertainty=0
const stderror=0
const fieldsurvey=0
const inventorymkm3=0
const interest=3.0
```

```
incl PARAMETERS/*mkm3:*end
ctran
incl PARAMETERS/*defaults:*end
incl PARAMETERS/*corrections:*end
/
xtran
incl MODELS/*uncertainty:*end
x1499.1=(up111*x1181)+(up112*x1182)+(up121*x1184)+(up122*x1185)+ >
        (up131*x1187)+ (up132*x1188)+(up141*x1190)+(up142*x1191)
incl MODELS/*cost:*end
x1454.1=mancosts+machinecosts
if (schedule.ne.0.and.s.eq.schedule.and.fieldsurvey=yes) then
x1454.1=x1454.1+inventorymkm3*x1195
end if
x1454.r=x1454.1
x1499.r=x1499.1
x1370.r=x1370+x1454-x1499-x1454.r+x1499.r
x1500.r=x1499.r-x1454.r
*
x1499.s=x1499.1
if (year.lt.1991) then
x1454.s=0
x1500.s=up211*x1181+up212*x1182+up221*x1184+up222*x1185+ >
        up231*x1187+up232*x1188+up241*x1190+up242*x1191
x1370.s=x1370+x1454-x1499+x1500.s
end if
if (year.ge.1991.and.method_1=2) then
x1454.s=c311*x1181+c312*x1182+c321*x1184+c322*x1185+ >
       c331*x1187+c332*x1188+c341*x1190+c342*x1191
end if
if (year.ge.1991.and.method_1=1.and. >
(x1502=0.and.x1503=0)) then
x1454.s=c211*x1181+c212*x1182+c221*x1184+c222*x1185+ >
       c231*x1187+c232*x1188+c241*x1190+c242*x1191
end if
if (year.ge.1991.and.method_1=1.and. >
(x1502.gt.0.or.x1503.gt.0)) then
x1454.s=c111*x1181+c112*x1182+c121*x1184+c122*x1185+ >
        c131*x1187+c132*x1188+c141*x1190+c142*x1191
end if
if (year.ge.1991) then
x1500.s=x1499.s-x1454.s
x1370.s=x1370+x1454-x1499-x1454.s+x1499.s
end if
*
if (salepoint=roadside) then
x1499=x1499.r
x1454=x1454.r
x1500=x1500.r
x1370=x1370.r
end if
if (salepoint=standing) then
x1499=x1499.s
x1454=x1454.s
x1500=x1500.s
x1370=x1370.s
end if
pnv=npv(interest,x1370,period1,x2370,period2,x3370,period3,x4370,perio
d4,>
        x5370,period5)
/
make
*end
*
*=========
*1
```

```
*=========
*begin
outl 0
show/noxfirst
prob 1 NTN maksimointi
pnv max
/
solve
*end
*
*=========
*2
*=========
*begin
outl 0
show/noxfirst
prob 2 NT1 maksimointi
x1370 max
/
solve
*end
*
*=========
*3
*=========
*begin
outl 0
show/noxfirst
prob 3 Tuottoarvon maksimointi
x3823 max
/
solve
*end
*
```

APPLICAT.JLP

```
*!============================================================
*!  Module      <application>.jlp
*!  Header    JLP macro for application
*!  System
*!  Author    30.12.1992 Tuula Nuutinen, METLA/JOE
*!  Storage
*!  Note:  EXTERNAL, INTERNAL, SCENARIO, SOLUTION assigned in optimize
*!  Usage:
*!  jlp> incl <application>.jlp/*import-mela:*end     !Read external
files
*!  jlp> incl <application>.jlp/*import-index:*end   !Read modified
.NX
*!  jlp> incl <application>.jlp/*unsave:*end         !Read internal
files
*!  jlp> incl <application>.jlp/*multiple:*end       !Reject on use >
1
*!  jlp> incl <application>.jlp/*protection:*end     !Reject on
zone=22,24
*!  jlp> incl <application>.jlp/*adjacency:*end      !Reject on
adjacency=1
*!  jlp> incl <application>.jlp/*restrict:*end       !Restrict all
```

```
*!  jlp> incl <application>.jlp/*boundary:*end       !Production
possibilities
*!  jlp> incl <application>.jlp/*report:*end         !Writes summary
report
*!  jlp> incl <application>.jlp/*table:*end          !Writes tables
*!  jlp> incl <application>.jlp/*solution:*end       !Writes solution
into .svs
*!
*!==============================================================
*
*===========
*import-mela
*===========
*begin
*incl EXTERNAL/*mela:*end
incl INPUT/*mela:*end
*end
*============
*import-index
*============
*begin
incl EXTERNAL/*index:*end
*end
*
*======
*unsave
*======
*begin
incl INTERNAL
*end
*
*=========================
*multiple
*       1 timber production
*       2 conservation
*       5 experimental area
*=========================
*begin
xtran
if
(use.ne.1.and.(x1007>0.or.x2007>0.or.x3007>0.or.x4007>0.or.x5007>0.))
>
then reject
/
make
*end
*
*==================================================
*protection
*       22 around waterbody - no regeneration
*       24 around watercourse - no clearcutting
*==================================================
*begin
xtran
if (zone.eq.22.and.>
(x1002>0.or.x2002>0.or.x3002>0.or.x4002>0.or.x5002>0.or. >
x1005>0.or.x2005>0.or.x3005>0.or.x4005>0.or.x5005>0.or.  >
x1006>0.or.x2006>0.or.x3006>0.or.x4006>0.or.x5006>0))    >
then reject
if (zone.eq.24.and.>
(x1002>0.or.x2002>0.or.x3002>0.or.x4002>0.or.x5002>0.))>
then reject
/
make
*end
/
```

```
*
*=====================================================
*adjacency
*       0 not adjacent to a young stand
*       1 adjacent to a young stand - no clearcutting
*=====================================================
*begin
xtran
if (adjacency.eq.1.and.>
(x1002>0.or.x2002>0.or.x3002>0.or.x4002>0.or.x5002>0.)) >
then reject
/
make
*end
*
*=====================================================
*restrict
*=====================================================
*begin
xtran
if
(use.ne.1.and.(x1007>0.or.x2007>0.or.x3007>0.or.x4007>0.or.x5007>0.))
>
then reject
if (zone.eq.22.and.>
(x1002>0.or.x2002>0.or.x3002>0.or.x4002>0.or.x5002>0.or. >
x1005>0.or.x2005>0.or.x3005>0.or.x4005>0.or.x5005>0.or.  >
x1006>0.or.x2006>0.or.x3006>0.or.x4006>0.or.x5006>0))    >
then reject
if (zone.eq.24.and.>
(x1002>0.or.x2002>0.or.x3002>0.or.x4002>0.or.x5002>0.))>
then reject
if (adjacency.eq.1.and.>
(x1002>0.or.x2002>0.or.x3002>0.or.x4002>0.or.x5002>0.)) >
then reject
/
make
*end
*
*========
*boundary
*========
*begin
outl 1
show/pro
show/noco
*
prob
pnv max
/
solve
prob
pnv min
/
solve
prob
x1370 max
/
solve
prob
x1370 min
/
solve
prob
x5700 max
/
```

```
solve
prob
x5700 min
/
solve
prob
x1195 max
/
solve
prob
x1195 min
/
solve
prob
x1478 max
/
solve
prob
x1478 min
/
solve
prob
pnv max
x5700 <10000 />12500 <15000 />15000 <20000 />20000 <25000 />25000
<30000/>30000
/
solve
do 10
solve +1
end do
*
prob
pnv max
x1370 = 243000.
x5700 <10000 />12500 <15000 />15000 <20000 />20000 <25000 />25000
<30000/>30000
/
solve
do 10
solve +1
end do
*
prob
pnv max
x1478 < 152.
x5700 <10000 />12500 <15000 />15000 <20000 />20000 <25000 />25000
<30000/>30000
/
solve
do 10
solve +1
end do
*
prob
pnv max
x1195 = 262.
x5700 <10000 />12500 <15000 />15000 <20000 />20000 <25000 />25000
<30000/>30000
/
solve
do 10
solve +1
end do
*
prob
x5700 max
```

```
x1370 <100000 />100000 <200000 />200000 <500000 / >500000 <1000000 / >
1000000
/
solve
do 10
solve +1
end do
*
outf
*end
*
*======
*report
*======
*begin
outf REPORT
outl 1
show/inte
show/cost
show/all
recall
outf
outl 0
*end
*
*=====
*table
*=====
*begin
outl 1
show/inte
show/cost
show/prob
recall
outf
outl 0
*end
*
*========
*solution
*========
*begin
outf SOLUTION
outl 1
sched
outf
outl 0
*end
```

FFRI.JLP

```
*bug    Add formulae for felling productivity and manproductivity
*       Add first thinning
*       Add a rule to recognize if formulae can be used "if
sizeofstem..."
*===========
*uncertainty
*===========
*begin
if (uncertainty.eq.yes) then
x1181=(stderror+ran(1181))*x1181
x1182=(stderror+ran(1182))*x1182
x1184=(stderror+ran(1184))*x1184
x1185=(stderror+ran(1185))*x1185
x1187=(stderror+ran(1187))*x1187
x1188=(stderror+ran(1188))*x1188
```

```
x1190=(stderror+ran(1190))*x1190
x1191=(stderror+ran(1191))*x1191
x1193=x1181+x1184+x1187+x1190
x1194=x1182+x1185+x1188+x1191
x1195=x1193+x1194
end if
*end
*
* COST FUNCTIONS
* ==============
*
* Costs of harvesting (Metsatilasto)
*                    1989    1990    1991
*      felling(manual)       47.35   49.51   54.04
*      felling(moto) 29.17   30.10   29.35
*       felling              40.01   40.65   40.44
*       extraction   22.36   23.17   21.88
*
*       harvesting   62.39   63.70   62.33
*       transportation       35.49   38.41   37.44
*
*
* Costs of harvesting (Uotila & Toivanen 1992, Pohjois-Savo)
*      Pine
*                    First thinningThinning      Clearfelling
*      Overhead                     11           8
*      Felling                      26           19
*      Extraction                   33           25
*      Harvesting                   70           51
*
*      Spruce
*                    First thinning  Thinning        Clearfelling
*       Overhead                                          10
*       Felling                                           24
*       Extraction                                        25
*       Harvesting                                        54
*
* Costs of harvesting (Metsalehti 1992)
*       Clearfelling                                35-40 mk/m3
*       Thinning                                    50-60 mk/m3
*       First thinning                              80-100 mk/m3
*
*
*
* Felling (manual)
* ------------------
*
* The length of an average working day:            6.3 h
* Average daily production of manual felling:              5-9 m3/day
* Average daily production of harvesting (Sjoki):          8 m3/day
*
* Average production of manual felling (Tapion Taskukirja 1991, p.
419):
*                    First thinningThinning      Clearfelling
*      Pine-dominated       6-9     8-13          18-22
*      Spruce-dominated     5-7     7-10          16-19
*
* Average daily earnings of a forest worker (time)        221.90-231.30
mk/day
* Average daily earnings of a forest worker (contract)    264.60-278.35
mk/day
* Average daily earnings of a forest worker (state -89)   282.51
mk/day
* Average daily earnings of a forest worker (state -91) 312.51  mk/day
*
*
```

```
* Costs of forest worker (earnings + 100%)
*       582.08 mk/day
*       70 mk/hour + 30 mk/h + 10-15 %
*
* Costs of manual felling
*                      47.35 mk/m3 (Metsatilasto 1989)
*                      49.51 mk/m3 (Metsatilasto 1990)
*                      54.04 mk/m3 (Metsatilasto 1991)
*                      100-150 mk/m3 (cf. 582 mk/day / 6 m3/day)
*
*
* Felling (mechanized)
* ------------------
*
* Average production of mechanized felling
*         15-25 m3/day (small)
*         20-30 m3/day (harvester)
*
* Average production of mechanized felling (Tapion Taskukirja 1991, p.
419)
*
*                        First thinning  Thinning        Clearfelling
*       Small                  15-25  40-70
*       Harvester              20-30   60-100           120-150
*
* Average unit cost
*        one-grip harvester 269.66 (MKA), 332.22 mk/hour
*
* Cost of mechanized felling
*                      29.17 mk/m3 (Metsatilasto 1989)
*                      30.10 mk/m3 (Metsatilasto 1990)
*                      29.25 mk/m3 (Metsatilasto 1991)
*
* Felling (excluding first thinning):
*
* f11-f13      productivity, m3/h
* measurementpoint    0, if measurementpointment on the roadside
*                     1, if tallying standing trees on stumapage
* e_season            0, if K0
*                     3, if K3
* mmethod             0, if clearcutting
*                     1, if thinning
* size                dm3
*
*Pine
*f11=60/(1.176/(exp(0.327+0.104*measurementpoint-0.0730*e_season)- >
*0.101*mmethod-0.235*log(size)+0.0703*log(size)**2- >
*0.000000420*size**2+0.0000000000000487*size**4)/60))
*Spruce
*f12=60/(1.176/(exp(-0.0468+0.082*measurementpoint-0.0720*e_season- >
*0.124*mmethod-0.131*log(size)+0.0571*log(size)**2- >
*0.000000305*size**2+0.0000000000000319*size**4)/60))
*Broadleaved
*f13=60/(1.176/(exp/0.458+0.098*measurementpoint-0.0745*e_season- >
*0.124*mmethod-0.00167*size- >
*0.391*log(siz)+0.110*log(size)**2+0.000000284*size**2)/60))
*
*
* Extraction
* ----------
*
* Average production of extraction:
*       70-80 m3/day (forwarder)
*       35-50 m3/day, 1.2-6.6 m3/hour (farm tractor)
*
* Average production of extraction (Tapion Taskukirja 1991, p. 419)
```

```
*
*                       First thinningThinning      Clearfelling
*       Forwarder              70-80  80-90         90-100
*       Small forwarder               35-50  45-60
*       Farm tractor           40-50  50-60         55-65

* Average unit cost of extraction
*       farm tractor  170.6 mk/hour (Valkonen)
*                     209.39 mk/hour (Rummukainen)
*
* Costs of extraction
*                     22.36         (Metsatilasto 1989)
*                     23.17         (Metsatilasto 1990)
*                     21.88         (Metsatilasto 1991)
*                     30 mk/m3
*
*
* Farm tractor:
*
* note: p21,p22       productivity, m3/h could be used instead of t21,
t22
*              because they are easier to compare with productivity
1.2-6.6
* t21-t22      time, min/m3
* e_distance   extrction distance, m
* density      m3/100 m
* snow         cm
* mmethod      0, if clearcutting
*              1, if thinning
*
*cost
*Logging systems:
*       0 Manual cutting, 3 m pulpwood, farm tractor
*
mmethod=0
if
(method_1.gt.0.and.loggingsystem.eq.manual.and.method_1.eq.thinning)
then
mmethod=1
end if
*
* Saw log density, m3/100m
density1=0
if (method_1.gt.0.and.loggingsystem.eq.manual.and.x1193>0.and.>
method_1.eq.clearcutting) then
density1=(x1193/(10000/cc_routedensity))*100
end if
if (method_1.gt.0.and.loggingsystem.eq.manual.and.x1193>0.and.>
method_1.ne.clearcutting) then
density1=(x1193/(10000/t_routedensity))*100
end if
*
* Pulpwood 3m density, m3/100m
density2=0
if (method_1.gt.0.and.loggingsystem=manual.and.x1194>0.and.>
method_1.eq.clearcutting) then
density2=(x1194/(10000/cc_routedensity))*100
end if
if (method_1.gt.0.and.loggingsystem=manual.and.x1194>0.and.>
method_1.ne.clearcutting) then
density2=(x1194/(10000/t_routedensity))*100
end if
*
* Cutting (man work)
* Because no information of log size available, 8 m3/day is used
mancosts=0
```

```
if (method_1.gt.0.and.loggingsystem=manual) then
mancosts=(x1195/8)*mandaymk
end if
*
t21=0.
t22=0.
* Extraxtion (farm tractor, saw logs)
if (method_1.gt.0.and.loggingsystem=manual.and.density1.ge.1) then
t21=1.248*1.045*(1+0.07*mmethod)* >
(1/(exp(1.46-0.00531*snow-0.000000000201*(snow**5)+ >
0.428*log(density1)- 0.124*(log(density1))**2+ >
0.162*sqrt(density1)+0.104*log(e_distance)- >
0.0535*sqrt(e_distance))/60))
end if
* Extraxtion (farm tractor, pulpwood)
if (method_1.gt.0.and.loggingsystem=manual.and.density2.ge.1) then
t22=1.248*1.045*(1+0.025*mmethod)* >
(1/(exp(2.18-0.000158*(snow**2)-0.0100*sqrt(snow)+ >
0.280*log(density2)- >
0.0328*(log(density2))**2-0.0446*sqrt(e_distance))/60))
end if
*
machinehour=0
machinecosts=0
if (method_1.gt.0.and.loggingsystem=manual) then
*machinehour=(x1193/p21)+(x1194/p22)
machinehour=((t21*x1193)+(t22*x1194))/60
machinecosts=machinehour*machinehourmk
end if
*end
```

PROJECT.JLP

```
*!=================================================================
*!  Module     <project>.JLP
*!  Header     JLP macro for project
*!  System
*!  Author     24.6.1992 Tuula Nuutinen, METLA/JOE
*!  Storage
*!  Comments
*!             If MELA-files area re-read again
*!                    * rename .NX3 -> .NX before /*mela:*end
*!             If new gis-variables (c) retrieved using DBMSNX
*!                    * check ALL cvar and keepc compared to
MODIFIED.SQL
*!             If new mela-variables (x)
*!                    * check ALL xvar and keepx
*!                    * check CRETBL.SQL (SCHEDULE) and XDADBMS
*!  Usage:
*! jlp> incl EXTERNAL/*mela:*end       !Creates SJOKI04 .SAV/.CDA/.XDA
*! jlp> incl EXTERNAL/*export:*end     !Exports schedule
*! Bug: *index xvariable-list is from modified .SAV
*!=================================================================
*
*====
*mela
*====
*begin
*list <application>.PAR/*dictionary:*end
batch
init
xform m
xdat SCHEDULES
xvar x1001,x2001,x3001,x4001,x5001,x1002,x2002,x3002,x4002,x5002,>
     x1004,x2004,x3004,x4004,x5004,x1005,x2005,x3005,x4005,x5005,>
     x1006,x2006,x3006,x4006,x5006,x1007,x2007,x3007,x4007,x5007,>
```

```
     x1008,x2008,x3008,x4008,x5008,x1035,x2035,x3035,x4035,x5035,>
     x1181,x1182,x1184,x1185,x1187,x1188,x1190,x1191,x1193,x1194,>
     x2181,x2182,x2184,x2185,x2187,x2188,x2190,x2191,x2193,x2194,>
     x1195,x2195,x3195,x4195,x5195,x1370,x2370,x3370,x4370,x5370,>
     x1454,x1458,x1462,x1466,x1470,x1474,x1478,x1498,x1499,x1500,>
     x2454,x2458,x2462,x2466,x2470,x2474,x2478,x2498,x2499,x2500,>
     x501,x502,x503,x504,x505,x506,x507,x508,x509,>
     x1501,x1502,x1503,x1504,x1505,x1506,x1507,x1508,x1509,>
     x5501,x5502,x5503,x5504,x5505,x5506,x5507,x5508,x5509,>
     x700,x1700,x2700,x3700,x4700,x5700,>
     x823,x1823,x2823,x3823,x4823,x5823
cvar ns
read
write/* SCHEDULES
*system addns <interactive> <project> <project>_<application>
*note: PROJECT and SCHEDULES defined using setenv in .mela-file
system addns batch
init
xdat SCHEDULES.xda
xform *
xvar x1001,x2001,x3001,x4001,x5001,x1002,x2002,x3002,x4002,x5002,>
     x1004,x2004,x3004,x4004,x5004,x1005,x2005,x3005,x4005,x5005,>
     x1006,x2006,x3006,x4006,x5006,x1007,x2007,x3007,x4007,x5007,>
     x1008,x2008,x3008,x4008,x5008,x1035,x2035,x3035,x4035,x5035,>
     x1181,x1182,x1184,x1185,x1187,x1188,x1190,x1191,x1193,x1194,>
     x2181,x2182,x2184,x2185,x2187,x2188,x2190,x2191,x2193,x2194,>
     x1195,x2195,x3195,x4195,x5195,x1370,x2370,x3370,x4370,x5370,>
     x1454,x1458,x1462,x1466,x1470,x1474,x1478,x1498,x1499,x1500,>
     x2454,x2458,x2462,x2466,x2470,x2474,x2478,x2498,x2499,x2500,>
     x501,x502,x503,x504,x505,x506,x507,x508,x509,>
     x1501,x1502,x1503,x1504,x1505,x1506,x1507,x1508,x1509,>
     x5501,x5502,x5503,x5504,x5505,x5506,x5507,x5508,x5509,>
     x700,x1700,x2700,x3700,x4700,x5700,>
     x823,x1823,x2823,x3823,x4823,x5823
cdat INDEX
cform *
cvar ns,melakey,coverkey,planyear,arckey,inveyear,ha,x,y,>
     zone,adjacency,d_distance,schedule,cuttingyear,cuttingmethod,>
     c1181,c1182,c1184,c1185,c1187,c1188,c1190,c1191,c1195,>
     e_season,e_distance,e_terrain,loggingsize,>
     haulageseason,haulageclass,storage,storagesize,>
     timberparcel,timberlot,gis1,gis2,gis3,gis4,gis5,>
     land,subclass,soil,hydro,site,stones,tax,develop,quality,use,>

sitehist,siteyear,standhist,standyear,siteprop,standprop,regenprop,>
     urgency
const period1,-period5=1,3,6,10,10
const interest=3.0
const nocut,thinning,clearcutting,holdovers,seedtrees,sheltertrees= >
0,5,7,8,6,6
xtran
pnv=npv(interest,x1370,period1,x2370,period2,x3370,period3,x4370,perio
d4,>
       x5370,period5)
method_1=0
if (x1007=0.) then method_1=nocut
if (x1001>0.) then method_1=thinning
if (x1002>0.) then method_1=clearcutting
if (x1004>0.) then method_1=holdovers
if (x1005>0.) then method_1=seedtrees
if (x1006>0.) then method_1=sheltertrees
method_2=0
if (x2007=0.) then method_2=nocut
if (x2001>0.) then method_2=thinning
if (x2002>0.) then method_2=clearcutting
if (x2004>0.) then method_2=holdovers
```

```
if (x2005>0.) then method_2=seedtrees
if (x2006>0.) then method_2=sheltertrees
method_3=0
if (x3007=0.) then method_3=nocut
if (x3001>0.) then method_3=thinning
if (x3002>0.) then method_3=clearcutting
if (x3004>0.) then method_3=holdovers
if (x3005>0.) then method_3=seedtrees
if (x3006>0.) then method_3=sheltertrees
method_4=0
if (x4007=0.) then method_4=nocut
if (x4001>0.) then method_4=thinning
if (x4002>0.) then method_4=clearcutting
if (x4004>0.) then method_4=holdovers
if (x4005>0.) then method_4=seedtrees
if (x4006>0.) then method_4=sheltertrees
method_5=0
if (x5007=0.) then method_5=nocut
if (x5001>0.) then method_5=thinning
if (x5002>0.) then method_5=clearcutting
if (x5004>0.) then method_5=holdovers
if (x5005>0.) then method_5=seedtrees
if (x5006>0.) then method_5=sheltertrees
/
keepx x1001,x2001,x3001,x4001,x5001,x1002,x2002,x3002,x4002,x5002,>
     x1004,x2004,x3004,x4004,x5004,x1005,x2005,x3005,x4005,x5005,>
     x1006,x2006,x3006,x4006,x5006,x1007,x2007,x3007,x4007,x5007,>
     x1008,x2008,x3008,x4008,x5008,x1035,x2035,x3035,x4035,x5035,>
     x1181,x1182,x1184,x1185,x1187,x1188,x1190,x1191,x1193,x1194,>
     x2181,x2182,x2184,x2185,x2187,x2188,x2190,x2191,x2193,x2194,>
     x1195,x2195,x3195,x4195,x5195,x1370,x2370,x3370,x4370,x5370,>
     x1454,x1458,x1462,x1466,x1470,x1474,x1478,x1498,x1499,x1500,>
     x2454,x2458,x2462,x2466,x2470,x2474,x2478,x2498,x2499,x2500,>
     x501,x502,x503,x504,x505,x506,x507,x508,x509,>
     x1501,x1502,x1503,x1504,x1505,x1506,x1507,x1508,x1509,>
     x5501,x5502,x5503,x5504,x5505,x5506,x5507,x5508,x5509,>
     x700,x1700,x2700,x3700,x4700,x5700,>
     x823,x1823,x2823,x3823,x4823,x5823,>
     pnv,method_1,method_2,method_3,method_4,method_5
*
cvar ns,melakey,coverkey,planyear,arckey,inveyear,ha,x,y,>
     zone,adjacency,d_distance,schedule,cuttingyear,cuttingmethod,>
     c1181,c1182,c1184,c1185,c1187,c1188,c1190,c1191,c1195,>
     e_season,e_distance,e_terrain,loggingsize,>
     haulageseason,haulageclass,storage,storagesize,>
     timberparcel,timberlot,gis1,gis2,gis3,gis4,gis5,>
     land,subclass,soil,hydro,site,stones,tax,develop,quality,use,>

sitehist,siteyear,standhist,standyear,siteprop,standprop,regenprop,>
     urgency
read
*title plan <project>
*note PROJECT defined using setenv in .mela-file
incl SETUP/*title:*end
save SCHEDULES
write/* SCHEDULES_2
end
*end
*
*======
*export
*======
*-save <project>_<application>
*-write/* <project>_<application>
*-system xdadbms export SCHEDULES DICTIONARY
*-system xdadbms import SCHEDULES
```

```
*end
*
*=====
*index
*=====
 xform *
 xdat XMAT
 xvar
x1001,x2001,x3001,x4001,x5001,x1002,x2002,x3002,x4002,x5002,x1004, >

x2004,x3004,x4004,x5004,x1005,x2005,x3005,x4005,x5005,x1006,x2006,x300
6, >

x4006,x5006,x1007,x2007,x3007,x4007,x5007,x1008,x2008,x3008,x4008,x500
8, >

x1035,x2035,x3035,x4035,x5035,x1181,x1182,x1184,x1185,x1187,x1188,x119
0, >

x1191,x1193,x1194,x2181,x2182,x2184,x2185,x2187,x2188,x2190,x2191,x219
3, >

x2194,x1195,x2195,x3195,x4195,x5195,x1370,x2370,x3370,x4370,x5370,x145
4, >

x1458,x1462,x1466,x1470,x1474,x1478,x1498,x1499,x1500,x2454,x2458,x246
2, >

x2466,x2470,x2474,x2478,x2498,x2499,x2500,x501,x502,x503,x504,x505,x50
6, >
 x507,x508,x509,x1501,x1502,x1503,x1504,x1505,x1506,x1507,x1508,x1509,
>

x5501,x5502,x5503,x5504,x5505,x5506,x5507,x5508,x5509,x700,x1700,x2700
, >
 x3700,x4700,x5700,x823,x1823,x2823,x3823,x4823,x5823,pnv,method_1, >
 method_2,method_3,method_4,method_5,x2370.o
 cform *
 cdat INDEX
 cvar ns,melakey,coverkey,planyear,arckey,inveyear,ha,x,y,>
      zone,adjacency,d_distance,schedule,cuttingyear,cuttingmethod,>
      c1181,c1182,c1184,c1185,c1187,c1188,c1190,c1191,c1195,>
      e_season,e_distance,e_terrain,loggingsize,>
      haulageseason,haulageclass,storage,storagesize,>
      timberparcel,timberlot,gis1,gis2,gis3,gis4,gis5,>
      land,subclass,soil,hydro,site,stones,tax,develop,quality,use,>

sitehist,siteyear,standhist,standyear,siteprop,standprop,regenprop,>
      urgency
 read
*- save <project>_<application>
*- write/* <project>_<application>
*end
```

P788_89.JLP

```
* SUONENJOKI 1989
* ===============
*
* Price at roadside by tree species (8, NFI7) and assortment
(log,pulpwood)
* pine, spruce, s.birch, d.birch, softw., hardw., o.softw., o.hardw.
(log)
* pine, spruce, s.birch, d.birch, softw., hardw., o.softw., o.hardw.
(pulp)
*
```

```
* Standing price by tree species (8, NFI7) and assortment
(log,pulpwood).
* pine, spruce, s.birch, d.birch, softw., hardw., o.softw., o.hardw.
(log)
* pine, spruce, s.birch, d.birch, softw., hardw., o.softw., o.hardw.
(pulp)
*
* Tienvarsihinnat puulajeittain (8, VMI7) ja puutavaralajeittain
(tukki,kuitu)
* m{, ku, rk, hk, ha, le, mha, mle (tukkirivi)
* m{, ku, rk, hk, ha, le, mha, mle (kuiturivi)
*
* Kantohinnat puulajeittain (8, VMI7) ja puutavaralajeittain
(tukki,kuitu)
* m{, ku, rk, hk, ha, le, mha, mle (tukkirivi)
* m{, ku, rk, hk, ha, le, mha, mle (kuiturivi)
*
*
* Price at roadside 1989 in Savolax, (1.5.1988-30.4.1989 SUONENJOKI
778)
* Tienvarsihinnat 1989 Pohjois-Savo,  (1.5.1988-30.4.1989 SUONENJOKI
778)
* TIENVARSIHINNAT
* 254.00 205.00 268.00 268.00 165.50 165.50 177.50 165.50
* 177.50 201.50 165.50 165.50 165.50 165.50 177.50 165.50
*
* 246.50 200.00 259.00 259.00 154.00 154.00 168.00 154.00
* 168.00 190.00 154.00 154.00 154.00 154.00 168.00 154.00
*
* Standing price 1989 in Savolax,  (1.5.1988-30.4.1989 SUONENJOKI 778)
* Kantohinnat 1989 Pohjois-Savossa,  (1.5.1988-30.4.1989 SUONENJOKI
778)
* KANTOHINNAT
* 211.00 157.00 224.00 224.00 82.50 82.50 95.50 82.50
* 95.50 111.50 82.50 82.50 82.50 82.50 95.50 82.50
*
* 200.50 151.00 212.00 212.00  73.00 73.00 86.00 73.00
* 86.00 102.00 73.00 73.00 73.00 73.00 86.00 73.00
*
* PRICE CORRECTIONS 1989
* ======================
*
* An average harvesting unit:
* Size of a sawlog 0.401-0.500 m3/stem
* Size of a timber parcel 301-500 m3
* Extraction distance 301-400 m
* Density of timber 61-100 m3/ha
* Extraction terrain I-II
* Haulage class I-II
*
* Perusleimikko:
* J{reys (tukkipuurunkolajeilla k{ytt|osan keskij{reys) 0.401-0.500
m3/runko
* Leimikon koko 301-500 m3
* Mets{kuljetusmatka (Leimikon keskim{{r{inen) 301-400 m
* Tiheys (Leimikosta hakattava puum{{r{) 61-100 m3/ha
* Maasto (Mets{traktorin ohjemaksujen maastoluokka) I-II
* Kuormauspaikkaluokka I-II
*
* For the difficult harvesting conditions real harvesting costs should
be used
*
* ROADSIDE UNIT PRICE CORRECTIONS 1989
* ------------------------------------
*
* Haulage season, month
```

```
* Luovutusaika, kuukausi
* 8-10,11-1,2-4,5-7
* Unit price correction, mk/m3
* Yksikkohinnan korjaus, mk/m3
* +15,+10,0,-4
*
* Haulage class
* Varastopaikkaluokka
* I-II III-IV
* Unit price correction, mk/m3
* 0, -4.5
*
* Size of sawlog, m3/jm
* Tukin yksikk|kuutioluokka, m3/jm
* -0.035 0.036-0.040 0.041-0.045 0.046-0.050 0.051-0.055 0.056
* Unit price correction, mk/m3
* Tukin yksikk|hinnan korjaus j{reyden mukaan, mk/m3
* Pine/M{: -6,-4,0,+4,+6,+8
* Spruce/Ku: -3,-2,0,+2,+3,+4
* Birch/Ko: -8,-5,0,+5,+8,+12
*
* Proportion of good quality pine sawlogs, %
* Laatutyvien osuus m{ntytukkien "kuutiom{{r{st{", %
* 0,5,10,15,20,30,...
* Unit price correction, mk/m3
* M{ntytukkien laatukorjaus, mk/m3
* -30,-25,-20,-15,10,0,...
*
* Top diameter, cm
* Latval{pimittaluokka, cm
* -19,21-27,29-
* Maximum  diameter of a dry branch
* Laatutyvien kuivan oksan enimm{isl{pimitat luokittain
* 10,15,25
*
* STUMPAGE UNIT PRICE CORRECTIONS 1989
* -----------------------------------
*
* Size of a timber parcel, m3
* Leimikon koko, m3
* -30 31-100 101-300 301-500 501-1000 1001-
* Unit price correction, mk/m3
* Yksikk|hinnan korjaus leimikon koon mukaan, mk/m3
* -20,-12,-4,0,+2,+5
*
* Extraction distance, m
* Mets{kuljetusmatka, m
* -100 101-300 301-400 401-600 601- (kutakin alkavaa 200 m matkaa
kohti)
* Unit price correction, mk/m3
* Yksikk|hinnan korjaus mets{kuljetusmatkan mukaan, mk/m3
* +4,+3,0,-3,-3 (kutakin alkavaa 200 m matkaa kohti 601-)
*
* Season for mechanized logging and the size of timber parcel
* Korjuun kausiluokka ja leimikon koko, m3
* (tiheys v{h 100 m3/ha ja maastoluokka v{h II)
* 200-500  500-
* Unit price correction
* Korjuun menetelm{- ja kausilis{
* +10,+13
*
* Terrain class
* Maastoluokka
* I II III IV
* Unit price correction
* Yksikk|hinnan korjaus maastoluokan mukaan
```

```
* 0,0,-6,-12
*
* Density of timber, m3/ha
* Tiheys, m3/ha
* -30 31-60 61-100 101-150 151-
* Unit price correction
* Yksikk|hinnan korjaus tiheyden mukaan, mk/m3
* -8,-3,0,+3,+5
*
* Size of sawlog, m3/stem
* J{reys, m3/runko
* -0.300  0.301-0.400 0.401-0.500 0.501-0.600 0.601-
* Unit price correction, mk/m3
* Yksikk|hinnan korjaus, mk/m3
* M{+Ko: -4,-2,0,+2,+4
* Ku   : -8,-4,0,+3,+6
*
* Size of pulpwood, cm
* Keskim{{r{inen d1.3, cm
* -7 9 11 13 15 17 19-
* Unit price correction, mk/m3
* Kuitupuun yksikk|hinnan korjaus d1.3:n mukaan, mk/m3
* M{+Ko: -25,-15,-5,0,+5,+10,+15
* Ku   : -30,-20,-10,0,+10,+20,+30
*
* HARVESTING COSTS 1989
* =====================
*
* Harvesting costs by methods for each assortment
* pine s., spruce s., s.birch s., d. birch s. (first thinning)
* pine p., spruce p., s.birch p., d. birch p. (first thinning)
* pine s., spruce s., s.birch s., d. birch s. (later thinning)
* pine p., spruce p., s.birch p., d. birch p. (later thinning)
* pine s., spruce s., s.birch s., d. birch s. (regeneration)
* pine p., spruce p., s.birch p., d. birch p. (regeneration)
* pine s., spruce s., s.birch s., d. birch s. (avg. 1990/91)
* pine p., spruce p., s.birch p., d. birch p. (avg. 1990/91)
*
* Korjuukustannukset menetelmittain kaikille puulajeille
* mantytukki, kuusitukki, koivutukki (ensiharvennus)
* mantykuitu, kuusikuitu, koivukuitu (ensiharvennus)
* mantytukki, kuusitukki, koivutukki (muu harvennus)
* mantykuitu, kuusikuitu, koivukuitu (muu harvennus)
* mantytukki, kuusitukki, koivutukki (uudistus)
* mantykuitu, kuusikuitu, koivukuitu (uudistus)
* mantytukki, kuusitukki, koivutukki (keskim. 1990/91)
* mantykuitu, kuusikuitu, koivukuitu (keskim. 1990/91)
*
* Hrvesting costs 1989 SUONENJOKI (778)
* Korjuukustannukset 1989 SUONENJOKI (778)
* KORJUUKUSTANNUKSET
* 48 48 48 48
* 101 101 101 101
* 48 48 48 48
* 101 101 101 101
* 48 48 48 48
* 101 101 101 101
* 68 68 68 68
* 68 68 68 69
*
*====
*mkm3
*====
*begin
const p111,p112=254.00,177.50
const p121,p122=205.00,201.50
```

```
const p131,p132=268.00,165.50
const p141,p142=268.00,165.50
const roadcorr=4.5
const minp111,minp112=251.50,175.00
const minp121,minp122=201.00,199.00
const minp131,minp132=265.00,162.00
const minp141,minp142=265.00,162.00
const maxp111,maxp112=256.50,180.00
const maxp121,maxp122=209.00,204.00
const maxp131,maxp132=271.00,167.00
const maxp141,maxp142=271.00,167.00
const p211,p212=211.00,95.50
const p221,p222=157.00,111.50
const p231,p232=224.00,82.50
const p241,p242=224.00,82.50
const minp211,minp212=208.50,92.00
const minp221,minp222=154.00,109.00
const minp231,minp232=221.00,80.00
const minp241,minp242=221.00,80.00
const maxp211,maxp212=213.50,97.00
const maxp221,maxp222=162.00,114.00
const maxp231,maxp232=227.00,85.00
const maxp241,maxp242=227.00,85.00
const c111,c112,c121,c122,c131,c132,c141,c142=48,101,>
48,101,48,101,48,101
const c211,c212,c221,c222,c231,c232,c241,c242=48,101,>
48,101,48,101,48,101
const c311,c312,c321,c322,c331,c332,c341,c342=48,101,>
48,101,48,101,48,101
const c411,c412,c421,c422,c431,c432,c441,c442=48,101,>
48,101,48,101,48,101
* - machinehourmk
*       one-grip harvester 332.22 mk/hour
*       farmtractor 209.39 mk/hour
const machinehourmk=209.39
const mandaymk=582.08
*end
*
*========
*defaults
*========
*begin
if (e_distance=0.or.mode=standard) then e_distance=301
if (e_season=0.or.mode=standard) then e_season=3
if (e_season=3.or.mode=standard) then snow=30
if (e_terrain=0.or.mode=standard) then e_terrain=1
if (loggingsize=0.or.mode=standard) then loggingsize=301
if (haulageseason=0.or.mode=standard) then haulageseason=3
if (haulageclass=0.or.mode=standard) then haulageclass=1
if (storagesize=0.or.mode=standard) then storagesize=301
*end
*
*===========
*corrections
*===========
if (attitude=neutral) then
up111=p111
up112=p112
up121=p121
up122=p122
up131=p131
up132=p132
up141=p141
up142=p142
up211=p211
up212=p212
```

```
up221=p221
up222=p222
up231=p231
up232=p232
up241=p241
up242=p242
end if
if (attitude=optimist) then
up111=maxp111
up112=maxp112
up121=maxp121
up122=maxp122
up131=maxp131
up132=maxp132
up141=maxp141
up142=maxp142
up211=maxp211
up212=maxp212
up221=maxp221
up222=maxp222
up231=maxp231
up232=maxp232
up241=maxp241
up242=maxp242
end if
if (attitude=pessimist) then
up111=minp111
up112=minp112
up121=minp121
up122=minp122
up131=minp131
up132=minp132
up141=minp141
up142=minp142
up211=minp211
up212=minp212
up221=minp221
up222=minp222
up231=minp231
up232=minp232
up241=minp241
up242=minp242
end if
if (haulageclass.ge.3) then
up111=up111-roadcorr
up112=up112-roadcorr
up121=up121-roadcorr
up122=up122-roadcorr
up131=up131-roadcorr
up132=up132-roadcorr
up141=up141-roadcorr
up142=up142-roadcorr
up211=up211-roadcorr
up212=up212-roadcorr
up221=up221-roadcorr
up222=up222-roadcorr
up231=up231-roadcorr
up232=up232-roadcorr
up241=up241-roadcorr
up242=up242-roadcorr
end if
*end
```

AN EXAMPLE RUN

Phase 1. UPDATE INVENTORY DATABASE (CURRENT_STAND)

```
1) Initialize
-------------

Arc: MELALOGIN
Arc: VMSMELA


2) Prepare CURRENT_STAND
------------------------

Arc: edit S04INV84.SQL
Arc: edit S04INV87.SQL

Process S04INV84 and S04INV87 separately
Import CURRENT_STAND into database
Arc: MELA S04INV84
Arc: edit GROWTH.PAR 6
Arc: DBMSNX S04INV84 S04INV84
Arc: DBMSVES
Arc: GROW VES
Arc: GROW EXPORT
Arc: GROW IMPORT
```

Phase 2. PREPARE LONG-TERM SCENARIOS

```
1) Initialize
-------------

Arc: &run ATOOL:LOGIN 4207
Arc: MELALOGIN
Arc: VMSMELA
Arc: MELA SJOKI04PLA

2) Create a TREATMENT_UNIT coverage
-----------------------------------


3) Draw a TREATMENT_UNIT coverage
---------------------------------

Arcplot: &run ATOOL:PLAN SJOKI04 SJOKI04PLA SJOKI04


4) Save a TREATMENT_UNIT coverage as TREATMENT_STANDs
-----------------------------------------------------

Import TREATMENT_STANDs into database
Arc: SAVE SJOKI04PLA SJOKI04PLA
Arc: NXDBMS EXPORT
Arc: NXDBMS IMPORT


5) Create management schedules
------------------------------

Arc: edit S04PLA84.SQL
```

```
Arc: edit S04PLA87.SQL

Arc: edit S04PLA84.COM
Arc: edit S04PLA87.COM
       SIMULATE SHORT SHORT

Process S04PLA84 and S04PLA87 separately
Arc: MELA < S04PLA84 ! S04PLA87 >
Arc: edit GROWTH.PAR < 6 ! 3 >
Arc: DBMSNX STANDARD < S04PLA84 ! S04PLA87 >
Arc: DBMSVES
Arc: GROW VES
Arc: SUBMIT < S04PLA84 ! S04PLA87 >

Import CALCULATION_UNITs and SCHEDULEs into database
Arc: edit SJOKI04.JLP
Arc: jlp
     jlp> incl harvest.jlp/*import-mela:*end


Modify schedules for stands 23 and 84 using JLP (see .SAV)

jlp> include harvest.jlp/*unsave:*end
jlp> include sjoki04.jlp/*modify:*end
jlp> save SJOKI04PLA (remember upper-case)
jlp> write/* SJOKI04PLA
jlp> system edit sjoki04pla.sav (title)

       Stand 23

       - clearcut period 1
             move period 1 cutting overstorey to clearcutting
             no change in cut or income of period 1
             change volume trajectory
             change age-classes
       - regenerate period 2
             add regeneration costs in period 2
             calculate new net income and pnv
       - note the problem with expected forest value

       Stand 84, schedule 1

       - move overstorey cut from period 2 to period 1
       - move all change variables from period 2 to period 1
       - initialize all change variables of period 2
       - calculate net income of period 1
       - calculate new pnv


Arc: CDADBMS EXPORT
Arc: CDADBMS IMPORT
Arc: XDADBMS EXPORT
Arc: XDADBMS IMPORT
```

6) Create production possibility boundaries

A diagram of production possibilities pnv vs. end volume

a) productive forest area
b) as a) but reject cutting when landuse outside timber production (no of)
c) as b) but reject regeneration around water bodies and
       clearcutting around watercourses (no of)
d) as c) but reject clearcutting in adjacent stands (no of)
       - sustainable yield constraint

```
        - man power constraint
        - net income constraint
e) as c) but using session-parameters

Session-parameters
        year=1989
        loggingsystem=manual
        cc_routedensity=20
        t_routedensity=30
        measurementpoint=roadside
        salepoint=roadside
        attitude=neutral
        uncertainty=no
        stderror=0
        fieldsurvey=no
        inventorymk=0

Arc: jlp # # # SJOKI04 SJOKI04PLA

jlp> incl harvest.jlp/*unsave:*end
jlp> outf S04PLA.bn0
jlp> title PRODUCTIVE FOREST LAND
jlp> incl harvest.jlp/*boundary:*end
jlp> init
jlp> incl harvest.jlp/*unsave:*end
jlp> incl harvest.jlp/*multiple:*end
jlp> outf S04PLA.bn1
jlp> title MULTIPLE-USE ZONES
jlp> incl harvest.jlp/*boundary:*end
jlp> init
jlp> incl harvest.jlp/*unsave:*end
jlp> incl harvest.jlp/*multiple:*end
jlp> incl harvest.jlp/*protection:*end
jlp> outf S04PLA.bn2
jlp> title MULTIPLE-USE AND PROTECTION ZONES
jlp> incl harvest.jlp/*boundary:*end
jlp> init
jlp> incl harvest.jlp/*unsave:*end
jlp> incl harvest.jlp/*multiple:*end
jlp> incl harvest.jlp/*protection:*end
jlp> incl harvest.jlp/*adjacency:*end
jlp> outf S04PLA.bn3
jlp> title MULTIPLE-USE, PROTECTION AND ADJACENCY ZONES
jlp> incl harvest.jlp/*boundary:*end
jlp> init
jlp> incl harvest.jlp/*unsave:*end
jlp> incl harvest.jlp/*multiple:*end
jlp> incl harvest.jlp/*protection:*end
jlp> incl harvest.jlp/*adjacency:*end
jlp> incl harvest.jlp/*session:*end
jlp> outf S04PLA.bn4
jlp> title PRODUCTIVE FOREST LAND - modified costs
jlp> incl harvest.jlp/*boundary:*end

After this use modified SCHEDULE-table for SCENARIO-queries
note: you have to add plan and scenario into tables PLAN and ANALYSIS
(see SJOKI04.JLP *export:*end)
jlp> save SJOKI04PLA
jlp> write/* SJOKI04PLA
jlp> system melalogin SJOKI04PLA
jlp> XDADBMS EXPORT DBMS SJOKI04PLA
jlp> XDADBMS IMPORT DBMS SJOKI04PLA

7) "Standard" scenarios

Scenario 0. multiple-use&protection                              .SC0
```

```
Scenario 1. multiple-use&protection&adjacency
        .SC1
Scenario 2. multiple-use&protection&adjacency with man power
constraint .SC2
Scenario 3. Multiple-use&protection&adjacency with man power
                and allowable cut constraint
        .SC3

Session-parameters
        mode=standard
        year=1989
        loggingsystem=manual
        cc_routedensity=20
        t_routedensity=30
        measurementpoint=roadside
        salepoint=roadside
        attitude=neutral
        uncertainty=no
        stderror=0
        fieldsurvey=no
        inventorymk=0

Decision problem

Scenario 0. multiple-use&protection

max NPV
s.t.    > end volume requirement

Scenario 1. multiple-use&protection&adjacency

max NPV
s.t.    > end volume requirement


Scenario 2. multiple-use&protection&adjacency with man power
constraint

max NPV
s.t.    > end volume requirement
        < man power constraints

Scenario 3. multiple-use&protection&adjacency with man power and
                allowable cut constraint.

max NPV
s.t.    > end volume requirement
        < man power constraints
        = 1213

For each scenario

Arc: jlp # # # SJOKI04 SJOKI04PLA

jlp> system edit SJOKI04PLA.SAV
        title SCENARIO0
jlp> incl harvest.jlp/*unsave:*end
jlp> incl harvest.jlp/*multiple:*end
jlp> incl harvest.jlp/*protection:*end
jlp> incl harvest.jlp/*session:*end
jlp> incl harvest.jlp/*scenario1:*end
jlp> outf S04PLA.SC0
jlp> incl harvest.jlp/*report:*end
jlp> incl harvest.jlp/*solution:*end
jlp> system SVSDBMS EXPORT
jlp> system SVSDBMS IMPORT
```

```
jlp> init

jlp> system melalogin SJOKI04PLA
jlp> system edit SJOKI04PLA.SAV
       title SCENARIO1
jlp> incl harvest.jlp/*unsave:*end
jlp> incl harvest.jlp/*restrict:*end
jlp> incl harvest.jlp/*session:*end
jlp> incl harvest.jlp/*scenario1:*end
jlp> outf S04PLA.SC1
jlp> incl harvest.jlp/*report:*end
jlp> incl harvest.jlp/*solution:*end
jlp> system SVSDBMS EXPORT
jlp> system SVSDBMS IMPORT
jlp> init
```

and return to edit title

```
Arcplot: &run ATOOL:LOGIN  0
Arcplot: &RUN ATOOL:SCENARIO SJOKI04PLA SCENARIO0
Arcplot: DISP 1039
        : scenario0.plt
Arcplot: &RUN ATOOL:THEME SJOKI04 SJOKI04PLA SJOKI04 PROPOSAL  ~
        METHOD_1 PROPOSAL-LUT PROPOSAL SCENARIO0 20000
Arcplot: Q
Arc: POSTSCRIPT SCENARIO0.PLT SCENARIO0.PS 1
Arc: LPR SCENARIO0.PS
Arcplot: &RUN ATOOL:SCENARIO SJOKI04PLA SCENARIO1
Arcplot: DISP 1039
        : scenario1.plt
Arcplot: &RUN ATOOL:THEME SJOKI04 SJOKI04PLA SJOKI04 PROPOSAL  ~
        METHOD_1 PROPOSAL-LUT PROPOSAL SCENARIO1 20000
Arcplot: Q
Arc: POSTSCRIPT SCENARIO1.PLT SCENARIO1.PS 1
Arc: LPR SCENARIO1.PS
Arcplot: &RUN ATOOL:SCENARIO SJOKI04PLA SCENARIO2
Arcplot: DISP 1039
        : scenario2.plt
Arcplot: &RUN ATOOL:THEME SJOKI04 SJOKI04PLA SJOKI04 PROPOSAL  ~
        METHOD_1 PROPOSAL-LUT PROPOSAL SCENARIO2 20000
Arcplot: Q
Arc: POSTSCRIPT SCENARIO2.PLT SCENARIO2.PS 1
Arc: LPR SCENARIO2.PS
```

Phase 3. SENSITIVITY ANALYSIS FOR SCENARIO 3

use

```
jlp> incl run.jlp
```

```
Scenario 4. optimist                                        .SC4
Scenario 5. pessimist                                       .SC5
Scenario 6. Stderror 15                                     .SC6
Scenario 7. Stderror 20                                     .SC7
Scenario 8. Stderror 25                                     .SC8
Scenario 9. Routedensity 15                                 .SC9
Scenario 10. Routedensity 25                                .SC10
Scenario 11. Interest = 5                                   .SC11
Scenario 12. Interest = 7                                   .SC12
```

```
Arc: jlp # # # SJOKI04 SJOKI04PLA

jlp> system melalogin SJOKI04PLA
```

```
jlp> system edit SJOKI04PLA.SAV
       title SCENARIO4
jlp> system edit HARVEST.JLP
       const ...
jlp> incl harvest.jlp/*unsave:*end
jlp> incl harvest.jlp/*restrict:*end
jlp> incl harvest.jlp/*session:*end
jlp> incl harvest.jlp/*scenario3:*end
jlp> outf S04PLA.SC4
jlp> incl harvest.jlp/*report:*end
jlp> incl harvest.jlp/*solution:*end
jlp> system SVSDBMS EXPORT
jlp> system SVSDBMS IMPORT
jlp> init
goto edit .SAV

1) market change
       mode=standard
       attitude=0 neutral (scenario 3)
       attitude=1 optimist (scenario 4)
       attitude=2 pessimist (scenario 5)

Pessimist attitude in scenarios 6-12:

2) error in yield estimates
       mode=standard
       attitude=2 pessimist (scenario 5)
       uncertainty=1
       stderror=.15 (scenario 6)
       stderror=.20 (scenario 7)
       stderror=.25 (scenario 8)

3) test the effect of route density
       mode=standard
       attitude=2 pessimist (scenario 5)
       uncertainty=0
       cc_routedensity=15 (scenario 9)
       cc_routedensity=25 (scenario 10)


6) test the effect of interest rate
       mode=standard
       attitude=2 pessimist (scenario 5)
       uncertainty=0
       cc_routedensity=20
       interest=5 (scenario 11)
       interest=7 (scenario 12)
```

Phase 4. IMPLEMENTATION ANALYSIS

```
1) Create a CUTTING_STAND coverage

2) Modify TREATMENT_STAND
       - insert *CUT.PAT into TREATMENT_STAND
       - fix schedules
              Stand 23 - schedule 1
              Stand 41 - schedule 7
              Stand 84 - schedule 1
              Stand 85 - schedule 1

3) Replace previous .CDA

jlp> incl harvest.jlp/*import-index:*end

4) "Modified" scenarios
```

Modified:

```
Scenario 13. Use d_distance                                        .SC13
Scenario 14. Fixed - cutting allowed outside parcel
       .SC14
Scenario 15. Fixed - cutting allowed outside parcel, manual costs
       .SC15
```

```
Session parameters
       mode=modified
       year=1989
       loggingsystem=manual
       cc_routedensity=20
       t_routedensity=30
       measurementpoint=roadside
       salepoint=roadside
       attitude=pessimist
       uncertainty=no
       stderror=0
       fieldsurvey=no
       inventorymk=0
       interest=3
```

Decision problem

Scenario 13. Use d_distance (*scenario12:*end)

```
max NPV
s.t.   > end volume requirement
       < man power constraint
       = allowable cut
```

Scenario 14. Use d_distance for outside timber parcel and
fixed schedules inside timber parcel

```
max NPV
s.t.   > end volume requirement
       < man power constraint
       = allowable cut
```

Note reject cutting outside timberparcel -
cannot be solved because all schedules rejected for units
4,5,54,84,85,93,100.

Scenario 15. Fix schedules costs manually
and reject cutting outside timberparcel

```
max NPV
s.t.   > end volume requirement
       < man power constraint
       = allowable cut
```

For each scenario

```
Arc: jlp
jlp> system edit SJOKI04PLA.SAV
       title SCENARIO13
jlp> incl harvest.jlp/*unsave:*end
jlp> incl harvest.jlp/*restrict:*end
jlp> incl harvest.jlp/*session:*end
jlp> incl harvest.jlp/*scenario13:*end
jlp> outf S04PLA.S13
```

```
jlp> incl harvest.jlp/*report:*end
jlp> incl harvest.jlp/*solution:*end
jlp> system SVSDBMS EXPORT
jlp> system SVSDBMS IMPORT
jlp> init
and goto edit title (note: unsave because rejects in scenarios)

for scenario 14

jlp> save SJOKI04PLA_M
jlp> write/* SJOKI04PLA_M
jlp> system melalogin SJOKI04PLA_M
jlp> XDADBMS EXPORT
jlp> XDADBMS IMPORT
```

Phase 5. APPLICATIONS FOR SCENARIO (14)

```
Session parameters
       mode=modified
       year=1989
       loggingsystem=manual
       cc_routedensity=20
       t_routedensity=30
       measurementpoint=roadside
       salepoint=roadside
       attitude=pessimist
       uncertainty=no
       stderror=0
       fieldsurvey=no
       inventorymk=0
       interest=3

Applications:
Scenario 16. Standing sale                                .SC16
       salepoint=standing
Scenario 17. Sensitivity to the price of man day 450      .SC17
       salepoint=roadside
       mandaymk=450
Scenario 18. Field survey                                 .SC18
       mandaymk=582.08
       salepoint=roadside
       uncertainty=1
       stderror=.20
       fieldsurvey=1
       inventorymk=1
Scenario 19. Intensive field survey                       .SC19
       uncertainty=1
       stderror=.10
       fieldsurvey=1
       inventorymk=2
```

RESULTS

LIST OF VARIABLES

PNV
Present value of net income during the planning horizon 1989-2019, FIM

VOLUME0
Total standing volume in 1989 (before harvesting), m3.

VOLUME1
Total standing volume in 1989, m3.

VOLUME2
Total standing volume in 1992, m3.

VOLUME3
Total standing volume in 1999, m3.

VOLUME3
Total standing volume in 2009, m3.

VOLUME5
Total standing volume in 2019, m3.

NI1
Net income in 1898, FIM

CUT1
Cut volume in 1989, m3

MAN1 Man days/harvesting in 1989, days.

DESCRIPTION OF ZONING

"Timber"
All productive forest in timber production.

"Multiple"
Multiple-use forest set aside from timber production.

"Protect"
Multiple-use forest set aside and environmentally sensitive areas set under restricted timber production.

"Adjacency"
Multiple-use forest set aside, environmentally sensitive areas and adjacent stands set under restricted timber production.

"Market"
As "Adjacency" but with current market price and costs.

Table. Production possibilities. (See map of zones.)

	Timber	Multiple	Protect	Adjacency	Market
Number of rejected schedules	520	548	614	614	
PNV					
max	1197641	859209	858216	706365	428418
min	107389	107389	107389	108939	61792
VOLUME5					
max	25717	25717	25717	25717	25717
min	7416 12840	12903	14093	14093	
NI1					
max	1159665	826258	826258	670564	382008
min	111970	111970	111970	113524	64963
CUT1					
max	7087 4947	4947	4121	4121	
min	720 720	720	720	720	
MAN1					
max	309 216	216	185	185	
min	32 32	32	32	32	

Table. Production possibility boundary PNV-VOLUME5.

	PNV				
	Timber	Multiple	Protect	Adjcency	Market
VOLUME5					
7815	1197641				
8762					
9423					
12500	1167343				
13171	859209				
13234		858216			
14436			706365	14447	

Table. Production possibilities PNV-VOLUME5. (Timber2 under constraint NI1=243000. Timber3 under constraint MAN1<152.)

	PNV	
	Timber2	Timber3
VOLUME5		
7814		
8762		909421
9423	693273	
12500	605278	887102
15000	580882	859695
20000	452469	719379
25000	238170	246835

Table. Production possibilities PNV-VOLUME5. (Adjacency2 under constraint NI1=243000. Adjacency3 under constraint MAN1<152.)

	PNV	
	Adjacency2	Adjacency3
VOLUME5		
14436		
14308		691935
14912	442439	
15000	442355	690000
20000	404076	647911
24984	231382	
25000		228995

DESCRIPTION OF SCENARIOS

```
Session parameters        mode=standard
         year=1989
         loggingsystem=manual
         cc_routedensity=20
         t_routedensity=30
         measurementpoint=roadside
         salepoint=roadside
         attitude=neutral
         uncertainty=no
         stderror=0
         fieldsurvey=no
         inventorymk=0
         interest=3
         mandaymk=582.08

Decision problem in scenarios 0-1:
max      PNV
s.t.     VOLUME5 > 17129 M3

Decision problem in scenario 2:
max      PNV
s.t.     VOLUME5 > 17129 M3
         MAN1 < 153

Decision problem in scenarios 3-19.
max      PNV
s.t.     VOLUME5 > 17129 M3
         MAN1 < 153
         CUT1 = 1213
```

Scenario 0 "Multiple-use and protect"

Scenario 1 "Multiple-use and protect and adjacency"

Scenario 2 "Multiple-use and protect and adjacency with man power constraint"

Scenario 3 "Multiple-use and protect and adjacency with man power and allowable cut constraint"

Scenario 4 "Optimist's market price"

Scenario 5 "Pessimist's market price"

Scenario 6 "Randomized cut estimate error=15%"

Scenario 7 "Randomized cut estimate error=20%"

Scenario 8 "Randomized cut estimate error=25%"

Scenario 9 "Extraction route density of clearcutting 15 m"

Scenario 10 "Extraction route density of clearcutting 25 m"

Scenario 11 "Interest rate 5%"

Scenario 12 "Interest rate 7%"

Scenario 13 "Extraction distance as crow flies for all stands"

Scenario 14 "Extraction distace and other cost parameters from GIS for treatment stands cut in a given timber parcel, extraction distance as crow flies for other stands"

Scenario 15 "Harvesting costs from actual logging operations for treatment stands cut in a given timber parcel, extraction distance as crow flies for other stands"

Scenario 16 "Standing sale"

Scenario 17 "Price of man day 450 FIM"

Scenario 18 "Field survey 1 FIM/m3 and random error in cut estimate 20%"

Scenario 19 "Field survey 2 FIM/m3 and random error in cut estimate 10%"

Scenarios

Real solution
Integer solution

	0	1	2	3
PNV	493155	413539	408148	321321
	494695	417650	413756	325779
MAN1	207	176	152(U)	53
	207	176	153(INF)	54
NI1/roadside	464931	373684	352558	115842
	464931	373684	354331	118390
CUT1	4819	3995	3666	1213
	4819	3995	3687	1240
VOLUME0	10239	10239	10239	10239
VOLUME1	5539	6382	6742	9252
	5630	6542	6929	9297
VOLUME2	5946	6786	6765	6766
	6085	6903	6888	6766
VOLUME3	8255	9131	9110	9158
	8505	9272	9253	9158
VOLUME4	12856	13855	13779	13851
	13289	13977	13964	13852
VOLUME5	17128	17128	17128	17128
	17638	17164	17374	17155

	4	5
PNV	324282	318234
	3288000	322606
MAN1	53	53
	54	54
NI1/roadside	118891	112662
	121502	115122
CUT1	1213	1213
	1240	1240
VOLUME0	10239	10239
VOLUME1	9252	9252
	9297	9297
VOLUME2	6766	6766
	6766	6766
VOLUME3	9158	9158
	9158	9158
VOLUME4	13851	13851
	13852	13852
VOLUME5	17128	17128
	17155	17155

	6	7	8
PNV	290271	296411	301636
	311287	319523	298544
MAN1	66	63	60
	67	68	56
NI1/roadside	105256	106559	107570
	109024	117584	97909
CUT1	1213	1213	1213
	1254	1335	1107
VOLUME0	10239	10239	10239
VOLUME1	8915	8989	9056
	9217	9212	9160
VOLUME2	6772	6775	6766
	6772	6775	6766
VOLUME3	9163	9167	9158
	9164	9167	9158
VOLUME4	13834	13842	13840
	13845	13849	13840
VOLUME5	17129	17129	17129
	17217	17222	17147

	9	10
PNV	317853	318775
	316025	323187
MAN1	53	53
	51	54
NI1/roadside	112483	113219
	108344	115721
CUT1	1213	1213
	1169	1240
VOLUME0	10239	10239
VOLUME1	9252	9252
	9297	9297
VOLUME2	6766	6766
	6766	6766
VOLUME3	9158	9158
	9158	9158
VOLUME4	13850	13851
	13852	13852
VOLUME5	17129	17129
	17155	17155

	11	12
PNV	300752	285118
	306926	291027
MAN1	53	53
	54	54
NI1/roadside	112662	112662
	115122	115122
CUT1	1213	1213
	1240	1240
VOLUME0	10239	10239
VOLUME1	9252	9252
	9440	9440
VOLUME2	6766	6766
	6877	6877
VOLUME3	9158	9158
	9327	9327
VOLUME4	13841	13841
	14130	14130
VOLUME5	17129	17128
	17553	17553

	13	14	15
PNV	315049	308189	352922
	319422	307348	351635
MAN1	53	52	52
	54	52	51
NI1/roadside	109382	105033	151528
	111842	104022	149638
CUT1	1213	1213	1213
	1240	1202	1193
VOLUME0	10239	10239	10239
VOLUME1	9252	9257	9247
	9440	9268	9268
VOLUME2	6766	6766	6766
	6877	6877	6766
VOLUME3	9158	9158	9159
	9158	9158	9159
VOLUME4	13841	13872	13872
	13851	13873	13873
VOLUME5	17129	17128	17128
	17155	17179	17179

	16	17
PNV	384687	327632
	382978	326622
MAN1	51	52
	51	52
NI1/roadside	125060	123875
/standing	183880	181844
CUT1	1213	1213
	1200	1202
VOLUME0	10239	10239
VOLUME1	9260	9257
	9274	9268
VOLUME2	6764	6766
	6764	6877
VOLUME3	9155	9158
	9155	9158
VOLUME4	13867	13872
	13867	13873
VOLUME5	17129	17128
	17175	17179

	18	19
PNV	289101	276418
	304080	275224
MAN1	65	70
	67	67
NI1/roadside	101285	96398
	107609	91163
CUT1	1213	1213
	1280	1156
VOLUME0	10239	10239
VOLUME1	8943	8800
	9125	8870
VOLUME2	6772	6772
	6772	6772
VOLUME3	9163	9163
	9163	9163
VOLUME4	13857	13862
	13866	13862
VOLUME5	17129	17128
	17199	17188