STAGES:
A SYSTEM FOR GENERATING STRATEGIC ALTERNATIVES FOR FOREST MANAGEMENT

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STAGES: A System for Generating Strategic Alternatives for Forest Management

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Stellingen

Behorende bij het proefschrift van Jan Bos:
STAGES: A system for generating strategic alternatives for forest management.

1. In een systeem van hiërarchisch geordende beslissingsniveaus is het voor afstemming benodigde aantal terugkoppelingen naar een naast hoger liggend niveau een maat voor de kwaliteit van de decompositie van het oorspronkelijke beslissingsprobleem in deelproblemen.
   (dit proefschrift)

2. Zowel de effectiviteit als de efficiëntie bij het genereren van alternatieven wordt verhoogd wanneer de strategische planning wordt ondersteund door kwantitatieve, op computers gebaseerde, beslissingsmodellen.
   (dit proefschrift)

3. Het zoneringsprobleem in de bosbeheersplanning is te formuleren als een kwadratisch toewijzingsprobleem, waardoor het enerzijds oplosbaar is met behulp van een simulated annealing heuristiek en anderzijds meer mogelijkheden biedt om om te kunnen gaan met de ruimtelijke aspecten van zoneringsbeslissingen dan de lineaire objectfunctie van LP-modellen biedt.
   (dit proefschrift)

4. Het niet combineren van beslissingen over het doelbos met beslissingen over het omvormingsbeheer leidt tot niet-realiseerbare plannen.
   (dit proefschrift)

5. De strikt formele beschrijving die kenmerkend is voor wiskundige modellen vormt geen beperking voor de gebruiker, maar biedt juist ruimte voor creativiteit.

6. Het streven naar biodiversiteit zal in Nederland, gezien de beperkte beschikbare oppervlakte, synoniem zijn met het streven naar kleinschaligheid.

7. Zolang de door de overheid voor onderzoek ter beschikking gestelde middelen niet direct gekoppeld zijn aan de daarvoor te realiseren onderzoeksdoelen, kan er schijnbaar ongestraft worden bezuinigd bij rijksinstituten voor onderzoek, omdat niet duidelijk is welk onderzoek als gevolg daarvan niet meer wordt uitgevoerd.

8. Het synergetisch effect van de integratie van verschillende disciplines in interdisciplinair onderzoek is moeilijk te beoordelen vanuit de disciplines waar het interdisciplinair onderzoek gebruik van maakt en zal daarom vanuit de toepassingen moeten worden beoordeeld.

9. De eenvoud van de uitkomst van een structureringsproces zegt niet veel over de complexiteit van het proces dat nodig is om die eenvoud te bereiken. Beoordelen van de kwaliteit van onderzoek louter op grond van de uitkomsten is daarom te beperkt.

10. Wanneer alle slachtoffers van roken en meeroken op 12 april tussen 14.00 uur en 15.00 uur op de Dam in Amsterdam zouden overlijden en niet in de loop van het jaar en verspreid over het hele land, zoals nu, dan zullen veel mensen stoppen met roken.
    (vrij naar Meerjarenplan verkeersveiligheid)

11. Muggen bezitten evenveel leven als olifanten, muggen sterven alleen niet zo gemakkelijk uit.

ABSTRACT

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228 pp, 29 figures, 21 tables, 135 references, English and Dutch summaries.

Strategic planning is important in forest management. However, it has never been described clearly in literature. In this study a framework for strategic planning was developed and based on this a STrategic Alternatives Generating System (STAGES) to support decision making in strategic planning for forest management. This strategic planning consists of deciding on zoning, future forest and transition management. STAGES consists of a zoning model (which addresses the zoning decision problem that is formulated as a Quadratic Assignment Problem and is solved by Simulated Annealing) and a management model (which addresses the desired future forest decision problem and the transition management decision problem simultaneously; these are formulated as a linear programming problem). STAGES was tested in a case study. The models which constitute STAGES can also be applied in natural resource management planning in general, regional planning and land use planning.

Keywords: linear programming, quadratic assignment problem, forest management, strategic planning, zoning, desired future forest, transition management, simulated annealing, land use planning

PREFACE AND ACKNOWLEDGEMENT

In this research decision models for strategic planning in forest management were developed. The research was done in the Department of Forestry of Wageningen Agricultural University in the Netherlands and in the Department of Planning, Use and Management of the DLO Institute for Forestry and Nature Research also in Wageningen. I wish to thank Wageningen Agricul- tural University and the DLO Institute for Forestry and Nature Research for the opportunity to do this research.

For this research I went in 1988 on a study trip to North America. I am most grateful to the LEB Foundation (Stichting "Fonds Landbouw Export Bureau 1916/1918") for providing financial support for this. During my studytrip I visited Professor L.S. Davis who was on sabbatical in Fredericton, New Brunswick (Canada). I wish to thank him for the fruitful discussions we had and for his encouraging words. I also wish to thank Dr. G.L. Peterson and the members of his staff from the Land Management Planning Systems section of the Rocky Mountain Forest and Range Experiment Station, Fort Collins, for the discussions we had during my stay in Fort Collins (Denver, Colorado, USA).

The first versions of the models developed in this study were tested by applying them to the preparation of the management plan for the Waterbloem national forest in the Netherlands. I wish to thank the State Forest Service for providing this opportunity, because the results of this trial enabled the zoning model to be developed (see chapters 5 and 6). In relation to this I wish to thank M. Nieuwelink, regional planner of the State Forest Service who prepared the management plan for Waterbloem, for his pleasant cooperation. Furthermore I would like to thank R.A.C.M. Broekmeulen, formerly of Wageningen Agricultural University, for providing the original algorithm for the zoning model and J. Burrough-Boenisch for editing and correcting the english.

Special thanks are due to Professor P. van Beek, Professor A. van Maaren, A.M. Filius, P.J.W. Hinssen and J.W.M. Langeveld for being my scientific conscience. They read, commented and discussed the various drafts with me, and most of all they taught me how to do scientific research. Their support has been crucial to this research.

Last but not least I want to thank Karin and Janine, for putting up with the fact that their husband and father spent too much time that should have been spent with them on this research. This time will be made up now.

Veenendaal,
January, 1994
Jan Bos

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1. INTRODUCTION

1.1. Need for changes in forest management planning

Forests can be valuable for a society, because they can fulfil functions. A forest function can be defined as a relationship between society and forest (Van Maaren, 1988) in which needs of society are fulfilled. In the Netherlands the most important functions of the forest are (in arbitrary order) giving opportunities for outdoor recreation, production of timber and nature conservation. The relationships between society and forests,can differ from country to country. For example, the gathering of fuelwood, which is not important in the Netherlands, is important in developing countries. Also, through time the importance of a particular function can change.

> 'When increasing incomes means bigger and better wooden houses the lumberman needs to worry only about whether he would have enough timber to supply the hungry saw. But when larger incomes mean houses made of steel, glass, and bricks instead of wood, the lumberman should give serious thought to markets.' (Gregory, 1972)

Forests fulfil more than one function simultaneously: multiple-use. Multiple-use of forests is an old phenomenon. In former days people exploited forests for the production of timber, hunting, grazing of livestock, secure water supplies and gathering fruits (Gregory, 1972). Although multiple-use of forests is an old phenomenon, its manifestation changes continuously. The mix of products and especially the importance of the various products varies in time. Multiple-use of forests used to be restricted solely to use. *Managing* the forest for multiple-use is a much more recent phenomenon. In industrialized countries, interest in the management of forests for multiple-use also reflects the increasing demand for timber, opportunities for recreation and awareness of ecological value. Forest policy and forest managing organizations face a growing demand for forest "products" such as nature conservation, recreation opportunities, timber and landscape, but the supply of these is under stress because of financial-economic factors and environmental factors (such as pollution) (see NRLO, 1990a and LNV, 1990a). In addition to these developments, major shifts occur in the demand for these products. Nature conservation and opportunities for recreation, for example, are becoming relatively more important in the Netherlands.

In the Netherlands, a country with high population density and a restricted amount of forest, forest management is usually aimed at multiple use. The main objective in the Master Plan for Forestry in the Netherlands of 1986 is (L&V, 1986):

> " The promotion of conditions and circumstances within the framework of the total governmental policy so that the forest area in the Netherlands meets the wishes of society with respect to the attainment of functions now and in the future as best as possible, with respect to area and quality, at a cost level acceptable to society."

In addition to the abovementioned trends in society, the forests themselves also are developing. Forests in the Netherlands are relatively young. The 4th national forest assessment (CBS, 1985) shows that a considerable part of the forests in the Netherlands is less than 100 years old. Ecological processes and forest management are causing Dutch forests to change (NRLO, 1989a). They are growing older and are maturing. Hence there are more management options than before.

As a result of the social changes and the changes of the allocation of functions to forests, forest management can no longer be based on traditional empirical knowledge (NRLO, 1989a). Hence, forest management in the Netherlands is becoming more complex. In former days the objectives of forest management were clear: create forests and produce timber (CBS, 1985). Nowadays, decisions on the functioning and development of a complex ecosystem have to be made in a context in which the demand for forest products/services is growing in intensity and in diversity and concomitantly the number of management options is increasing. At the same time, production factors such as capital and labour are becoming scarcer than ever.

If it is decided that a forest has to fulfil certain functions, then these functions are elaborated into objectives about which management decisions can be taken. Decisions are needed, because the extent to which a forest fulfils a certain function is related not only to social factors, but also to site conditions and characteristics of the forest (Lammerts van Bueren, 1983). Forest management exploits relationships between fulfilment of functions and characteristics of the forest by altering the characteristics of the forest so that the objectives concerning the fulfilment of functions are met. When managing forests for multiple-use, decision making is complicated by non-complementary relationships between functions: a change in characteristics that promotes one function may hinder another.

In decision making in forest management, not only the effects in terms of fulfilment of functions have to be considered, but also the efficiency in the use of capital, land and labour needed to realize the objectives. In doing this the forest manager has to take into account that a forest is a very complex ecosystem in which many variables determine the state and the course of development of the system. Intervention in the ecological processes of a forest can influence the state and the course of development over a long period (Gregory, 1972). The forest manager must therefore anticipate the long term as well as the short term effects of his decisions (Johnston *et al.*, 1967). Interventions in the forest will not only influence the fulfilment of functions today, but also the likelihood of functions being fulfilled in the future. In making decisions, prior and future decisions have to be considered. The effect of a certain decision can be negated by a subsequent decision. Decisions therefore have to be considered simultaneously. If management decisions are not mutually consistent or are not consistent with the ecological processes that determine the development of the forest, the sustainability of the forest and the relationship between the society and the forest can be endangered.

1.2. The research topic

As demonstrated above, decision making in forest management is a very complex process. Decisions in forest management are therefore usually not taken ad hoc, but are incorporated in an organized set of planning processes called a planning system. In forestry a planning system often consists of long term planning, medium term planning and short term planning (Jöbstl, 1978). In the ideal situation this planning system is constructed in such a way that all the relevant effects are weighted and all the relevant relationships between decisions are addressed.

The developments in society and the forest mentioned in the preceding section clearly have major consequences for decision making in forest management. In the past, management objectives were indisputable, so planning could be restricted to allocation of means to achieve them. The shift to managing forests for multiple use imposes new questions on forest management planning. New objectives are added to the existing ones. What management is needed to achieve these new objectives? Managing forests for multiple use also means that several objectives have to be achieved simultaneously. How can this be done? The range of objectives is enlarged, and can differ from site to site. In certain sites, recreation and timber production can be important, but in others the emphasis must be on nature conservation in combination with preserving beautiful scenery. What are the objectives for a particular forest? In other words, the questions are not only about how to achieve the objectives, but are also about which objectives should be achieved. As a result, planning not only allocates means, it must also search for objectives. The forest owner has to solve the problem of how to choose objectives, how to develop strategies to realize them and how to identify and weigh the consequences of choosing them. The consequences to be considered are not only financial, social, economic and environmental (OECD, 1986), but also include consequences in terms of the extent to which functions will be fulfilled (NRLO, 1989b). Further, a variety of ecological, financial, labour, capital and technical constraints restricts the set of feasible decisions.

Strategic planning is the process in which decisions are made about the social function, the internal objectives and policy of an organization (Botter, 1981). Therefore the problem of making decisions for forest management focuses on strategic planning in forest management. Strategic planning is not only a search for objectives, but it also produces objectives (Irland, 1986; Botter, 1981; Keuning & Eppink, 1987). As well as deciding on the objectives of an organization, it also involves deciding on strategies (ways and means) for achieving the objectives (Keuning & Eppink, 1987). If strategic planning in *forest management is to be able to deal with the changing tasks of forest management*, planners not only need to be aware that planning involves seeking objectives, but must also have the instruments to do this seeking.

Forest managers make use of all kinds of models to deal with the complexity of decision making in strategic planning in forest management. Models are abstract representations of the real world that are useful for purposes of thinking, forecasting and decision making (Buongiorno & Gilles, 1987). Examples of traditional models are maps, classification systems, growth tables etc. More recently mathematical models have been developed and introduced in forest management. In these models the real world system is represented by mathematical symbols, which form a set of variables with relationships between them. These kinds of models can be used to examine how the modelled system will react to changes in variables. Variables can be divided into controllable variables (decision variables) and uncontrollable variables (climate, soil, wage rate, growth rate per specie etc.). By changing controllable variables the effect of decisions can be assessed. In strategic planning these mathematical models can play a role in exploring which alternative objectives are possible and what are their consequences.

In the USA linear programming models are used as planning instruments in forest management. However, the context of forest management in the USA differs from the context of forest management in the Netherlands. In the USA natural forests are being transformed into more regulated forests, whereas in the Netherlands plantation forests are being transformed into more natural forests. Most of the forests in the USA are managed on a large-scale basis, but in the Netherlands all the forests are managed on a small-scale basis. In the USA legislation (in particular the National Forest Management Act of 1976) gives a considerable number of directives for forest management. These include statements about which alternatives have to be generated, which information has to be processed when generating these alternatives and how the alternatives have to be generated. There is no such legislation in the Netherlands. Therefore the models used in the USA cannot be applied to the Dutch context without modifications, because they are attuned to the context of US forest management. It takes a long time to build models like this.

The lack of instruments for forest planning in the Netherlands means that:
- alternatives are seldom identified;
- insufficient attention is given to long term implications of decisions;
- decisions made in strategic planning are difficult to justify.

The importance of the development of instruments, i.e. models with which alternatives and their consequences can be generated, was also recognized by the Kampfraath committee. The committee was set up in 1972, to evaluate the forest management of the

State Forest Service. In its final report it recommended testing the suitability of a number of quantitative methods for identifying the weight of management alternatives (Kampfraath Committee, 1975).

The identification of alternatives and their consequences is an important part of a planning process. The explanation of why the alternative chosen is the best, is the justification for a decision. This explanation is based on a comparison of the consequences of the various alternatives in terms of decision criteria, intentions, ends or preferences. The identification of alternatives and their consequences is clearly crucial to a planning process. Therefore, the lack of suitable instruments to generate alternatives and to assess them is a serious shortcoming in forest management planning in the Netherlands. This lack is the problem addressed in this study.

1.3. Objectives, restrictions and research questions of this research

1.3.1. Research objectives

The objective of this research was to develop a system for generating strategic alternatives, to support decision making in strategic planning in forest management. By generating strategic alternatives and indicating their financial, economic, social and environmental consequences, such a system should help to overcome the current shortcomings in strategic planning in forest management in the Netherlands mentioned in the preceding section (no alternatives, no consequences, no justification).

As noted earlier, the main task of strategic planning is to identify potential objectives and to select the most appropriate. To be able to make decisions on objectives the decision maker has to know the implications of choosing an objective and of a set of chosen objectives. The system for generating strategic alternatives has to support this decision making process by generating management alternatives and contributing to the assessment of the implications of alternative objectives. Furthermore, although the scope of the system for generating strategic alternatives is the forest enterprise, the models it uses have to be able to identify effects of regional and national policy decisions, by assessing how strategic decisions and their effects will alter at the level of the forest enterprise because of the regional and national policy.

To be able to develop the system for generating strategic alternatives, the concept of strategic planning in forest management must be understood. This understanding can also be used for other ends, such as rectifying another problem in forest management planning: the inadequacy of planning systems. The relationships between strategic planning and tactical planning are insufficient (NRLO, 1990b). Thus the analysis of the concept of strategic planning in forest management could be the first step towards improving planning systems in forest management. The analysis of strategic planning was therefore also an objective of this research.

Thus, the main aims of the research described in this thesis were:
- analysis of strategic planning in forest management in the Netherlands;
- development of a system to generate strategic alternatives for decision support in strategic planning in forest management.

1.3.2. Restrictions to the research

The decision problems to be solved in strategic planning in forest management had to be decoded into a mathematical system consisting of relevant variables and relationships between them. This formed the basis of the system for generating strategic alternatives. Further, in order to solve these problems, algorithms were needed to find the optimal solution to the modelled problem. An algorithm is a calculation procedure that ensures that starting from a feasible solution, an optimal or 'good' solution is approached within a reasonable number of steps (Buongiorno & Gilles, 1987).

The mathematical system developed was restricted to the level of the forest enterprise. This restriction in relation to the scale level is emphasized because in 1984 the Dutch government presented a planning concept based on forest types (SBB, 1984), to support long term thinking in forestry. The basic idea was to describe the future forest in terms of forest types (A forest type is a silvicultural description of the long term objective). The concept never worked well because it was not tuned to the level of the forest enterprise nor to regional and national policy (LNV, 1992).

In a forest managing organization all kinds of strategic decisions have to be made. These decisions can range from employment to investments in buildings and equipment. However, the research described here was deliberately restricted to decisions on the management of the forest (decisions such as what should the future forest look like, what management is needed to achieve the desired future forest, etc.). If necessary, other strategic decisions that are related to these decisions were taken as constraints.

The system for generating strategic alternatives has to be suitable for different types of forest ownership. This means that the models have to be flexible and easy to adjust to some specific characteristics of a specific type of forest ownership. This also means that the models have to focus on the headlines of strategic planning. They have to address those decisions common to all types of ownership. The system for generating strategic alternatives has to serve as a blueprint for tailor made decision support systems for particular types of forest ownership.

Decision problems can be divided into two classes depending on their nature: repetitive decision problems and non-repetitive decision problems (Johnston *et al.*, 1967). The non-repetitive type usually involve questions of a unique nature and cannot be solved by the application of routine processes (Johnston *et al.*, 1967). A planning system does not normally include such non-repetitive problems, because their occurrence cannot be foreseen. In contrast, the repetitive problems usually involve questions that can be foreseen and for which solution routines can be developed. It is this category of problems that the system for generating strategic alternatives has to cope with.

1.3.3. Research questions

To achieve the objectives of this study, the following main research question had to be answered:

> Is it possible to develop a model or a system of models that supports the identification and selection of strategic objectives in forest management planning in the Netherlands on the level of the forest enterprise by generating alternatives and assessing the consequences of these alternatives ?

This main research question can be broken down into the following sub-questions:

1. What are the characteristics of forest management planning in the Netherlands?
2. What is the role and position of strategic planning in forest management?
3. What decisions have to be made in strategic planning in forest management?
4. What requirements must a system for generating strategic alternatives fulfil in order to be suitable for supporting decision making in strategic planning in forest management in the Netherlands?
5. How can the decisions that have to be made in strategic planning in forest management in the Netherlands be modelled so that they constitute the basis of a system for generating strategic alternatives?

The first three research questions focus on achieving the first objective of this study: analysis of strategic planning in forest management. The fourth and the fifth focus on achieving the second objective of this study: development of a system for developing strategic alternatives for decision support in strategic planning in forest management.

1.4. Method of research

To answer the first three questions posed above, the literature was reviewed to ascertain the characteristics of forest management, the role and position of strategic planning and the decisions that have to be made in strategic planning in forest management. In addition, these topics were discussed with experts. The information gathered to answer the first three questions could also be used to answer the fourth research question (the requirements that a system for generating strategic alternatives has to fulfil). The answer to the fourth research question was largely based on reformulating the answers to the first three research questions into requirements that have to be fulfilled in order to be able to deal with the characteristics of forest management and to address the decisions that have to be made in strategic planning. To answer the fifth research question (how to model decisions in strategic planning) the literature was reviewed for ways in which the decisions that have to be made in strategic planning are dealt with in existing models. Here too, discussions with experts were needed. The results of the literature study and discussions were used to develop the system for generating strategic alternatives. This system was then implemented on a computer and applied in a case study, to test its usefulness.

The four thrusts followed in this research were:

1. analysis of the decision situation in strategic planning in forest management.
2. search for forest management models suitable for solving the decision problems described in 1.
3. development of mathematical models to support decisions in strategic planning in forest management.
4. validation and implementation developed models.

The first thrust answers research questions 1 - 4. The other thrusts answer research question 5.

Thrust 1:
The decision situation in strategic planning in forest management was analysed. The literature was reviewed for general concepts of forest management, general concepts of strategic planning and specific concepts of strategic planning in forest management. It was expected that strategic planning would consist of several interrelated decision problems. The outcome was a description of decision problems that have to be solved in strategic planning in forest management. Requirements for models were also described. These findings served as the basis for the evaluation of existing models (see 2 below) and were used when adjusting models (see 3 below).

Thrust 2:
In the second thrust literature was reviewed for forest management planning models that are suitable to represent and solve the problems described in 1 above. It was hypothesized that some strategic decision problems in forest management planning are well covered by existing models but that for other problems no models exist that address the problem properly. This thrust resulted in clear directives for the model(s) to be developed.

Thrust 3:

The third thrust involved mathematical models for strategic planning in forest management in the Netherlands. This part was the core of the study. The research in this part fell back on the first two thrusts, especially on the results of the second which were used as a toolkit.

Thrust 4:

In this trust the models developed were validated and their applicability was demonstrated by means of case studies. To do this the models were implemented on a computer. The focus was on the models, not on the data needed to run those models. If real-world data were lacking, best professional judgement was used instead.

The method described above forms the framework of this theses.

2. FOREST MANAGEMENT

2.1. Introduction

Clearly, in order to be able to construct a system that generates alternatives for strategic planning in forest management, decisions to be made in strategic planning must be properly defined. These decisions depend on the role strategic planning fulfils in forest management. This role and the decisions to be made in strategic planning are described in chapter three. However, to properly understand the role of strategic planning in forest management, some insight in decision making in forest management is needed. This chapter therefore focuses on decision making in forest management.

In this chapter, the decisions and their mutual relationships which together constitute forest management will be sought out. Because decision making is the central role of (forest) management (Davis & Johnson, 1987), an outline of decisions mentioned above and relationships between them also can be seen as a basic description of the scope of forest management.

2.2. Forest management

To be able to determine which decisions belong to forest management and which do not, we need to start with a definition of forest management. The various definitions of forest management that exist are discussed here, to develop the definition of forest management adopted in this study. Brumelle *et al.* (1991) claim that forest management refers to all the conscious decisions to intervene or not to intervene in the dynamics of forest ecosystems. Further they mention that any consideration of forest management cannot be separated from the methodologies and institutional and social structures which support these decisions. This is a very broad definition of forest management. Leuschner (1990) admits that forest management widely has been defined as the application of a wide range of scientific, economic, and social principles to administer and solve problems in forested areas. He himself, however, defines forest management as the study and application of analytical techniques to aid in choosing those management alternatives that contribute most to organizational objectives. The latter definition is more restricted than the first but implies that knowledge needed to biologically manage forests and analyse their outputs is imparted under headings such as silviculture, protection, and biometrics (Leuschner, 1990). The difference between the definition of forest management by Brumelle *et al.* and Leuschner's definition is that the latter is more specific about how decisions should be supported and about the fact that forest management is aiming at achieving organizational objectives. Buongiorno and Gilles (1987) define forest management as the art and science of making decisions with regard to the organization, use and conservation of forests. They state that such decisions may involve the very long-term future of the forest or the day-to-day activities. Further, these decisions may deal with very complex forest systems or with simple parts. The geographical area of concern may be an entire country, a region, or a single stand of timber (Buongiorno & Gilles, 1987). The difference between the definition of forest management by Buongiorno and Gilles and the other definitions given is that Buongiorno and Gilles divide the decisions into categories. The most important is the division into decisions concerning the organization of forest, decisions concerning the use of forests and decisions concerning the conservation of forests. Davis and Johnson (1987) do not give a definition of forest management, but they state that the focus in forest management is on decision making, choosing among alternative courses of action. They identify three forms of scheduling activities. The first form is harvest scheduling. This scheduling is the traditional term for scheduling a timber harvest. The second form is timber management scheduling. This covers timber harvest activities, silvicultural activities and other activities associated with the present and future stand production. The third form is forest management scheduling. This describes comprehensive analysis that considers timber and non-timber outputs in land allocation and activity scheduling decisions (Davis & Johnson, 1987). In other words, forest management deals with decision making about land allocation, about harvesting (timber and nontimber output) and silvicultural activities needed for present and future production of timber and non-timber outputs. The difference between the (implicit) definition of forest management by Davis and Johnson and the foregoing definitions is that in discussing forest management Davis and Johnson emphasize the production of outputs. Duerr *et al.* (1979) also state that management is the process of making and effectuating decisions or plans, to meet people's aims. They add to this that management creates resources, which are the aggregated valuable attributes of persons and objects. They use the term forest resource management. Forest resources are aggregates of valuable attributes of forests. This means that it is not the forest, but the valuable attributes of forests, that are managed. The forest is then treated as a production factor and the forest attributes are the result of management.

Kanowski *et al.* (1992) point at a dualism in forest management. One element is the sophisticated, quantitative management science developed for managing large-scale resources and wood-using industries. Such an approach is characteristic of forest management in industrial societies where methodologies, usually based on mathematical optimization, have been developed for purposes such as multiple-use planning, harvest schedules, and evaluation of silvicultural alternatives. A second element is the existence of traditional forest management as similarly sophisticated, albeit qualitative, and the development of management practices that build on them (Kanowski *et al.*, 1992). Kanowski *et al.* do not explicitly define forest management, but the dualism they identify emphazises the broad field of forest management. From Kanowski *et al.* it becomes clear that if the forest manager has advanced techniques such as computer implemented decision models at his disposal to support decision making, the forest planning practices will be different from the situation in which the forest manager has only got the back of a cigarette packet at his disposal to support decision making (and does the rest in his mind). But this, however, does not mean that the essence of forest management therefore has to be different. In the remainder of this section we will concentrate on the essence of forest management.

In the definitions given above the common factor is that decision making plays a central role in forest management. These definitions, however, do not make clear what is the difference between forest management and all other (for example industrial) management processes. The answer to this question lies in the object to be managed and its characteristics. The object of forest management is described below.

Forests are complex dynamic systems in which many variables determine the state of the system and the direction in which it will develop. Society is even more complex and dynamic. In forest management both systems have to be adjusted to each other to achieve a sustainable fulfilment of needs. Forest management exploits relationships between fulfilment of functions and characteristics of the forest, by altering the characteristics of the forest so that the objectives concerning the fulfilment of functions are met. In this way forests are adjusted to society to achieve a sustainable fulfilment of needs. Forest management will also adjust the use society makes of the forest ecosystem. This means that forest use has to be restricted to avoid over-use. For example periodical harvest has to be in equilibrium with the periodical increment of wood. Recreational use has to be restricted in order to avoid too much disturbance of wildlife. In other words forest management is the process in which the forest ecosystem and the society are adjusted to each other. This means that the main object of forest management is not the forest ecosystem, nor the needs of society, but the relationship between society and forest (functions of the forest). Decision making in forest management is therefore complicated by the combination of the characteristics of the forest ecosystem and the characteristics of society. For example, in the Netherlands the needs of society are changing more rapidly than the forest characteristics necessary to make the forest suitable for these new needs. Decision making is not complicated because the needs of society change relative quickly, nor because a forest reacts slowly to a change in management, but because of the combination of these characteristics.

Braat (1992) defines forest management as the set of human actions designed to obtain and mantain control over forest ecosystem structure and processes. This definition covers only part of forest management which deals with the forest ecosystem. The part of forest management which deals with use of forests is missing from this definition. Controling the structure of and the processes in a forest is important, but so is controlling the use society makes of the forest.

Concluding, we can say that in this study forest management is defined as the set of human activities aiming at a sustainable fulfilment of needs of society (including the forest owner) by adjusting the forest ecosystem to the needs of society and adjusting society (i.e. how society uses forest) to the forest. The kernel of decision making in forest management is therefore to answer the question which mix of functions and level of fulfilment per function maximizes the satisfaction of society's needs (Lammerts van

Bueren, 1983). The answer to the question is determined by society's needs, the physical suitability of forestland to fulfil functions, economic implications and social acceptance (Lammerts van Bueren, 1983).

In cases where the forest is privately, not publically owned, it is the forest owner who decides which needs and whose needs will be satisfied. He will make his decisions in such a way that he maximizes the utility of the forest for himself. Thus he adjusts the forest to the needs of society that best serve his ends, not to the needs of society as a whole.

The complexity of decision making in forest management is made clear in the rest of this chapter by addressing basic concepts of forest management and complicating factors in decision making (i.e. characteristics of the object of decision making) in forest management.

2.3. Sustainability

Sustainability is one of the two basic concepts in forest management (The other is multiple use - see section 2.4) (Behan, 1990). It was the Brundlandt report that first introduced sustainable development as a new concept. It was defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland, 1987). In forest management, however, the concept of sustainability has long existed. The principle of sustention originated in the early 18th century in Central Europe (Speidel, 1984). It had been formulated in the 16th century, but the expression "Nachhaltend" (sustainable) was first used by H.C. Von Carlowitz in 1713 (Speidel, 1984). Although the principle of sustainability is still being discussed in forestry literature, it has been adopted throughout the world as a basic concept in forestry (Von Gadow, 1980). The discussion on sustainability in forest management is not the same as the discussion on sustainability in agriculture. In forest management the discussion centres on the question of how the functioning of the forest can be sustained. In agriculture, the discussion focuses more on the external environmental effects of agriculture.

To determine how the sustainability concept influences decision making in forest management, we need to answer the following questions:
- What is sustainability;
- Why is sustainability important in forest management;
- How does sustainability influence decision making in forest management.

These questions are answered below (subsections 2.3.1 and 2.3.2).

2.3.1. Sustainability: its meaning and role in forest management

The term sustention is a formal one. Sustainability is a neutral concept which may express a variety of ideals, such as steadiness, stability, regularity or continuity. The principle of sustention is, therefore, not confined to forestry but it is a fundamental objective in any endeavour that aims at continuity and stability (Von Gadow, 1980).

There are restrictions to an ecosystem's potential to produce goods and services. If forest use is of low intensity, the forest will react with regeneration within natural dynamic processes in such a way that the ecosystem will maintain itself. If, however, the use is greater than the carrying capacity of the forest, the ecosystem or components of it will degenerate (Van Maaren, 1991). As a result of this, the production potential will decline and so will the flow of goods and services.

Von Carlowitz emphasized (in 1713) that if the concept of sustainability is abandoned, humanity will have to face poverty and destitution (cited by Speidel, 1984). This is what happened in the 17th and 18th centuries. Central European forests declined and disappeared because of over-use. Forest science arose in the aftermath of this environmental catastrophe. Early forestry focussed on the rebuilding of the forest as a resource. It started as forest restoration on a technical-biological basis. In 19th century Europe, attention shifted from purely planning the state of the resource, towards planning the continuing availability of goods and services: sustainability (Van Maaren, 1991).

In forestry, sustainability means in its basic form that forest use is adjusted to the carrying capacity of the forest. Traditional planning methods aimed at identifying and maintaining the highest production level on which this equilibrium could be established (allowable cut). In practice this can be done in two ways. The first is by conditioning the forest. For timber production this means, among other things, sustaining the increment of wood. The second way is by conditioning the use of the forest. For timber production this means, for example, that the periodic harvest of wood has to be less than or equal to the increment of wood during the same period. If the harvest of wood exceeds the increment of wood, then the forest is overused and will ultimately decline.

Traditional sustainability means aiming at sustained yields, i.e. the same amount of timber is produced per period, perpetuity. But, as technology changes, the economic significance of a ton of wood changes. Therefore, sustained yield does not bring stability (Duer *et al.*, 1979). In this context Duer *et al.* (1979) even state that the sustained-yield doctrine is untenable, though useful as a device to restrict our uncertainty.

Sustention on its own means nothing. The question is what has to be sustained. This brings us to the object of management: the adjustment of forest and society. As society changes, the functions of the forest and their importance can change. Although it is often operationalized into maintenance of future production potential of the forest ecosystem, sustainability is more than sustaining a certain yield. It is the situation in which a continuously ongoing relationship between the forest ecosystem and society is ensured.

Sustainability is not restricted to a static situation. The characteristics of the forest, the needs of society and as a result the relationships between the forest and society can and will continuously change. In one respect the situation has to be static, namely that to enable there to be an ongoing relationship between society and forest, the forest ecosystem has to remain as a resource. Trees are not only product, they are also the production factor. If the trees disappear, the functioning of the forest will stop.

2.3.2 How to deal with sustainability in decision making

Below, I draw heavily on work published elsewhere (Bos & Hekhuis, 1994). Forestry in the Netherlands can be characterized as multiple-use forestry. This type of forestry offers a wider range of possible objectives than traditional forestry. Hence, the choosing of objectives becomes more important. The result of this is that the question of how to ensure sustention has been extended to what should be sustained. The answer to this question is crucial, because it determines which management option is chosen. A management option is considered as a consistent, coherent line of forest management activities that satisfies certain land use objectives. These activities include the use and protection of the stock of trees as well as silvicultural activities to develop and enhance the value of the forests (Brumelle *et al.*, 1991).

The basic problem we have to deal with if we wish to apply the concept of sustainability is how to measure sustention. This problem originates from an unclear formulation of objectives. If we want a forest which sustainably offers opportunities for outdoor recreation, the question is what kind of forest do we judge to be suitable for outdoor recreation. If this question can be answered then sustainability objectives can be formulated in such a way that the achievement of these objectives can be measured. In this section we will focus on how to formulate clear sustainability objectives.

One way to formulate the sustainability objectives is to express them in the following dimensions:
- object;
- scale;
- time.

The first and most important dimension of sustainability objectives is the object to be sustained. Gale & Cordray (1991) present several possible approaches towards sustainability and related objectives. Some of these concentrate on society, others on the relationships between society and forest and still others on the forest. Whatever the approach, the dimension "object" can be split into statements concerning the use and statements concerning the condition of the forest. In certain approaches, utilization of the forest is the goal and the condition of the forest is a means to attain this goal. In other approaches the condition of the forest is the goal and restrictions to the use are the means to attain this goal. Either way, statements about the use of the forest as well as statements about the condition of the forest are necessary.

The next dimension in which sustainability objectives have to be formulated is the scale. If the forest enterprise is the scale at which sustainability is wanted (for example sustained yield of timber) then a different set of forest characteristics is important than if sustainability is required at the level of the stand (for example, protection from erosion). If timber production at a national scale is at stake, timber production from non-sustainable forests could also be accepted. For example, temporary forests established under the "set-aside ruling" of the EC can lead to the situation of a forest never lasting longer than a few decades, and yet at national level the production of wood from such forests is sustainable, because the total area of such forests may be constant. Thus statements on the scale on which sustention is needed or will be monitored are important.

The last dimension in which sustainability objectives have to be expressed is the time. The time dimension implies that it must be stated which fluctuations in flow of products (here in the condition of the forest) within a particular time period are accepted. Another aspect of the time dimension is that the period needed to achieve a balanced forest is very long. Forests have to be maintained a very long time at a particular location to develop their full production (carrying) capacity. This puts constraints not only on the management, but also on the environment of forests (acid deposition, changing land uses, changing objectives).

If sustainability objectives are formulated in the dimensions mentioned above, an attempt can be made to operationalize them, using criteria and desired characteristics of the forest. The role of the sustainability concept in decision-making in forest management is twofold. On the one hand it leads to additional decisions on the object, the time and the scale of sustention. On the other hand it leads to restrictions to the range of feasible alternatives. These restrictions stem from the fact that not every alternative meets the requirements of sustention.

2.4. Multiple use

The second basic concept of forest management is multiple use. As in the case of sustainability, what it is, why it is important and how it influences decision making are discussed below.

Being an ecosystem, a forest almost inevitably produces a variety of products and services (Gregory, 1972). A forest not only shapes the landscape with its vertical structure, it also has other effects, which are discussed below.

Even though the Netherlands is a very densely populated country, with a very cultivated and managed landscape (BLB, 1990) its forests, which cover less than 10% of the surface (CBS, 1985) are major components of the country's ecological structure (LNV, 1990b). Because of their intrinsic nature and slow development, the ecological processes in forests bring a certain continuity to the landscape (Trees and forests change slowly; Gregory, 1972.). The scenery inside forests can be experienced as a giving tranquillity, space, a sense of adventure and the illusion of being in a natural environment far from home (Nip, 1984). In addition forests have other important functions. In the Netherlands, the following functions are commonly seen as the most important (Kampfraath Committee, 1975; Zonneveld, 1977; Sissingh, 1978; Verkoren, 1978; Hessels, 1978; L&V, 1986, Van Maaren, 1993):

- production of timber;
- providing opportunities for outdoor recreation;
- nature conservation;
- providing a pleasant scenery;
- fixing carbon.

Forests have the inherent capacity to produce such goods and services single or in combination. (Duer *et al.*,1979). Thus, in forestry, multiple use refers to the use of the forest ecosystem for the fulfilment of different needs simultaneously. Multiple-use management of forests creates an opportunity for efficient land use and, when land is scarce (as in the Netherlands), multiple use of forests is often very desirable. Hence, in the Netherlands multiple use is the objective of forest management in most forests (LNV, 1992).

To determine the way in which the multiple use concept influences decision making in forest management, we need to answer the following questions:

- What is multiple use;
- Why is multiple use important in forest management;
- In which way does multiple use influence decision making in forest management.

These questions will be discussed below.

2.4.1 Concepts of multiple use

As already stated, Dutch forestry is multiple use forestry. Dutch forestry therefore has to deal with the problems associated with multiple use. One of the most important of these is the incompatibility of certain forest uses (Clawson, 1976). This can give rise to conflicts.

There are two ways of dealing with these conflicts (Gregory, 1972). The first way is to accept them. This approach is known as the Dana-McArdle approach. It leads to an integration of functions. Helliwel (1987) interprets integration as segregation but on a smaller scale. The term integration in the Dana-McArdle approach does not mean segregation on a smaller scale. It means that functions are "interwoven" (cannot be separated) (Buiten *et al.*, 1982). Whether this approach succeeds or fails depends on the feasibility of identifying management options that lead to a forest that can fulfil the desired mix of functions on the same spot at the same time.

The second way to deal with conflicts, is to avoid them. This approach is known as the Pearson approach and leads to the temporal or spatial segregation of functions. This approach calls for some form of zoning and its success depends on how well the zoning is carried out. The Pearson approach is also called dominant use management. Under such management, land areas are allocated to a primary (single) use and the overall pattern of land use across the forest, provides for the multiple uses (Bowes and Krutilla, 1989). Forms of secondary uses are allowed in a certain zone as long as they do not hinder the dominant use.

The main difference between the approaches is the vision on how to deal with trade-off relationships between functions. The "wake theory/Kiewassertheorie" (Glück, 1982) is a concept built on the assumption that there are only complementary relationships between functions (all functions are compatible). Although the basis of this theory is that there are only complementary relationships between functions, management has to be directed to produce timber, because the timber production function is considered to be the most valuable (see Glück, 1982).

Which concept is used depends on many factors. In the Netherlands, zoning is a widely applied type of regulation. This does not mean that forest management in the Netherlands is based on a segregation of functions, because in any given zone the forest is often managed for more than one forest use.

The importance of multiple use in forest management cannot be overestimated. In the USA, multiple use and sustained yield was declared the objective of the management of State Forest, in the Multiple Use and Sustained Yield Act of 1960. In the Netherlands multiple use is the management objective for most of the forests (L&V, 1986; LNV, 1992). The Dutch government aims at a use and management of the forests in which the functions are continuous and in general simultaneously fulfilled (LNV, 1992). Behan (1990) states that multiple use is one of the basic conceptions of forest management.

In relation to the extreme concepts in multiple use, I agree with Clawson (1978) who stated that the assumption that a forest simultaneously fulfils all functions everywhere is just as absurd as the assumption that the forest fulfils only one function in a certain area.

2.4.2 How to deal with multiple use in forest management

In a multiple use situation the forest is managed to produce more than one kind of goods and services. This is called multiple production. Multiple production can be established

in one joint production process or in several single production processes. In a joint production process more than one kind of good and/or service is produced simultaneously. In a single production process only one kind of good or service is produced. In forestry, multiple production is often caused by a joint production process. There are two categories of joint production processes. In the first category the products are produced in fixed ratios. In the second category the ratios in which products are produced can be changed. Joint production in forestry belongs to the second category (Gregory, 1972). This means that multiple use calls for decisions about which functions have to be fulfilled in which quantities, and therefore which management activities are needed. The following information is needed to be able to make these decisions:
- input-output relationships;
- trade-off relationships between functions;
- preferential relationships between functions (valuation).

Input-output relationships

Input-output relationships or production functions describe how the output of different products and services will respond to changes in the amount, combination and/or quality of production factors. To be able to construct input-output relationships a clear product definition has to be available. Often, product definitions are lacking. Apart from growth and yield tables, quantitative input-output relationships are seldom known (see also Bos & Hekhuis, 1991).

Trade-off relationships

In a joint production process the production of one product or service depends on the production of other products and services (trade-off relationships). There are three types of trade-off relationship (Duer *et al.*, 1979):
- competitive: the relationship between two products and/or services is said to be competitive if an increase of the output of one reduces the output of the other,
- complementary: the relationship between two products and/or services is said to be complementary if an increase of the output of one is accompanied by an increase in the output of the other,
- indifferent: the relationship between two products and/or services is said to be indifferent if an increase of the output of one does not affect the output of the other.

Quantitative trade-off relationships between outputs are seldom known. Qualitative relationships are known (see Clawson, 1974). The existence of trade-offs among mutually exclusive choices is an economic characteristic of forest management (Duer *et al.*, 1979).

Preferential relationships

If input-output relationships and trade-off relationships are known, assessments are needed of relative economic values and demand for the various products and services of the forest (Bowes & Krutilla, 1989). In doing this the following problems have to be faced:

- If market prices exist, values can be expressed in one dimension and can easily be compared. Market prices do not exist for all the products and services of the forest. This leads to the problem that there is not always a proper procedure for determining the value.
- There is not always a clear product definition. If such a definition is lacking, then the question of what is being valued arises, instead of the question of what is the value of producing a certain amount of a certain product or service.
- It is difficult to determine the discount rate to be used in evaluating the financial implications of forest management projects.
- There is also a problem of how to value the possibility of producing products and services in the future in relationship to the valuation of producing products and services now (Helliwel, 1987). At this point the valuation problem is connected to the discussion about sustainability.
- Related to abovementioned factors is the question of how the owner balances his personal values against the values of society. This is a problem related to ownership. The owner of the forest can attach different values to the functions of the forest than the rest of society does (Bosschap, 1984).

From the above it becomes clear that multiple use complicates decision making in forest management. It leads not only to additional decisions, but also to the need for extra information - related to multiple production processes - which is not always available.

2.5. Complications in decision making in forest management

Although multiple production is an obvious characteristic of forest management it is not unusual in itself. Many firms are characterized by multiple production processes. In forest management, complications in decision making about multiple production arise from a number of other related sources (Bowes & Krutilla, 1989). Industries may share one or more of these characteristics, but only forestry has them all (Gregory, 1987). These features that complicate decision making in forest management are addressed below.

Many of the goods and services a forest produces are difficult to quantify

Because several goods and services a forest produces are intangible, the definition and mensuration of the quantity produced is sometimes troublesome. This results in vague objectives. It is difficult to evaluate alternatives if the objectives are not clear. One way

to deal with this problem is to operationalize these objectives. In Bos & Hekhuis (1991) a blueprint of a system for operationalizing of objectives regarding forest functions in forest management is described. The following three types of elements and relationships between them form the basis of that system:
- objectives concerning functions;
- objectives concerning function criteria;
- objectives concerning forest characteristics.

Objectives concerning functions are often defined in an abstract manner, which makes them unsuitable for guiding forest operations. To make such objectives more concrete they have to be translated into objectives concerning function criteria. Function criteria are measurable entities, which express the extent to which functions in a particular forest are fulfilled. For eample, the timber production function can be expressed in m^3 of a certain quality that can be harvested per hectare per year. Most of the function criteria for other functions have not yet been defined. Objectives concerning function criteria have to be further operationalized being elaborated into objectives concerning forest characteristics. These characteristics are entities that are measurable and can also be changed by means of forest management and do have an impact on the functioning of the forest. Changeable means changeable within the planning horizon. If production periods are very long, intermediate forest characteristics can also be defined (e.g. a particular state in the succession that leads to the final desired state). Objectives concerning forest characteristics can be defined at different scales, from stand level to forest level.

The basic idea is that by determining or defining relationships between functions and function criteria and determining relationships between function criteria and forest characteristics, the objectives relating to the functions a forest has to fulfil can be translated into objectives concerning desired forest characteristics. In this way, abstract functions can be translated into measurable targets (desired forest characteristics) and alternative plans can be evaluated. Knowledge about relationships between forest structure and composition and the suitability of a forest for fulfilling a certain function is necessary not only in valuation, but is also very helpful in generating alternative management plans. The more knowledge about these relationships is available, the more the process of generating alternatives can change from a trial and error process into a process in which good alternatives will be identified in a straightforward manner.

However, as long quantified relationships between forest characteristics and the functioning of the forest remain unknown, the operationalization of abstract objectives concerning forest functions into clear targets concerning measurable forest characteristics (as described above) has to be based on the decisions the decision maker makes in his mind.

Goods and services are often nonmarketable

Decision making in forest management means comparing alternative plans. In traditional economic theory alternatives can be compared because plan effects are valued by means of a price system (Delft & Nijkamp, 1977). In forestry, however, direct pricing of plan effects is not always possible, because not all the goods and services of a forest are marketable (Duer *et al.*, 1979). This makes it very difficult to value goods and products in order to make decisions about which goods and services to produce in what amount. Moreover, it is almost impossible to assess the level of demand for the various goods and services of the forest (Bowes & Krutilla, 1989). The consequences of this imperfect insight into values and demands are considerable. Because trees grow slowly, the effects of management activities are long-lived. Consequently, there is a need tȯ determine the demands and relative values for resource services many years into the future - an almost insurmountable task (Bowes & Krutilla, 1989).

Forest values originate in the interaction of society with the physical environmental system of which forests form a part (Kennedy, 1985). Forest value is therefore not an intrinsic quality of the forest (Pearce & Turner, 1990), but is also related to the characteristics of the valuing subject (Bergstrom & Cordell, 1991: use value depends among other things on characteristics of the user population) and on the relationships of this subject to the forest. The value attached to a certain forest can therefore differ from person to person. The decision maker is a very important person in a planning process. This is the person who chooses the plan to be implemented from all the identified alternative plans. In most cases the decision maker is the forest owner or a person who is authorized to decide on behalf of the forest owner (Davis & Johnson, 1987). Forest owners are those who hold the property rights of the forest and are responsible for that forest. They can have different interests in forests (Brabänder, 1991). Therefore, different owners can value particular effects of a management plan in different ways: the utility derived from the forest by a certain owner can differ from the utility derived from a similar forest by another owner. Therefore, if market prices are not available, the value system and the economic objectives of the forest owner are likely to govern the manager's decisions on forests (Gregory, 1987).

Natural processes

Natural processes play an important role in forest management. In fact, forest management means conditioning and controlling natural processes in order to achieve certain objectives (Cleiren, 1992). Natural processes complicate decision making, because there is an inherent uncertainty attached to natural processes (Bowes & Krutilla, 1989). This kind of uncertainty will always remain in forest management, because in many cases the objective is not to gain optimal controll over natural processes, but to allow natural processes more or less go their way.

The working of natural processes is not yet completely understood. For example, not all the relationships between plants and animals are known. On the other hand, some relationships that are considered stochastic could turn out to be deterministic if all the factors involved were known. The result of this lack of knowledge is that decision making in forest management has to deal with risk and uncertainty.

Natural processes are affected by changes in external factors such as climate, environmental pollution etc. This means not only that the course of the process is uncertain, but also that the process can be only partly controlled. The decision space is thus restricted by ecological constraints. This is all the more so because if a forest has to be sustained, the ecological laws, which enables it to exist, have to be obeyed.

Length of production period

Trees and forests change slowly (Gregory, 1972). Forestry therefore is a long-term activity. Decisions taken today will influence the forest for decades ahead and it is unwise to respond to what may be a temporary change in circumstances without considering what the long-term effect of the response may be (Johnston *et al.*, 1967). Furthermore, projecting the outcome of forest management actions becomes difficult as time horizons become larger (Bowes & Krutilla, 1989). The production period in timber management is so long that the analytical techniques and decision-making processes must take time itself as a variable (Gregory, 1987).

As already stated, not only the future consequences of management activities have to be assessed, but also the future value of and demand for forest goods and services. According to Bowes & Krutilla (1989) this is an almost insurmountable task.

Objectives can change over time. The longer the time period, the more likely it is that objectives will change. One way to react to this is to formulate vague plans, which, however, do not clearly direct management (Maessen, 1985). Although the planning horizon is immensely long, and although the effects are not completely foreseeable, clear plans must nonetheless be made. The problem of the long planning horizons in forest management boils down to the problem of planning the future, knowing that the future can not completely be known (uncertainty). Forest management planning therefore has to balance between flexibility and continuity (Johnston *et al.*, 1967). The plans have to be flexible enough to react to changes in circumstances, but also have to bring continuity in management. In this context, Johnston *et al.* (1967) state that the more fundamental objectives should not be changed until a new situation is judged to be stable but, on the other hand, when a new situation has been recognized, the revised objectives should be stated clearly and unequivocally.

Trees are product, stock and production factor

Another complicating aspect is the fact that trees are simultaneously product, stock and production factor. Most goods and services of the forest depend upon the characteristics of the land and its stock of standing timber (Bowes & Krutilla, 1989). In timber production, trees are both the product which is harvested and the "factory" that has produced that product (Gregory, 1987). Until they are harvested, they are (a growing) stock of timber. Trees play more than one role in the forest. This applies not only to timber production, but also to recreation and nature conservation. Trees are the most important element of the visual image a recreationist gets of the forest. In addition, trees create the habitat needed by a variety of animals and plants and provide environmental benefits.

The current characteristics of a forest are difficult to change without cutting trees. By felling, the long-term development of the forest is also affected and, with it, the future production of goods and services is influenced in a complex manner for many years. The manager must therefore anticipate the effect of his current decision on the potential future flow of products and services. Under these conditions there can be no meaningful separation of the decision about current product mix from the long-run decision on the holding of capital stock in timber (Bowes & Krutilla, 1989).

However, on the other hand, the fact that trees are simultaneously product, stock and production factor means that there is a great flexibility in the time of harvesting (Gregory, 1987). The fact that trees are important for more functions is also the reason for the joint production processes in which the goods and services of the forest are produced. The consequence of this is that in most cases management activities implemented to make the forest more suitable to fulfil a particular function also affects the suitability of the forest for another function. In this context, harvesting trees in the context of timber management means eliminating the production factors in the context of nature development.

The scale of the planning problem

The factors mentioned so far determine the complexity of the planning problem. These factors also complicate that problem because they determine its scale. A large number of variables have to be considered in forest management planning. Davis & Johnson (1987) estimated the maximum number of different variables in a planning model as:

$$NR = ST \times AS \times PR \times TP$$

in which:

NR	number of variables to keep track of
ST	number of stand types
AS	average number of stands per stand type

PR number of prescriptions per stand type
TP number of time periods

The scale of the problem makes it expensive to assess the information needed. Remember that not only the characterictics of the forest have to be assessed, but also the consequences per period per prescription per stand type have to be estimated. These consequences depend on the actual situation of the forest in combination with the site potentials. When this is related to the fact that per plot of land a substantial number of management actions or combinations of such actions can be formulated, the scale of the problem becomes clear.

A forest is complex not only in the sense that there are relationships between now and the future, but also because of spatial relationships (LNV, 1992). Also, the relationship between society and the forest ecosystem has a spatial element and is related not only to the characteristics of the forest at one spot, but also to the characteristics of the forest as a whole. Management actions in one unit will potentially alter the use and value of other areas of the forest in a manner that can be troublesome to estimate (Bowes & Krutilla, 1989). The problem of dealing with these kinds of relationships increases concomitantly with the number of variables.

Davis & Johnson (1987) stress therefore that decisions about the number of land characteristics to use in creating stand types, the degree to which individual stands will be identified, and the number of prescriptions to be used are very important forest management decisions. They affect the entire management planning enterprise: the kinds of inventory and mapping to do, the computer hardware and software to buy, the character and effectiveness of planning models, and ultimately, the quality of forest management decisions.

Risk and uncertainty

Risk is the possible variation in effects which one can describe in terms of probabilities. Uncertainty is possible variation in effects which one cannot describe in terms of probabilities, because one does not know the probability distribution (OECD, 1986). Risk is considered as a restricted form of uncertainty. Risk and uncertainty have to do with limited knowledge, insights and predictability.

Uncertainty is the result of the other complicating factors. The production process is uncertain because of the natural processes in combination with the length of the production periods. On the other hand demand is uncertain. In combination with the fact that not only insight in present demand, but also insight in future demand is needed to make decisions in forest management, it becomes clear that forest management means decision making in the absence of perfect information.

In the remainder of this text no distinction will be made between risk and uncertainty.

2.6. Decisions in forest management

In this chapter forest management has been defined as the set of human actions aiming at the adjustment of the forest ecosystem and society to each other in order to achieve a sustainable fulfilment of needs of society. The object of forest management is the relationship between society and forest ecosystem.

The central question in this section is which kinds of decisions have to be made to achieve the adjustment of society and forest ecosystems. The key to answering this question lies in the fact that the relationship between society and forest ecosystem becomes an object of planning if a society consciously starts to use the forest to satisfy its needs. The most important decisions to be made in forest management are therefore land use decisions. The following kinds of decisions are found in forest management (see also FAO, 1984):

- decisions on the kind of land use;
- decisions on the land use objectives (for the land allocated to forest);
- decisions on the desired future forest (forest land utilization types);
- decisions on transition management[1];
- decisions on the execution of management activities.

Decisions on the kind of land use

Decisions concerning the kind of land use to choose deal with the choice between forestry and other kinds of land use. These kinds of decisions can include the conversion of other land uses to forestry, but also the conversion of forestry to other land uses (FAO, 1984). These kinds of decisions do not explicitly belong to forest management, but the outcome is very important for forest management, because it determines whether further forest management decisions are needed. If it is decided that the land will be used for forestry, then the reasoning behind this decision forms the ultimate justification of forest management activities on that land. The functions the forest has to fulfil are related to the reasons for allocating this land to forestry. This choice is determined not only by the needs of society, but also by the qualities of the land and the location of the land (i.e. functions of contiguous areas of land). All these aspects influence decision making in strategic planning in forest management, as we will see in the next chapter. Thus, although decisions concerning the kind of land use are not part of forest management, they are closely related.

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[1]Transition management is the management during a transition period aiming at the achievement of the desired future forest.

Decisions on the land use objectives

Decisions on the land use objectives for the land allocated to forestry deal with the relative importance that has to be attached to the different uses of the forest (FAO, 1984). The central question in this kind of decisions is which mix of functions and level of fulfilment per function maximizes the satisfaction of needs by society (including the forest owner). Deciding on the mix of functions the forest has to fulfil means deciding on land use objectives. To be able to determine the consequences of choosing a particular land use objective, these objectives have to be operationalized into land utilization types. The description of a land utilization type includes the inputs needed and the goods and services produced.

Decisions on the desired future forest

Decisions about the kind of forest management to choose deal with choosing the methods of forest management needed to realize the goods and services expected within the kind of forest use chosen, given the land that is under forest use (FAO, 1984). The forest management needed to realize the goods and services expected can be divided into the management needed to achieve a forest that produces the goods and services, and the management needed to sustain this desired future forest. This means that decisions are needed on the desired future forest. These are decisions on the forest land utilization types: which land will be allocated to which forest land utilization types.

Decisions on transition management

Land use planning is intended not only to indicate what is possible in the future in regard to land and its use (potential), but also what should be done to go from the present situation to the future one (Fresco *et al.*, 1990). Therefore, decisions are not only needed on the desired future forest, but also on how this desired future forest will be achieved. This means that the current forest has to be transformed into the desired future forest. The decisions on how to achieve the desired future forest are therefore called decisions on transition management.

Decisions on the execution of management activities

As well as decisions on objectives and means (see above), decisions also have to be made about the execution of the management activities decided on. These kinds of decisions include decisions about the priority of activities and related scheduling of activities in time, and decisions on who will do which activity where.

Bearing in mind the basis of the operationalization of objectives, the following relation-

ships can be identified:
- objectives concerning functions are translated into objectives concerning criteria;
- objectives concerning criteria are translated into objectives concerning characteristics;
- objectives concerning characteristics are realized by management activities;
- management activities can only be carried out if means are available.

The kinds of decisions described above each concentrate on a part of this chain (see Table 2.1)

Table 2.1 Kinds of decisions and their focus

	objectives concerning				
	functions	criteria	characteristics	activities	means
kind of land use	x				
land use objectives	x	x			
future desired forest		x	x		
transition management			x	x	
execution of activities				x	x

2.7. The effects of basic concepts and complicating factors on decisions in forest management

The decisions described above are marred in several ways by the basic concepts and complicating factors described earlier in this chapter. The influences are interrelated and complex, as will be explained below.

The concept of sustainability complicates decision making, because not only the future effects of decisions have to be assessed, but also differences in these effects from period to period. It has been shown that sustainability complicates forest management because it leads to additional decisions (object, scale and time of sustention). In addition to this, multiple use complicates decision making, because information about the trade-off between the fulfilment of different functions and relative value of functions is needed to be able to make a choice among alternatives. Furthermore as I have demonstrated above, in order to deal with problems related to multiple use insight is needed in input-output relationships, trade-off relationships and preferential relationships. Because this insight is not always available, multiple use complicates decision making in forest management in many ways. These are discussed below.

One of the difficulties of taking multiple use into account when making forest management decisions is the fact that some goods and services are intangible and hence the unit of product is difficult to define. The effect is that input-output relationships are difficult to assess. In turn, this makes it difficult to assess the relationship between society and the forest ecosystem and the factors which influence this relationship. In other words, the fulfilment of functions cannot be measured. This problem can be ameliorated to some extent by operationalzing functions into desired characteristics (via criteria).

Decision making means choosing the best alternative identified. This is done by valueing the consequences of the alternatives. The fact that certain goods and services are nonmarketable, complicates the valuation and therefore the decision making, because it is difficult to value the consequences of the alternatives. The value system of the owner will therefore often guide the management decisions. Furthermore, the fact that natural processes play an important role in forests complicates decision making. Natural processes complicate decision making because there is an inherent uncertainty attached to these processes. In decision making in forest management one therefore has to deal with risk and uncertainty.

The length of production periods also complicates decision making, in different ways. This length complicates decision making because not only the short-term consequences of management activities and current demand for and valuation of goods and services from the forest but also the long term consequences and future demand for and value of forest goods and services have to be taken into account: an almost impossible task. Furthermore, the length of production periods complicates decision making in the sense that needs and demands of society change faster than the forest can change. This means that the forester is aiming at a forest suitable to fulfil needs and demands of a future generation, although these needs and demands are difficult to assess and change more rapidly than the forest can change. An example of this is that fifty years ago timber was needed for pit props in the Netherlands. Forests planted and managed in that time to produce timber for mining are ready to clearcut now, but pit props are no longer needed, because all the mines in the Netherlands have been shut down.

The fact that trees are simultaneously product, stock and production factor complicates decision making and leads to complex relationships between functions, between functions and forest characteristics, and between characteristics of forest. Joint production means not only that the production of one good or services influences the production of another good or service, but also that the production of a certain good or service at a certain moment influences the feasibility of producing that same good or service on another moment. Therefore, decisions about present functioning of the forest cannot be seen in isolation from decisions on the future functioning of the forest.

Finally, scale and uncertainty are complicating factors. The scale of the planning problem complicates decision making because vast numbers of variables and relationships have to be taken into account in decision making in forest management. Uncertainty complicates decision making because decisions have to be made on the basis of imperfect and incomplete information.

2.8. The need for planning

In this chapter it has become clear that forest management includes a complex decision making process. The complexity is caused by the basic concepts of forest management *and other characteristics related to the object of forest management (the adjustment of* forest ecosystem and society). Decision making in forest management requires a large amount of information and involves dealing with all kinds of relationships between decisions. It is therefore better to incorporate decisions in forest management into a planning system[2], instead of making such decisions ad hoc.

As already mentioned in the introduction (chapter one) and as became clear in this chapter, planning is more than assigning means to objectives; it also involves searching for objectives. This calls for strategic planning in forest management, because strategic planning deals with decisions about objectives. In chapter three strategic planning in forest management is addressed. In that chapter it will become clear how the basic concepts of forest management and the complicating factors can be dealt with in planning in forest management.

[2]A planning system is an organized set of planning processes. A planning process can be seen as an interrelated set of (thinking) activities in which insight is gained, decisions are made and actions are undertaken (see further chapter three).

3. STRATEGIC PLANNING IN FOREST MANAGEMENT

3.1. Introduction

The developments in society and the forest mentioned in chapter one have resulted in the planning of objectives becoming important in forest management. In this chapter the role of strategic planning in forest management and the decisions to be made in strategic planning are described. This description covers a broad area, because the results of this study are intended to be useful for a broad range of ownership categories. However, the issue of strategic planning in forest management is hardly dealt with in literature, even though this type of planning is crucial in forest management. Therefore, in the literature study carried out to identify this broadly accepted description of decision problems[3] in strategic planning in forest management, no such description could be found. Neither could a clear definition of what strategic planning means in forest management be found. This lack of a generally agreed definition of strategic planning in forest management and of a description of decision problems in strategic planning in forest management complicated this study, because without such a description there is a risk of developing models that provide good solutions, but to the wrong problems. Therefore, in this chapter the following questions are central:

- What is strategic planning in forest management?
- What kinds of decision problems have to be solved in strategic planning in forest management?

Given the lack of literature on strategic planning in forest management, I decided to develop my own definition of the process, beginning from the general principles underlying planning in general.

[3]A decision problem is a formal mathematical description of a decision that has to be made.

3.2. Planning in general

3.2.1. General aspects of planning

Although everybody plans, there is no universally accepted definition of planning. Faludi, an eminent planning theorist, states that there are no rules saying what planning is. The meaning of terms is ultimately a matter of agreement (Faludi, 1982). Table 3.1 shows that there are many definitions of planning. The fact that there are so many definitions does not, however, mean that there is little agreement on what planning is. The definition of planning seems to depend on what is considered to be the object of planning: what has to be planned. Planning embraces so many aspects that, by emphasizing a certain aspect, several definitions can be given that are not mutually contradictory, but which cannot be reduced to one definition without losing essential elements. Therefore, in this section, instead of opting for one rigid definition of planning, a description of the most important aspects of planning will be given.

Van Vught (1982), a Dutch planning theorist, has made an assessment of existing definitions of planning (see table 3.1). In examining these definitions he found that planning has three aspects: gaining insight, decision making and undertaking actions (Van Vught, 1982). Planning is a process in which insight is gained about the problem to be solved, the objectives to be reached, the criteria to be used in decision making, the alternatives available to solve the problem and the implications of alternatives. In this respect planning can be seen as a learning process (Van Doorn & Van Vught, 1978). Planning is also a process in which decisions are being made, minds are made up. Ultimately, planning is a process in which actions take place. These actions not only include gathering information and analysing it, but also the intervening in the course of things in the real world (executing the plan).

Faludi gives an example of a definition of planning in which the emphasis is on decision making. He defines planning as a process of responsible decision making about future courses of action (Faludi, 1982). Another way of defining planning is to emphasize gaining insight into the future and making designs for it. Kleefmann, an eminent Dutch planning theorist, does so, by defining planning as a thinking activity in which from definitions of the concrete present situation, images of the future situation are made (Kleefmann, 1984). The emphasis may also be on activities within planning. Thus, Van Doorn and Van Vught define planning as a process of analysis (of past and present), of anticipation (of the future), of design (of alternative programs), of actions (effectuation of the chosen programme) and of evaluation (judgement of the results of the planning process) (Van Doorn & Van Vught, 1978). This definition does not mean that planning is a straightforward process. In reality, all kinds of feedbacks occur between the different phases. The sequence in which these phases are passed through is logical, but not immutable (Van Doorn & Van Vught, 1978). In many cases planning can even be seen as a cyclic process: the evaluation can give rise to new analysis.

Table 3.1 Some definitions of planning

Planning is the application of scientific knowledge in order to solve the problems and achieve the goals of a social system (Alden & Morgan, 1974).

Planning is the process by which an actor selects a course of action for the attainment of its ends (Banfield, 1959).

Planning is to look ahead and try to foresee the consequences of actions and trends in events instead of taking a series of ad hoc, uncoordinated decisions (Brown & Steel, 1979).

Planning is the application of conscious and deliberate methods to capture the future for purpose of either altering the present to redirect the future, or changing the future to pressure the present (Burke, 1979).

Planning is a process of determining goals and designing means by which those goals may be achieved (Chadwick, 1971).

Planning is an attempt at rationally calculated action to achieve a goal (Dahl & Lindblom, 1953).

Planning is a process for determining appropriate future actions through a sequence of choices (Davidhoff & Reiner, 1962).

Planning is the process of preparing a set of decisions for action in the future, directed at achieving goals by preferable means (Dror, 1963. In: Faludi, 1973b).

Planning is the application of scientific method - however crude - to policy making (Faludi, 1973b).

Planning is a certain manner of arriving at decisions and action, the intention of which is to promote the social good (Friedmann, 1959).

Planning is the process by which a scientific and technical knowledge is joined to organized action (Friedmann, 1973).

Planning is to take thought to determine and action or a series of actions beforehand (Hall, 1970).

Planning is an action-producing activity which combines investigation, thought, design, communication and other components (Horowitz, 1978).

Planning is an intellectual process, the conscious determination of courses of action, the basing of decisions on purpose, facts and considered estimates (Koontz & O'Donnel. In: Ewing, 1964)

Planning is a type of social decision-making; planning is a type of social action (McDougall, 1973).

Planning is foresight deliberately applied to human affairs (Mannheim, 1940)

Planning is an organized effort to utilize social intelligence in the determination of nation policies (Merriam. In: Galloway, 1941).

Table 3.1 Some definitions of planning (continued)

Planning are the conscious attempts by a government of a country - usually with participation of other collective bodies - to coordinate public policies (Myral, 1960).

Planning is the foresight in formulating and implementing programs and policies (Hudson, 1979).

Planning is to act on some object for some purpose; planning is the definition of the purpose; planning is the design of actions (Ozbekhan, 1968).

Planning is the decisional activity in which the individual (or organization) makes broad decisions regarding the values to which he is going to direct the activities, the general methods he is going to use to attain these values, and the knowledge, skills and informations he will need to make particular decisions within the limits of the policy laid down and to carry out the decisions (Simon, 1976).

Planning is that process of making rational decisions about future goals and future courses of action which relies upon explicit tracings of the repercussions and the value implications associated with alternative courses of action and, in turn, requires explicit evaluation and choice among the alternative matching goal-action sets (Weber, 1963).

Based on Van Vught, 1982 (Only the English definitions are presented and some definitions have been added.

3.2.2. Approaches to planning

Perhaps even more important than the definition of planning are the ideas of how planning has to be carried out: approaches to planning. These ideas are based on conceptions about how decisions are made and ought to be made (Etzioni, 1967. In: Faludi, 1973a). Much has been written on how planning should be carried out. Faludi (1973b) describes six extreme approaches to planning:

- blueprint planning versus process planning;
- normative planning versus functional planning;
- rational-comprehensive planning versus disjoined-incremental planning.

In blueprint planning first a complete blueprint of the future situation to be achieved is made. This blueprint cannot be altered. The next step is to search for means to establish this blueprint. The opposite extreme is process planning, in which the programmes can, if necessary, be altered during implementation. The second contrast is between normative planning, in which the goals and the objectives of planning are decided on, and functional planning in which these goals and objectives are not questioned, but the means to realize them are decided on. Finally the third pair of extremes contrasts the rational-comprehensive approach with the disjoined-incremental approach. The former is based on rationality. A decision is rational, if it results from an evaluation of all alternatives in the light of all their consequences (Faludi, 1982). Thus, the rational-comprehensive planning approach is based on an exhaustive definition of the problem to be solved (Faludi, 1973b) and results in comprehensive plans in which all aspects are covered. One criticism levelled at the rational-comprehensive approach is that it is too costly and too time consuming. The basis of the disjoined-incremental approach is to concentrate on the most urgent problems and solve them by comparing only a few promising alternatives in terms of their most important consequences. The objective of the disjoined-incremental approach is not to solve a problem, but to deal with it by a "neverending series of attacks" (Etzioni, 1967. In: Faludi, 1973a). The disjoined-incremental approach will result in an increasing number of partial plans for parts of the total problem. One of the criticisms of the disjoined-incremental approach is that it is unsuitable for large or fundamental decisions and that therefore it tends to lead to conservation of existing policies (Etzioni, 1967. In: Faludi, 1973a). For a more comprehensive description of the six planning approaches see Faludi (1973b).

In the event, none of these six planning approaches was adopted in this study, because all have shortcomings. Instead, it was decided to adopt a planning mode based on the mixed-scanning approach described by Etzioni (1967. In: Faludi, 1973a). The mixed-scanning approach is a combination of the rational-comprehensive approach and the disjoined-incremental approach and combines the advantages of both. In the following description of the mixed-scanning approach, Etzioni (1967. In: Faludi, 1973a) is closely followed.

The basis of the mixed-scanning approach is the differentation of fundamental decisions from incremental ones. "Fundamental decisions are made by exploring the main alternatives the actor sees in view of his conception of his goals, but - unlike what rationalism would indicate - details and specifications are omitted so that an overview is feasible. Incremental decisions are made, but within the contexts set by fundamental decisions (and fundamental reviews). Thus, each of the two elements of mixed-scanning helps to reduce the effects of the particular shortcomings of the other; incrementalism reduces the unrealistic aspects of rationalism by limiting the details required in fundamental decisions, and contextuating rationalism helps to overcome the conservative slant of incrementalism by exploring longer-run alternatives." (Etzioni, 1967. In: Faludi, 1973a). Therefore in a mixed-scanning approach there are at least two levels within the planning process: an encompassing level (so that no major option will be left uncovered) and a highly detailed level (so that the option selected can be explored as fully as possible).

3.2.3. Levels in planning

One strategy for dealing with complex planning problems is to simplify them by considering them as a hierarchical multilayer decision problem. This means breaking down the original problem into two or more interrelated subproblems, which form the multilayer decision problem. The relationships between the elements of a hierarchical multilayer decision problem consist of intervention from the hierarchically higher problem to the hierarchically lower problem and of performance feedback from the hierarchically lower problem to the hierarchically higher problem (Mesarovic *et al.*, 1970). In a planning context, intervention means that the solution to any problem in the sequence determines some of the parameters in subsequent problems, so that the latter are completely specified, and an attempt can be made at finding a solution. Information on the solution found is sent back to the hierarchically higher problem and this information confirms the solution at that level, or gives rise to a consideration of the current solution (see figure 3.1).

Although there is more than one way of dividing planning into levels, and the number of levels identified can vary, the following hierarchical levels are often identified (Davis & Olson, 1985):
- strategic planning;
- tactical planning;
- operational planning.

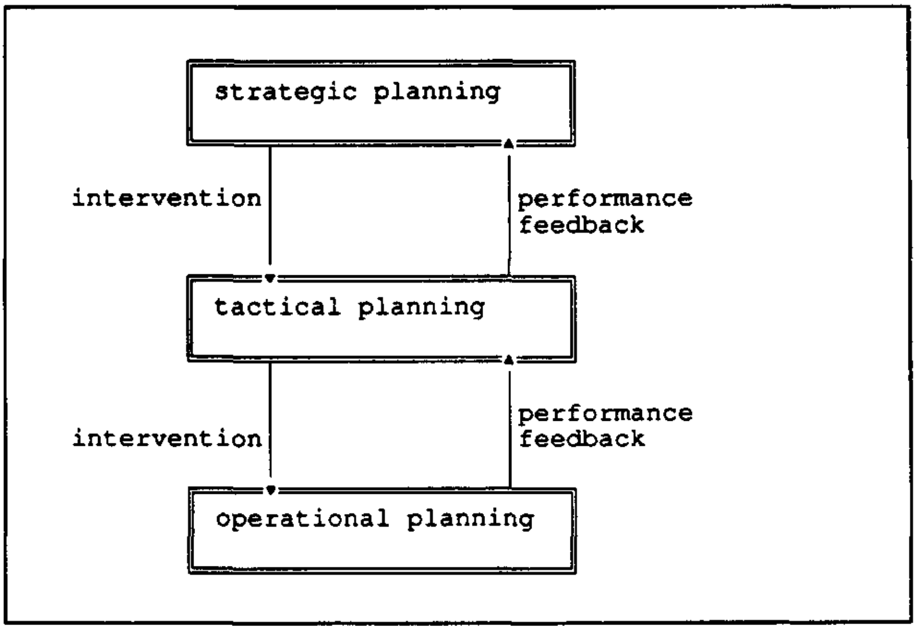

Figure 3.1 Planning as a multilayer decision problem

The point at which strategic planning becomes tactical planning and the point at which tactical planning becomes operational planning is arbitrary and varies depending on the situation. One of the most useful factors for distinguishing between the levels is the object of planning. The object of planning is that which has to be planned (PCRO, 1990). In strategic planning, the objects of planning are objectives: objectives have to be planned. In tactical planning the objects of planning are the means with which the objectives will be realized: the methods and related activities needed to achieve the strategic objectives have to be planned. In operational planning the objects of planning are activities: the execution of activities has to be planned. The difference in objects of planning does not mean that in strategic planning no attention is given to activities, or that in operational planning no attention is given to objectives, but that going from strategic planning, via tactical planning to operational planning, the emphasis shifts from intentions to activities.

Another distinguishing factor is the scale and the related level of abstraction. Sometimes, strategic planning, tactical planning and operational planning deal with the same object, but on a different scale and at a different level of abstraction. The relationship between strategic, tactical and operational planning , in this context, is one of stepwise refinement of decisions. In strategic planning, fundamental decisions are taken, based on an organization-wide analysis. The result is an organization-wide plan in headings. In tactical and operational planning these headings are elaborated into more detailed plans. Strategic planning is restricted to a high level of abstraction, because otherwise the process would become too costly and too time consuming. Tactical and operational planning can be carried out on a lower plane of abstraction, because only the alternative chosen in strategic planning has to be elaborated, and the consequences of decisions are more often restricted to parts of the organization. On the other hand, tactical and operational planning have to be carried out on a less abstract level, because the outcome will be used as a framework for the execution of activities.

The length of the planning horizon is the next distinguishing factor to consider. Strategic planning deals with fundamental decisions. These decisions include decisions about significant changes to the course of things. A significant change generally influences the course of development for a long time. If one takes into consideration that the longer the planning horizon, the more uncertainty has to be dealt with in the planning process, it is therefore logical to concentrate more on headings and main thrusts as the planning horizon lengthens. Even though the exact consequences may be uncertain, the main thrust of the consequences can usually be identified. The shorter the planning horizon, the more accurately consequences can be forecasted (Davidhoff & Reiner, 1962. In: Faludi, 1973a).

As can be seen from figure 3.2 the sequence and function of strategic, tactical and operational planning shows some analogy with the sequence of levels within the mixed-scanning approach of planning.

Mixed-scanning approach	Levels of planning
encompassing level (leaves no major option uncovered)	strategic planning
intermediate levels	tactical planning
very detailed level (explores selected option as fully as possible)	operational planning

Figure 3.2 Mixed-scanning approach and levels of planning

3.3. Strategic planning in general

In this section strategic planning is further elaborated within the context of the preceding section, by focusing on the definition of strategic planning, its nature and the need for it. Strategic planning is the decision making process in which the social function, the internal objectives and policy of an organization are decided on via a systematic assessment of the internal and external situation, developments and opportunities (Botter, 1981). Strategic planning is not restricted to deciding on the objectives of an organization, but also involves deciding on strategies (ways and means) with which the objectives will be realized (Keuning & Eppink, 1987). The nature of strategic planning can be characterized by the statements given in table 3.2.

Table 3.2 The nature of strategic planning

In strategic planning the objectives of an organization are variable. Strategic planning is a search for objectives. Objectives are the result of strategic planning (Irland, 1986; Botter, 1981; Keuning & Eppink, 1987).
Strategic planning deals with the (hierarchically) highest objectives of the organization. The more comprehensive a plan is, and the more direction it gives to other (planning) activities the more strategic that plan is (Irland, 1986; Blox et al, 1989).
Strategic planning focuses on the future of an organization (Irland, 1986).
Strategic planning is concerned with risk and uncertainty (Irland, 1986).
"Strategic planning incorporates decisions that have the potential to cause greater changes than others, including greater demands on resources, either directly by affecting major actions, or indirectly by triggering significant chain reactions among related activities. Thus, the concept of inter-relatedness between issues is a characteristic which, perhaps more than magnitude, can make decisions strategic" (Spencer, 1984).
Strategic planning deals with all parts of the organization ("Strategic planning is the process of deciding on objectives of the organization, on changes in these objectives, on the resources used to attain these objectives, and on the policies that are to govern the acquisition, use and disposition of these resources.") (Anthony, 1965)
"Strategic planning, as the term is used here, is a process having to do with the formulation of longe-range, strategic plans and policies that determine or change the character or direction of the organization" (Anthony, 1965)
Strategic planning is abstract in relation to tactical and operational planning. It means that the object of planning can be the same, but the more strategic the planning, the less the detail in which statements are expressed.
The strategic plan is the key document which gives guidance and elaborates resources among the major activities of the firm (Ansoff, 1965).
It should be noted that no type of decision is inherently strategic; decisions are strategic only in context. The introduction of a new product is a major event for a brewery, but hardly worth mentioning in a toy company (Mintzberg, 1979).

As noted in table 3.2 strategic planning incorporates decisions that have the potential to cause greater changes than others, including greater demands on resources, either directly by affecting major actions, or indirectly by triggering significant chain reactions among related activities (Spencer, 1984). These decisions are called strategic decisions. In every organization strategic decisions have to be made in the best possible way, because they determine or change the character or direction of the organization (Anthony, 1965).

In the management of organizations Keuning & Eppink (1987) distinguish two parts: external adjustment and internal adjustment. Strategic planning is very important in both. External adjustment means that the organization is adjusted to its environment. In short, this boils down to the fact that the organization has to supply society with products that society needs. Internal adjustment means that activities within the organization have to be coordinated and carried out in such a way that objectives are achieved. This means that objectives are transformed into operational targets via several steps of sub-objectives (means-ends[4] relationships). Strategic planning forms the first link in this chain, because in strategic planning the hierarchically highest objectives are formulated. In this context strategic planning is needed to give direction to tactical planning, which gives direction to operational planning, which manages the execution of activities in an organization.

The need for strategic planning has been pointed out by Van Soest *et al.* (1988) who stated that organizations which do not allocate time to reflect on the future, because they are too busy with daily problems, will ultimately be faced with the problem of no longer being capable of reacting adequately to new events and developments. Decisions taken to solve the present crisis erode away future options slowly, but irrevocably.

Strategic planning is a part of strategic management (Ansoff & Hayes, 1976). Strategic management could be described as managing the strategies of the firm (Van der Lee *et al.*, 1987). Zuurbier *et al.* (1991) define the objects of strategic management as: mission, goals, strategies, capacities and conditions. This is applicable to all strategic decisions about all elements and processes of a firm, such as the organization of the firm, financial policies, personnel policies. The research described in this thesis was restricted to the planning of forest management (objectives, methods and activities). Relationships with other areas of planning and management within the firm were recognized, but not explicitly included. For further readings on strategic management in forest managing firms see Sekot (1991). The strategic plan generated in strategic planning in forest management is a management plan and as such forms a part of the firm's business plan.

[4] Means-ends relationship between two objectives means that the achievement of one objective is a prerequisite for achieving the other objective.

3.4. Planning in forest management

Planning in forest management is needed to deal with the factors complicating decision making described in chapter two. Planning enables responsible decisions to be made in this very complex field of relationships. In this sense, planning is taken as deciding on the basis of rationality instead of deciding on the basis of intuition. Making decisions intuitively has the advantage of being very cheap in terms of time and means needed to come to a decision (Van Doorn & Van Vught, 1978), but the disadvantage is that the resulting decisions are not necessarily the best. Only these decisions made on the basis of a comprehensive analysis (all aspects of the problem are identified and all the consequences of all possible alternative solutions are considered in the decision process) are sure to be the best. A comprehensive analysis, however, is too costly in the case of forest management. Therefore a compromise between intuition and rationality has to be found. Decisions made on the basis of a restricted analysis have the advantage that some insight is gained in the decision situation (Van Doorn & Van Vught, 1978). In decision making by intuition this insight is not gained, but insight gained in past analyses is used. The following subsection addresses the question of how planning in forest management deals with the complexity of the planning object described in chapter two. Here, planning means decision making on the basis of a restricted analysis. In addition, this section is mainly restricted to procedural aspects of planning.

3.4.1. Complexity of planning in forest management

The various ways in which planning in forest management can deal with the factors complicating decision making described in chapter two are enumerated below.

The fact that many of the goods and services a forest produces are difficult to quantify can be dealt with by operationalizing objectives about functions into targets about the forest characteristics that have to be achieved. The consequence for planning is that decisions about forest functions are made at higher levels and that at lower levels these have to be elaborated into decisions about which criteria should be met and which forest characteristics should be achieved.

Because market prices are not available for all the goods and services a forest produces, the value system and the economic objectives of the forest owner are likely to govern the manager's decisions on forests (Gregory, 1987). However, the forest owner's value system is not always clearly stated. The repercussion for planning is that the identification of alternatives and their consequences plays a role not only when seeking solutions for the decision problem, but also when clarifying the forest owner's value system. By comparing alternatives and their consequences the forest owner may clarify certain parts of his value system.

The importance of natural processes in forest management is manifested in two ways in planning. The first is that planning has to deal with risk and uncertainty. This is elaborated later on (in the section on uncertainty). The second is that the natural processes constrain the solutions available.

The fact that trees are simultaneously product, stock and production factor means that in planning the effect of a current decision on the potential future flow of products and services has to be anticipated. Under these conditions there can be no meaningful separation of the decisions on current product mix from the long-run decisions about the holding of capital stock in timber (Bowes & Krutilla, 1989: see chapter two). These relationships can only be dealt with if instruments are available to assess the effect of management activities over time: forest development simulation models. If these instruments are available, planning in forest management has to have clear feedback relationships between planning processes, because (as will be shown later) the effect of hierarchically higher decisions becomes clear in hierarchically lower decisions.

The scale of the planning problem refers to the number of variables and relationships to be dealt with in planning. The problem to solve in forest management planning is so large that it is unlikely that the problem can be solved in one step. Planning deals with this problem by differentiating of the original problem into a set of sub-problems.

The length of the forestry production period influences planning in forest management in two ways. First, it requires long planning horizons. This makes the problem to be solved in planning so large, that it is unrealistic to expect it can be solved in one step. Without differentiation, the management activities per year would have to be planned simultaneously, for example for the first hundred years. This kind of problem can best be tackled by breaking down the original problem into a set of sub-problems, at different hierarchical levels. On the highest level, the planning horizon is long, but decisions are restricted to headings only (objectives). On the lower levels, planning horizons are shorter and decisions go into greater detail (the means to realize objectives). In this way each level refines the decisions made on the overlying level.

The second way in which the length of the production period influences planning in forest management is by the uncertainty about future events, which increases the further into the future they are expected to happen. Speidel (1972) identifies two ways to deal with uncertainty:
- a rolling planning system;
- flexible plans.

The introduction of a rolling planning system means preparing a plan with a certain planning horizon, say 50 years, and revising it every decade. In the case of more interrelated plans, for example a strategic plan, a tactical plan and an operational plan, the time between revisions may differ per planning level (see figure 3.3). The time period between two revisions must be chosen carefully. If it is taken too short, the costs will rise more than the value of the increase in effectivity. If it is too long, the plan's effectiveness will decrease, because the developments in the real world will deviate more and more from the developments assumed when preparing the plan.

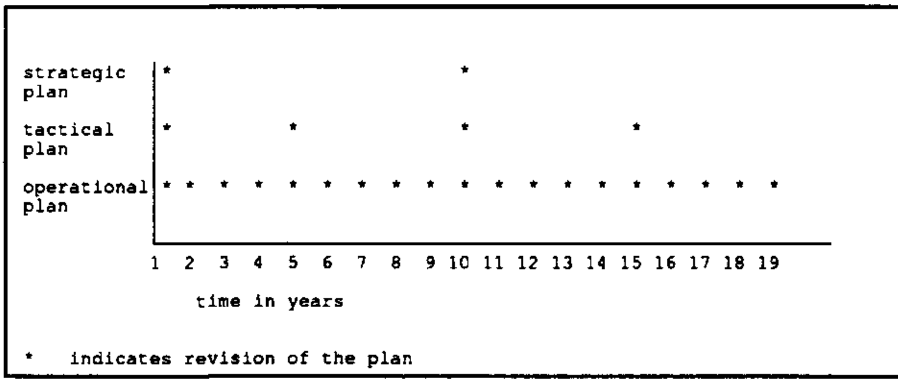

Figure 3.3 A rolling planning system

The other option for dealing with uncertainty is to make flexible plans. A plan is flexible if (Speidel, 1972):

- the hierarchically highest objectives that have to be realized at the end of the planning horizon are firm;
- the planning horizon can be divided into smaller parts for which interim sub-objectives can be formulated;
- the interim sub-objectives can be altered during the planning horizon;
- the management activities needed to realize the objectives are formulated in outline, but not in detail.

The resulting overall plan is very flexible. It can be modified to accommodate changes in the situation, without having to be totally revamped. The best way to deal with uncertainty is to combine both techniques: a rolling planning system with flexible plans.

Speidel also identifies a third way to deal with uncertainty: incorporating statements in the plan about how to react if a certain future event occurs (Speidel, 1972). I think that this principle would lead to an inefficient planning process. Because decisions in forest management are related to other decisions (about objectives and activities on other locations or in other periods), a reaction to a particular future event means designing a new alternative. The number of alternatives to be designed increases exponentially with the length of the planning horizon.

Combining a rolling planning system with flexible plans to deal with uncertainty also largely solves the problem of how to deal with the length of the production periods (uncertainty is related to the length of the production periods). In this way vague plans -

the hazard of a long planning horizon (Maessen, 1985) - can be avoided. The balance between flexibility and continuity, which is needed to deal with the long planning horizon (Johnston *et al.*, 1967) can also be found in this way. The problem of planning the future, while knowing that the future can never completely be known (see chapter two) remains, however. The abovementioned ways to deal with uncertainty and the length of production periods only partly deal with this problem. Nevertheless, they are the best option, because the other option would be a restriction to short term planning. The latter would result in a form of disjoined incremental planning, with all the related shortcomings.

One of the characteristics of planning described by Van Doorn and Van Vught (1978) summarizes the aspects of planning mentioned above: planning is a process in which flexibility and fixation go hand in hand. Planning is not a stepwise short-term policy and neither it is a fixed and unchangeable set of decisions from the outset.

3.4.2. Strategic, tactical and operational planning in forest management

Analogous to the levels in planning described in section 3.2.3, planning in forest management can be divided into strategic planning, tactical planning and operational planning (see also Hinssen, 1991). These differ in accordance with the general differences in:

- object of planning (objectives, methods and activities);
- stepwise refinement of decisions (other levels of scale and detail);
- planning horizon.

The identified levels of planning also differ because they tackle different planning problems or the same problems, but at a different level of detail. The decisions described in chapter two can be distributed among the three levels of planning as follows (see figure 3.4):

strategic planning:
1. decisions about the kind of land use
2. decisions about the land use objectives (for the land designated for forest)
3. decisions about the desired future forest (forest land utilization type)
4. decisions about management activities (including transition management)

tactical planning:
3. decisions about the desired future forest (forest land utilization type)
4. decisions about management activities
5. decisions about the execution of management activities

operational planning:
4. decisions about management activities
5. decisions about the execution of management activities

This distribution of decision problems among the levels of planning is based on a hierarchy between decisions. This hierarchy is based on means-ends relationships between the decisions. The highest decisions are dealt with in strategic planning. The lowest decisions are dealt with in operational planning.

In some cases decisions are allocated to more than one level of planning. This is done for reasons of efficiency as will be explained below. Consider a planning system consisting of five levels of planning. On the first level of planning, decisions are taken about the kind of land use. After this planning process has ended, the results are passed on to the second planning process, in which decisions are made about the land use objectives for the land allocated to forest. After this planning process has ended the results are passed on to the third planning process. This process of solving the problem and passing the solution on to the next level of planning continues until all the decisions have been made. However, this planning system will be inefficient, because the implications of hierarchically higher decisions often become clear in hierarchically lower decisions. For example, the costs of allocating land to forest become crystal clear in decisions on management activities. If the costs are unacceptably high, then hierarchically higher decisions have to be altered. In a complex decision problem such as forest management, there may be many feedback loops in the planning system considered. In the most ideal planning system decisions would be made in one pass (only one feedback: decisions are optimal). However, no such system exists (yet) for forest management. The second best system is one in which there is a minimal number of feedbacks that lead to an alteration in decisions. One way of reducing the number of feedbacks is by anticipating, i.e. by anticipating the consequences of decisions on hierarchically lower decisions. In the planning system described in this section this is taken on board by outlining decisions at a certain level of planning and elaborating them at a hierarchically lower level of planning.

Let us examine the decisions per level and the relationships between the levels. Figure 3.4 serves as a summary and guideline in this explanation.

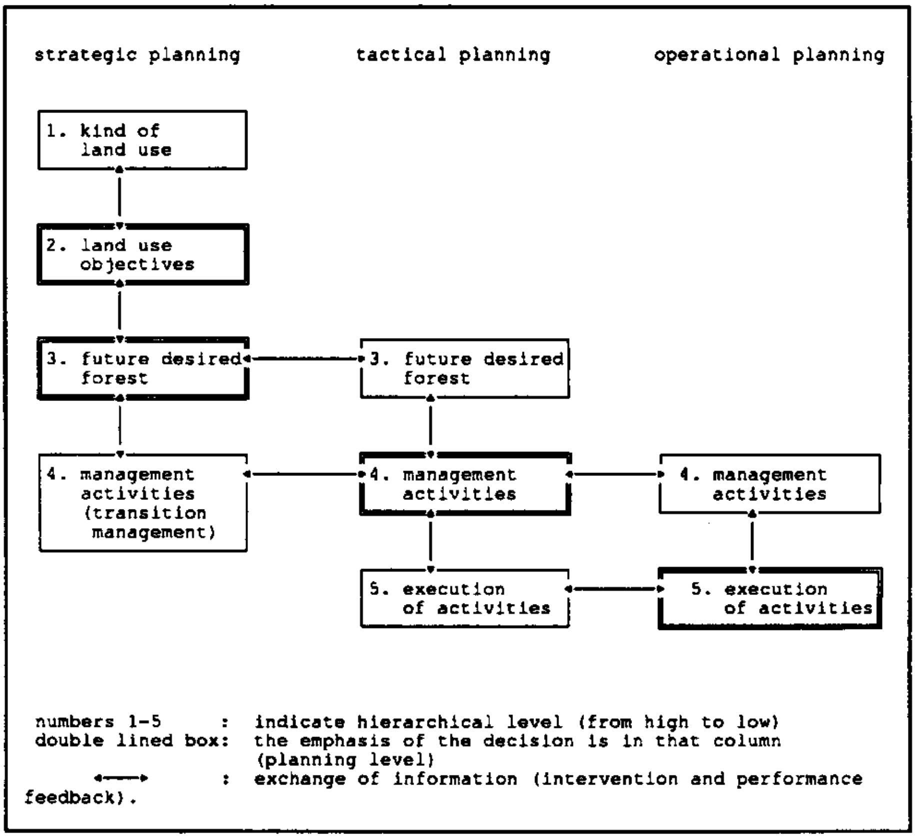

Figure 3.4 Relationships between strategic, tactical and operational planning

Strategic planning

Decisions on the kind of land use are not dealt with in strategic planning in forest management, but are assumed to be given. If it is decided to allocate land to land utilization types that include some kind of forest, strategic planning in forest management can start. Thus, although the decisions about the kind of land use do not belong to the set of forest management decisions, they form the starting point for the most fundamental decisions in forest management. The reason forestry has been opted for provides the framework for all subsequent decisions in forest management and also justifies those decisions (see also section 2.6). In this context, decisions on the kind of land use are related to decisions on the raison d'être of the firm: what business are we in?

Strategic planning deals with three types of decisions

1. decisions on the land use objectives for the land allocated to forest. This means deciding on the external adjustment of the organization (which basic values or what kinds of products should be realized and for whom). The way in which this decision process is carried out is related to the vision on multiple use (see section 2.4). In the Netherlands, decisions on land use objectives are elaborated into zoning decisions. This involves dividing the forest into zones and assigning land use objectives to each zone.

2. decisions on the desired future forest. The latter is a description of the future forest in terms of forest land utilization types. In this sense it is an operationalization of the land use objectives decided on. Statements on the desired future forest are needed so that a choice can be made between alternative management activities. The activity that achieves the desired future forest most effectively and efficiently is valued highest from this point of view. In this way, decisions about the desired future forest play a role in the internal adjustment of the organization (see section 3.3). The decision about the desired future forest is further elaborated in tactical planning. The difference between strategic and tactical planning at this point is that in strategic planning only the main points are given. The planning horizon for achieving the desired future forest is very long (several decades). In tactical planning these points are elaborated into more concrete objectives, which can be achieved within a shorter planning horizon.

3. decisions on management activities. If the characteristics of the desired future forest do not match the characteristics of the current forest, then the current forest has to be transformed into the desired future forest: this calls for transition management. Strategic planning deals with decisions about which parts of the forest have to be transformed from the current forest type into the desired future forest within a certain planning period. These kinds of decisions can be addressed as transition management decisions. Transition management decisions form the framework for tactical planning, which focuses on the elaboration of these decisions for the first decade and the planning of management activities needed for the parts of the forest that are not to be transformed to the future desired forest, but must be maintained in this decade.

Relationships between strategic planning and tactical planning

"Strategic decisions are made from considerations of major alternative courses of action, which usually can only be specified at a low level of detail to make an overview possible. These larger or "greater" strategic decisions are distinguished from more detailed and limited tactical decisions. Tactical decisions are taken with the benefit of more detailed specification of alternatives, but they can only be considered incrementally within the context of established strategic decisions" (Spencer, 1984).

This description of tactical decisions does not address the essential difference between tactical and strategic planning. Every planning level has this relationship with the next higher planning level. The essence of tactical planning in forest management is that it concentrates on decisions about the methods and related means (quantity and quality) needed to achieve the objectives decided on in strategic planning. Deciding on methods is not the same as the elaboration of objectives, although it can be a component of this elaboration.

Tactical planning deals not only with decisions about the management methods to achieve the strategic objectives, but also with decisions about how the capacity (quantitatively and qualitatively) needed to apply these methods can be generated in due time. In this study the focus is on decisions about the methods with which the strategic objectives will be realized.

In the ideal situation no decisions are made about objectives, unless the consequences are known and considered to be acceptable. These consequences are related to the methods and means for achieving these objectives. This implies that no decision can be justified in strategic planning before scrutinizing the possible effects of this decision on the tactical level (intervention and performance feedback). This, however, would lead to a very inefficient planning system, because for every alternative identified in strategic planning a complete tactical planning process has to be started to identify the consequences of this alternative. One way to bypass this problem is to incorporate tactical decisions and their consequences in strategic choices. This can be done by identifying which tactical decisions would be taken in principle if a certain decision is made in strategic planning. The next step is to aggregate these tactical decisions and their consequences to some high-level parameter and to incorporate this parameter as a consequence of a decision in strategic planning (anticipating). In this way, it is possible to meet Armson's criterion that setting objectives, no matter how great the consensus, presupposes that effective strategies - and the means to attain them - are available and credible (Armson, 1990).

Tactical planning

Tactical planning deals with decisions about the desired future forest. In strategic planning the desired future forest has been decided on in outline i.e. a certain number of hectares allocated to a certain forest land utilization type. In decisions on the management activities which form part of tactical planning, the location of the hectares allocated to a certain forest land utilization type is determined more precisely. This means that the desired future forest has to be determined on a less abstract level not for the whole forest, but only if the current forest has to be transformed into the desired future forest. Decisions about the desired future forest therefore form part of tactical planning. They are, however, more or less driven by decisions about management activities.

Tactical planning deals with decisions about management activities. First, it is determined more precisely which parts of the current forest have to be transformed into the future desired forest. Once these have been located, management activities have to be decided on for the remaining parts of the forest. Decisions have to be made not only about which management activities are needed in which part of the forest, but also about when they should be implemented. This scheduling of activities in time is often elaborated in assigning priorities to the most urgent activities. They have to be executed in the first period; activities with less priority are scheduled for a later period. In tactical planning all the management activities are coordinated and scheduled on a yearly basis.

On the one hand, the outcome of tactical planning is a performance feedback to strategic planning and on the other hand it is an intervention in operational planning. The performance feedback towards strategic planning can be a confirmation of the strategic choices or an incentive to reconsider (for example, because the costs are higher than was assumed in strategic planning). The intervention in operational planning is a clear formulation of the management activities that have to be executed.

Relationships between tactical planning and operational planning

In assigning priorities to management activities and scheduling management activities, tactical planning approaches operational planning. In fact, the relationship between tactical and operational planning is the same as between strategic and tactical planning. To be able to make decisions about scheduling activities in the first period, the consequences of these decisions for the operational planning must be understood. Therefore, in tactical planning, operational aspects of decisions are incorporated, but in aggregated form (anticipating).

Operational planning

Operational planning focuses on managing the execution of activities. The actual execution of the activity is planned. The planning horizon used in operational planning is short.

The management activities decided on in tactical planning are scheduled in time. In operational planning, the execution of activities scheduled first are planned. To make the execution possible, the required labour and the machinery must be present. The planning of this (logistics) is also an important item in operational planning. The last step is to estimate the budget needed to execute the planned activities. If the budget needed is within the constraints specified by the decision maker, then the plan can be effectuated. If the budget exceeds these constraints, then additional finance has to be found or the plan has to be altered.

In strategic planning the emphasis is on planning objectives; in tactical planning emphasis is on planning the methods to achieve the objectives; in operational planning the emphasis is on planning the actual execution of interventions in the forest. In strategic and tactical planning, planning is a learning process. In operational planning, planning is activity-orientated. The relatively short planning horizon, in combination with the activity-oriented character of operational planning means that the character of operational planning differs from strategic and tactical planning. In strategic planning the objective-seeking character prevails; in tactical planning the means-allocating character (effectiveness) of planning prevails; and in operational planning the search for efficiency prevails (see also introduction chapter 1). Only a planning system which integrates all three types of planning will result in responsible decisions that are mutually consistent (Hinssen, 1991)

The planning processes described above, constitute the basis of a planning system for forest management planning. This planning system forms the context of decision making in strategic planning in forest management.

3.5. Decisions in strategic planning in forest management

3.5.1. Decisions in the context of land evaluation

The decision problems of strategic planning form the basis of the planning instruments this study sought. Therefore, at this point these problems need to be clearly described. They fall under three main headings:

- zoning (decisions about land use objectives);
- desired future forest (decisions about desired future forest);
- transition management (decisions about management activities).

In order to fully understand the relationships between these problems, it is necessary to understand the procedure of Land Evaluation. A comprehensive description of Land Evaluation in forestry can be found in Laban (1981) and in FAO (1984). A short outline is given here. In a Land Evaluation procedure the needs (demands of society) are translated into land use objectives which, in turn, are translated into Land Utilization Types (LUTs). An LUT is a description of a specific type of land use that is able to meet the desired land use objectives (Andel *et al.*, 1981). The description of an LUT specifies the inputs required (including management activities, labour, capital and knowledge) and outputs produced (including forest structure and composition). The requirements of an LUT in terms of land qualities are called Land Use Requirements (LURs) and can be seen as a special form of input.

To be able to determine the suitability of the land for the identified LUTs and to deal with differences in land, the land must be divided into Land Mapping Units (LMUs), based on land characteristics (including existing (forest) ecosystems) considered important in determining suitabilities. Land qualities (LQs) are determined for each LMU. The next step is to match the Land Qualities of Land Mapping Units with the Land Use Requirements of Land Utilization Types. This step leads to a land suitability classification in which the suitability for each LUT is determined per LMU. The Land Evaluation Procedure is presented graphically in Figure 3.5.

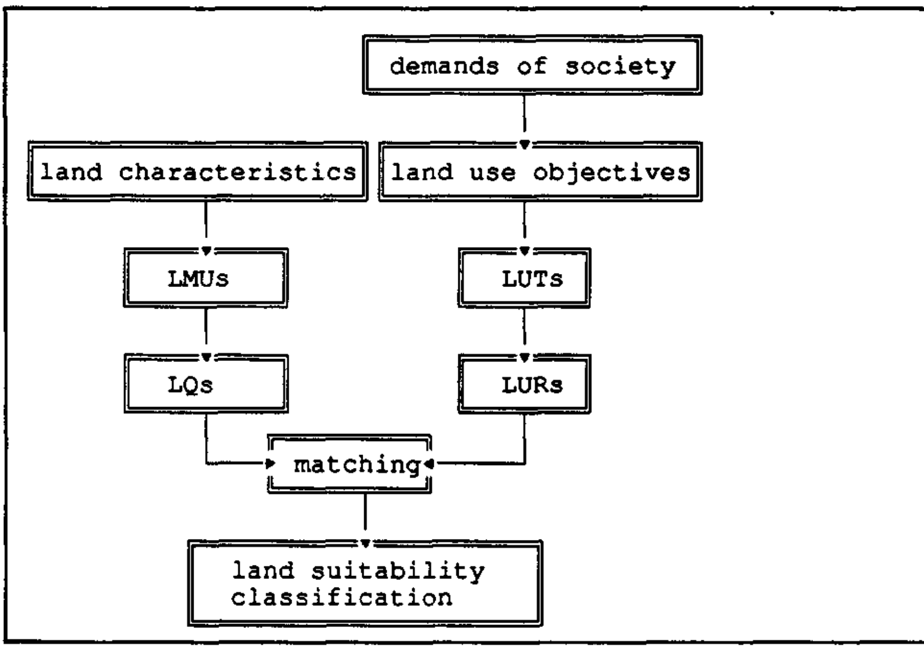

Figure 3.5 Land evaluation

A Land Evaluation procedure does not determine future land use. It merely provides data as a basis on which land use decisions can be taken (RINM, 1984). In forestry, land use decisions are taken in strategic planning. As already stated, the complexity of these decisions can be dealt with by defining strategic planning as a family of interrelated decision problems.

In zoning (the first decision problem) forest land is divided into zones and land use objectives are assigned to these zones. Zoning makes it possible to deal with the incompatibility of certain forest uses by spatially segregating these uses (see section

2.4.2). Furthermore, zoning also copes with differences in Land Qualities by taking such differences into consideration when assigning land use objectives to a certain location within the forest. Because land use objectives can be achieved with several Land Utilization Types, the land's suitability for a particular land use objective can be obtained by aggregating the suitabilities for LUTs that would achieve these land use objectives. Zoning results in a zoning map, showing the division of the forest into zones and, per zone, the specific land use objectives for which the forest will be managed. This solution is elaborated in the decision problem about the desired future forest (the second decision problem). This decision problem involves assigning land within a zone to LUTs belonging to the group of LUTs with which the land use objectives of the zone can be achieved. Finally, in the decision problem about transition management (the third decision problem) forest land is assigned to transition management in such a way that the desired future forest is achieved most effectively and efficiently. The transition management aims to transform the current forest into the desired future forest.

In the remainder of this section the three decision problems, zoning, desired future forest and transition management are elaborated. In appendix A these decisions are illustrated by means of a numerical example.

3.5.2. Zoning

Zoning concerns the planning of territorial structures by designating areal units for specific purposes (Walther, 1986). In forest management, zoning does not always mean prohibiting particular forest uses within certain zones; it refers to differences in functions to be fulfilled and hence to differences in management goals for different parts of the forest (see Haas *et al.*, 1987). The most important advantages of zoning are:

- Zoning makes it possible to give clear, specific and effective management directions (Haas *et al.*, 1987).
- Zoning makes it possible to reduce land use conflicts, because a territorial order is established (Walther, 1986).
- Zoning is a way of communication with the public (Haas *et al.*, 1986). It is easy to make clear what management is aiming for at a particular spot in terms of the forest's functions and why.

However, zoning does have some drawbacks. Walther (1986) gives a useful overview. A few criticisms are highlighted below because they are important in this study.

- First, zoning is based on the assumption that environmental problems can be defined in a spatial context, adjusted to the level of abstraction of the scale of mapping. This is arguable, because some problems need more detailed information and decisions than others. Furthermore, not every environmental problem can be defined in a well-specified spatial context; for example, pollution problems such as the damage to the ozone layer are worldwide.

* Second, zoning requires completeness in forest land classification. This means that all forest land must be classified. However, the number of classes has to be restricted and this often leads to generalization, which can conflict with the special circumstances of unique situations.
* Third, the forest is already being used. When zoning, one has to answer the question "should zoning sanction or correct the present forest use situation?". This problem cannot only be defined physically and technically (carrying capacity etc.), it also has to be defined in a social context (social acceptance of decisions).

The kernel of zoning decisions is dividing the forest into zones and assigning land use objectives to each zone. It cannot be decided to take a particular area as a separate zone in which management is directed towards the fulfilment of a certain function or mix of functions until the effect of this decision for the forest as a whole has been considered. This holds for every area and every function. When making these decisions in a sequential (and separate) order, the optimal decisions are almost sure to be overlooked, because there are so many possible solutions to the problem. Therefore, all the decisions have to be taken in one step. The problem is related to what Brown (1976) describes in the planning of management decisions for the 'Thomas Creek' management area (USA):

> "Any management decisions for Thomas Creek should consider the effect on adjacent areas and reflect general forest management direction. Ideally, all other areas in the working circle would be analyzed similarly, and the analysis could then be combined, in light of political, environmental, and other constraints, to arrive at an overall plan. Actual management decisions would not be made until all areas were examined and all relationships considered. Practically, however, this is both too cumbersome and time consuming. Decisions must be made today. While the forest manager must have the overall picture in mind, he is usually forced to make specific decisions about individual areas without knowledge of all forestwide relationships."

In zoning, only the land use objectives are decided on and not the way in which they have to be realized. The achievement of the land use objectives is planned when deciding about the desired future forest and about the transition management. Zoning deals explicitly with the spatial aspects of the assignment of land use objectives and provides a broad, aggregated, solution for the subsequent decision problems. As Brown's quotation (see above) clearly shows, this is a complex problem.

3.5.3. Desired future forest

There are two phases in deciding about the desired future forest. The first is to elaborate land use objectives per zone into the forest characteristics desired for that zone. The second is to assign forest land within a zone to Land Utilization Types in such a way that the land use objectives of that zone (represented by desired forest characteristics) are met. In fact, land use objectives have already been elaborated into desired forest characteristics. These characteristics are used as a reference (land use requirements) in the zoning procedure, to assess the forest's suitability for the land use objectives: a comparison of the potential of the forest land with the desired forest characteristics reveals the suitability of the forest land for land utilization types.
When deciding on the desired future forest this reference is used again, but it now becomes an objective. It no longer contains information needed to assess the suitability of the forest for a certain land use objective, but from now on contains information needed to guide decisions on forest management. Statements about the desired forest characteristics form the basis for constraints to and valuations of alternative future forests. In this way, land use objectives per zone are elaborated into constraints to desired forest characteristics for that zone. The decision variable in the desired future forest decision problem is the amount of forest land within a zone assigned to a certain Land Utilization Type. The decisions must enable the land use objectives of that zone to be met, which means that the constraints relating to desired forest characteristics have to be satisfied. Each Land Utilization Type is specified by inputs needed and outputs produced. Forest land is specified by zone and the growing conditions within a zone. The assignment has to fulfil all kinds of constraints (political, financial, social, economic and functional). The solution to this decision problem is the specification of hectares (specified by zone and growing conditions within that zone) that are allocated to a certain LUT. This information is passed on to the decisions on transition management.

It usually takes decades to achieve the future desired forest. But, as already described, the strategic plan will be reconsidered long before the planning horizon is reached (say every decade), in order to deal with uncertainty. This may lead to modifications to the description of the desired future forest. Therefore, the future desired forest should be seen as a beacon, which shows the direction in which to sail. Because the effects of interventions in the forest ecosystem are so long term, the beacon has to be placed far ahead. Hence the beacon itself will never be reached, but will be repositioned from time to time. However, the beacon is essential, to ensure the necessary continuity in management.

3.5.4. Transition management

There is no point in describing the desired future forest if it cannot be demonstrated that this forest can be achieved, how it can be achieved and what costs are incurred and revenue is earned by achieving this forest. Or as Kleefmann (1984) put it; the future planned situation remains an island, surrounded by ideals, without connections to the mainland if it is not made clear how it can be realized from the current situation. It is this aspect that the third decision problem - the transformation of current forest and management into desired forest and management - deals with. Here, the decision variable is the amount of forest land managed according to a certain transition management. The forest land is specified by zone, growing condition within a zone, and current state of the forest. The transition management specifies how current forest and management will be transformed into the desired forest and management. To do this, a timetable is drawn up, showing the necessary actions and their repercussions. The constraints surrounding this decision making also have a temporal dimension (production smoothing constraints, financial constraints, managerial constraints etc. in each period). The outcome of this decision problem is a statement that the solution to the desired future forest decision problem is feasible. The outcome also contains management directions for tactical planning.

Speidel (1972) recognizes two forms of transition management of forests. In the first form (Überführung) the current stand is sustained but managed in a different way. In the second form (Umwandlung) the current stand is clearcut and replaced by a new stand. In the present study, both forms were included and no difference was made. The difference will become obvious when identifying possible transition management strategies.

Transition management strategies can be divided into four main strategies (see table 3.3).

Table 3.3 Main strategies in transition management

	Characteristics of desired future forest and of current forest are the same	Characteristics of desired future forest and of current forest are dissimilar
land use objectives and current land use objectives are the same	no change	change forest
land use objectives and current land use objectives are dissimilar	change use	change use and forest

(loosely based on Ansoff, 1965)

The first category deals with situations in which the land use objective decided on is the same as the current land use objective and the characteristics of the current forest are the same as those of the desired future forest. In such situations the strategy can be described as "maintain the current forest". The second category deals with situations in which the land use objective decided on is the same as the current land use objective, but the characteristics of the current forest are dissimilar to those of the desired future forest. The strategy in this kind of situations can be described as "transform the current forest into the desired future forest". In the third category the land use objective decided on is dissimilar to the current land use objective, but the characteristics of the current and desired future forest are the same. Here, the strategy can be described as "change the way in which the forest is used, but maintain the current forest". Finally, the fourth category deals with situations in which neither the current and future land use objectives nor the current and future forest are the same. The strategy here is "transform the current forest into the desired future forest". The way in which the forest is used also has to change. The challenge here is that the forest enterprise will probably be unfamiliar with the new way in which the forest has to be used and probably also the way in which the forest has to be managed in order to provide the targeted values (new product on new market).

In this study, no distinction was made between the above four categories. They were all addressed as transition management. If the characteristics of the current forest are the same as those of the desired future forest, then the transition management must transform the current forest into the desired future forest by continuing current management.

3.6. Implications for modelling

What are the implications of the issues discussed in this chapter? Clearly, solving the decision problems described involves having to handle numerous variables and their interrelationships and processing vast amounts of data. This makes the generation of alternatives and their consequences in strategic planning in forest management difficult and very time consuming. However, effectiveness and efficiency in generating alternatives and their consequences can be increased if strategic planning is supported by quantitative decision models implemented on a computer.

4. QUANTITATIVE MODELS FOR STRATEGIC PLANNING: LITERATURE REVIEW

4.1. Introduction

In the preceding chapter it became clear that the three categories of decision problem in strategic planning (on zoning, desired future forest and transition management) cannot be correctly solved without quantitative models. These models must fulfil various requirements, depending on the decision problem. Thus, for *zoning*:
- they have to deal with spatial interrelationships between decisions;
- decisions to divide the forest into zones and decisions about land use objectives per zone have to be made simultaneously.

However, models intended to support decisions about the *desired future forest*:
- have to deal with the allocation of forest land to forest land utilization types;
- have to be able to show the consequences of these allocations.

And finally, models intended to support decisions about *transition management*:
- have to deal with the allocation of forest land to transition managements;
- have to be able to show the consequences of these allocations in time.

Ideally, these quantitative models should be capable of dealing with more than one of the decision problems or, even better, with all decision problems simultaneously. This is because when solving decision problems in a sequential way there is a risk that suboptimal solutions to the overall problem may be obtained, because not all the aspects related to the overall problem can be taken into consideration when solving one of the decision problems.

Before developing and implementing models to support the decisions in strategic planning, the literature on existing decision support models for strategic planning in forest management was examined to identify which parts and aspects of decision problems identified in the preceding chapter are adequately dealt with by existing models and which are not. The findings reported in this chapter therefore give an overview of the suitability of the existing models for handling the decision problems of strategic planning in forest management. Furthermore, useful ideas and elements from other models which can be used in developing models for strategic planning in forest management in the Netherlands are presented. Models dealing with forest management must cope with the fundamental concepts and characteristics underlying current forest management (see chapter two). The two main concepts are sustainability and multiple use. The characteristics special to forest management are:
- many of the goods and services a forest produces are difficult to quantify;
- goods and services are often nonmarketable, which makes valuation difficult;
- natural processes play an important role in forests;
- the production period is long;

- trees are simultaneously product, stock and productionfactor.

Also important are the scale of the planning problem and the risk and uncertainty involved.

To assess the suitability of existing models, two questions were posed:
- To what extent do existing quantitative models developed for strategic planning in forest management deal with respectively zoning, the desired future forest and transition management?
- In what way do existing quantitative models developed for strategic planning in forest management deal with the basic concepts of forest management and the complicating factors in forest management described in chapter two?

In carrying out the literature study it became clear that there is a large body of literature on quantitative models developed for strategic planning in forest management. It is, however, beyond the scope of this research to give a fully documented mathematical description of all these models. Instead, this chapter will provide a global overview of the ways in which decision problems in strategic planning in forest management and the related aspects are dealt with in existing quantitative models. When describing models in this chapter the original notation is, if necessary, replaced by the notation used in the models developed in this study in order to ease comparison.

4.2. Basic model structures

In this section the ways in which forest land is represented in quantitative models for strategic planning and the ways in which multiple use is dealt with in such models are discussed. As will become clear, these two aspects determine the basic model structures.

The representation of forest land

One of the basic aspects of quantitative models for forest management is the representation of the forest land. That land is the scarce resource that has to be assigned to management-options in order to achieve objectives. The way in which it is represented in a model determines the options to deal with spatial considerations, as we will see later on.

Johnson and Scheurman (1977) pointed out that most forest management models can be reformulated into one of two basic model formulations which they addressed as model I and model II. These are both Linear Programming (LP) models, i.e. a special type of mathematical programming model in which all relationships are linear equalities or inequalities. The essence of the two formulations is clearly described by Gunn (1991) who is closely followed here. Model I consists of enumerating a number of possible management options for a given land unit. (In this context a management option is defined as a complete set of management activities over the entire planning horizon). The decision variables consist of assigning the land unit wholly or partially to the management option. Model II consists of specifying a network of options in which each arc corresponds to a particular treatment/harvest strategy only until the next regeneration process. The main difference between the models is the integrity of individual land units. In model I the forest is divided into land units and this division is not changed through time. The integrity of an individual land unit is retained throughout the planning horizon. In model II, individual land units do not exist throughout the entire planning horizon. Here, a particular land unit is considered to exist from the time the area is regenerated until it is harvested. In model II the integrity of an individual land unit is retained only during the lifetime of the stand which it bears.

These differences result in different definitions of an allocation option[1]. In model I, an allocation option refers to a complete set of management actions that will occur on a particular land unit over the entire planning horizon. In model II, an allocation option refers to a complete set of actions that will occur on a particular land unit from the time the land unit is regenerated until it is regeneration harvested, or until it is left as ending inventory[2] at the end of the planning horizon (Johnson & Scheurman, 1977).

Table 4.1 Model I and Model II summarized

Aspect	MODEL I	MODEL II
definition of management options	a complete set of management acitivities over the entire planning horizon	a complete set of management activities over the lifetime of a stand
definition of decision variables	whole or partial allocation of the land unit to a management option	whole or partial allocation of clearcut land to a management option
integrity of land units	the integrity of an individual land unit is retained throughout the planning horizon	the integrity of an individual land unit is retained only during the lifetime of the stand it bears

[1]An allocation option is an alternative. It can refer to functions, management actions etc.

[2]The ending inventory of a forest describes the conditions of the forest at the end of the planning horizon.

The model for generating alternatives, STAGES which this study set out to build has to focus on a broad range of forest ownership categories and therefore it has to be flexible. Flexibility is also required to cope with the increasing number of management options. In the Dutch context this means the ability to include both even-aged management options as well as uneven-aged ones. Let us therefore examine the opportunities model I and II offer to deal with uneven-aged management. The structure of model I is very clear: per land unit of the forest, allocation options are elaborated and included in the model. It makes no difference for the structure of the model if the allocation options are based on even-aged or on uneven-aged management. In the model II approach it is less easy to deal with uneven-aged management. Model II is typically based on even-aged management. The definition of land in the model II approach is based on the existence of regeneration harvest. In uneven-aged management, however, regeneration harvest does not occur. Therefore from this point of view model I is more suitable for the Dutch context than model II.

In the USA many models have been developed to support decision making in strategic planning in forest management. One of these is FORPLAN (Kent *et al.*, 1991). Alston & Iverson (1987) compared TimberRAM (*Timber Resource Allocation Model*), MUSYC (Multiple Use Sustained Yield Calculation), FORPLAN (FORest PLANning model) 1 and FORPLAN 2. They conclude that FORPLAN 2 can do everything the other three models can and more. This is not surprising, because FORPLAN 2 is an improved version of FORPLAN 1, which in turn is an improved version of MUSYC. TimberRAM is a model which deals only with the planning of timber production (Chapelle *et al.*, 1976) and is commonly seen as the forerunner of MUSYC and FORPLAN.

There is a considerable body of literature on FORPLAN, because the USDA (United States Department of Agriculture) Forest Service uses it in the preparation of National Forest Plans (strategic management plans) for National Forests. FORPLAN is more than a decision model; it is a decision support system that generates several kinds of models (including models I and II). In FORPLAN version 2, land can be represented in two ways (Johnson *et al.*, 1986). The first is to divide the forest into unique geographical areas, each composed of one contiguous, heterogeneous piece of land. This way of representing forest land is called the area-based approach. The second way is to divide the forest into "strata". A stratum is a category of land use, such as oak aged 40, that responds in the same way to management actions, wherever that land use occurs. A stratum can therefore be composed of discontinuous, homogeneous pieces of land. This way of representing forest land is called the strata-based approach. Models I and II can both be based on an area-based approach as well as on a strata-based approach.

In the area-based approach it is assumed that an area either will or will not be assigned to an allocation option (discrete decision variables). Examples of allocation options are the construction of a road, zoning decisions etc. The consequences of assigning an area to an allocation option therefore have to be formulated on an area wide basis. In the strata-based approach it is assumed that only a part of the stratum will be assigned to an allocation option (continuous decision variables). An example of an allocation option is a complete set of management actions that can occur over the entire planning horizon. The consequences of assigning land from a stratum to a particular allocation option therefore have to be formulated on a per hectare basis. One advantage of the area-based approach is that the location of the land assigned to a particular allocation option is known exactly and the allocation option is attuned to the circumstances within the area. This facilitates the development of programmes for implementing the decisions (Mitchell *et al.*, 1987). The disadvantage is that there are no efficient algorithms to solve the complex integer problems that result from this approach. Moreover, the building of models based on the area-based approach is time-consuming, because a substantial analysis is needed when building the model (Mitchell *et al.*, 1987). Another advantage of the strata-based approach is that the problem can be solved by standard routines and furthermore, the analysis needed when building the model is relatively restricted (Mitchell *et al.*, 1987). However, a disadvantage of the model is the poor spatial representation of the forest. Because the location of forest land is dealt with very poorly, a considerable amount of time is required to develop programs for implementation of the solutions to the model (Mitchell *et al.*, 1987). This makes for an uneasy relationship with tactical planning. There is an intermediate definition which overcomes some of the disadvantages of the traditional strata and area definitions. In this new definition a stratum is a contiguous piece of homogeneous land. This definition differs from the traditional definition of a stratum, because in the current definition the land has to be contiguous, while in the traditional definition a stratum was only a category. This definition also differs from the definition of areas, because an area is not homogeneous and in the area-approach it is assumed that an area either will or will not be assigned. The current definition of strata is based on the assumption that only a part of the strata will be assigned to a particular allocation option. The advantage is that the location is known more exactly and the problems related to the use of integer variables are overcome; however, model size increases with the number of strata.

How multiple use is dealt with

Land use objectives generally include using the forest to fulfil more than one function simultaneously. The question how to deal with multiple use can be seen as the question of how to deal with multiple objectives. There is far too much literature on how to deal with the problems of planning with multiple objectives to be reviewed fully here. Instead, let us focus on some basic structures for models for forest management planning. I will specify three ways in which multiple objectives can be represented in a mathematical programming model (see also Jenkins and Robson, 1974. In: Cocklin, 1989):

1. Combining objectives into a 'super goal' (combined approach);
2. Promoting one goal as being most important, incorporating the others as constraints (constraint approach);
3. Goal Programming.

1: the combined approach

The combined approach means that contributions to different objectives are all expressed in the same dimension (for example, monetary units or utility). The basic model form to this approach is given below.

$$\max \text{UTILITY} = \sum_{s=1}^{S} \sum_{m=1}^{M} \text{UTILITY}_{sm}\ Y_{sm} \tag{1}$$

such that

$$\sum_{m=1}^{M} Y_{sm} = HA_s \qquad 1 \leq s \leq S \tag{2}$$

[other linear constraints]

$$\text{UTILITY}_{sm} = f\{\text{CONTR}_{smn},\ 1 \leq n \leq N\} \qquad 1 \leq s \leq S;\ 1 \leq m \leq M \tag{3}$$

in which:

UTILITY_{sm}	the utility for the forest owner that is derived from assigning one hectare of stratum s to management option m. The utility is a function f of the contributions to the different objectives if one hectare of stratum s is assigned to management option m
CONTR_{smn}	the contribution to objective n if one hectare of stratum s is assigned to management option m
Y_{sm}	decision variable: the number of hectares from stratum s assigned to management option m
HA_s	total number of hectares in stratum s
N	total number of objectives
S	total number of strata
M	total number of management objectives

The approach can be exemplified by considering a situation in which the decision maker has two objectives: timber production and recreation. CONTR_{sm1} is the number of m^3 timber harvested if one hectare of stratum s is assigned to management option m. CONTR_{sm2} is the number of visitor days realized if one hectare of stratum s is assigned to management option m (N=2). If one m^3 of timber is considered twice as valuable as one visitor day, then UTILITY_{sm} can be calculated. Relationship (3) then becomes:

$$\text{UTILITY}_{sm} = 2\ \text{CONTR}_{sm1} + \text{CONTR}_{sm2} \qquad 1 \leq s \leq S;\ 1 \leq m \leq M \tag{4}$$

The advantage of this approach is that linear trade-off relationships between objectives can be included in the model. A disadvantage is that instruments to conduct the realization of a particular objective are lacking. The other approaches, as we will see, provide better opportunities to conduct the realization of a particular objective.

2. the constrained approach

The constrained approach means that contributions to different objectives are expressed in different dimensions. In this approach, multiple objective problems are dealt with by eliminating all objects from the object function except one and including these objectives in the set of constraints (Rustagi, 1976). The basic model form for this approach is given below. It is assumed that the most important objective is numbered 1 (n=1).

$$\max \text{UTILITY} = \sum_{s=1}^{S} \sum_{m=1}^{M} \text{CONTR}_{sm1}\, Y_{sm} \tag{5}$$

such that

$$\sum_{s=1}^{S} \sum_{m=1}^{M} \text{CONTR}_{smn}\, Y_{sm} \geq \text{TARGET}_n \qquad 2 \leq n \leq N \tag{6}$$

$$\sum_{m=1}^{M} Y_{sm} = \text{HA}_s \qquad 1 \leq s \leq S \tag{7}$$

[other linear constraints]

in which:

TARGET_n Target for objective n

Other symbols as defined earlier.

The approach can be exemplified by considering the same situation as described for the combined approach. The decision maker wants at least 2000 visitor days and wants the m^3 of timber harvested to be maximized. Constraint set (6) for (N=2) becomes:

$$\sum_{s=1}^{S} \sum_{m=1}^{M} \text{CONTR}_{sm2}\, Y_{sm} \geq 2000 \tag{8}$$

There are two differences between this model and the basic model of the combined approach: At first, extra constraints are needed to ensure that for all objectives a minimum level is achieved. Secondly, only one objective is optimized in the objective function (the utility is a function of the contribution to that objective resulting from assigning one hectare of stratum s to management option m). The advantage of this approach is that the achievement of objectives can be controlled by changing the right hand side of the constraint in which the minimal target for the objective is set. This way ensures that a minimum required level of achievement per objective is always guaranteed. A disadvantage is that the objectives that are constrained all have the same priority (they all have to be achieved) in relation to the objective which has to be optimized.

3. Goal Programming

Goal programming[3] can be seen as a special form of the constrained approach. The model of Arp and Lavigne (1982) is an example of Goal Programming. This model is described in the section about the zoning problem (see section 4.4). In Goal Programming the priority problem is overcome, but other problems are introduced; targets in combination with weights given to deviations from targets determine priority. Thus, if weights are changed, the outcome of the model will change. If targets are changed, the outcome of the model will also change. Goal Programming can lead to inferior solutions, because perhaps one of the targets could be set higher and also be achieved without influencing the achievement of other targets (Dijkstra, 1984).

Parametric linear programming is another method that can be used in multiobjective programming. It is based on the systematic loosening of constraints (here, constrained objectives). Dijkstra (1984) demonstrates it for forest management. Parametric linear programming can be seen as a systematic sensitivity analysis and is intended to identify trade-offs.

From this overview, it is clear that the basic structure of decision models for strategic planning in the Dutch context had to be based on the model I approach. Within this model I approach, forest land should be represented by strata in the sense that a stratum is one contiguous piece of homogeneous land. This definition is the most flexible of the definitions described. The final aspect addressed in this section was how multiple use should be dealt with. In this study land use objectives were operationalized into objectives about forest characteristics. To achieve the land use objectives a certain number of units of forest characteristics have to be realized. This can best be done by means of constraints, and hence it was decided to use the constrained approach to deal with multiple use.

[3] For more information on Goal Programming see Winston (1991).

4.3. General aspects relating to modelling for decision-making in strategic planning in forest management

The general aspects dealt with in this section are not related to one particular decision, but are important for all decision problems. They are: sustainability; uncertainty; scale of the problem; problems of quantification.

Sustainability

Sustainability in decision models for strategic planning can have one of two basic connotations (Hof, 1993):
- sustainability of the conditions of the forest ecosystem;
- sustainability of the flow of any particular product or net benefit from the forest.

Speidel (1972) defines these approaches as static sustention (sustention of conditions) and dynamic sustention (sustention of efforts). Static sustention is often elaborated into ending inventory constraints[4]. An example of this can be found in Nautiyal and Pearse (1967). They developed a linear programming model which determines the optimal conversion of an irregular current forest into a future 'normal' forest. Forest land is defined by age class. The decision variables in the model are the number of hectares harvested in year t (t=1,..,T) of stands of age s. The objective of the model is to maximize the present worth of expected stumpage during a conversion period of T years, at the end of which the forest will consist of an even gradiation of age classes. Thus in the year T + 1, there will be N age classes, each occupying A/N hectares, where N is the rotation age under sustained yield and A is the total number of hectares within the forest. The model deals solely with timber production under even-aged management and does not give any answer to the question how to ensure sustainable fulfilment of the other functions of the forest.

Dynamic sustention is often elaborated into regulation constraints: constraints that regulate the flow of products. Those commonly known and used are even flow constraints, which restrict fluctuations (reduction or increase) in yields between consecutive periods (Dijkstra, 1984). Even flow constraints can be put on timber yields, or on any other yield related to other uses. Even flow constraints can also be elaborated into nondeclining yield constraints. This means that yield in period t has to be equal to or exceed the yield in period t-1 (Johnson & Stuart, 1987). Even-flow or regulation constraints are intended to do the same thing as ending inventory constraints. According to Dijkstra (1984) including both in one model will easily lead to infeasible problems.

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[4] Ending inventory constraints are constraints to the final conditions of the forest at the end of the planning horizon.

Dynamic sustention can also be elaborated into the MAXMIN approach (Hof, 1993). In that approach the minimum harvest for any time period is maximized. Eriksson (1983) applies a MAXMIN approach for assuring economic sustention. He maximizes the minimum net revenue for any time period.

Hof (1993) states that the MAXMIN approach can be applied to any measure of forest output or condition. The same holds for static sustention approaches. The dynamic sustention approaches do, however, have the advantage that the development of the forest outputs and conditions in time can be controlled more closely than can be done with ending inventory constraints. The latter merely determines the result at a certain moment in time (end of planning horizon), but does not indicate how this result should be achieved.

Risk and Uncertainty

Risk and uncertainty are related to the length of the production period and to the natural processes. The production process can be uncertain (related to natural biological and abiotic processes) and so can the appraisal of products (related to dynamic processes in society). One way to deal with uncertainty would be to use stochastic dynamic programming. However, there are no efficient algorithms to solve large scale stochastic dynamic programming problems (due to the so called 'curse of dimensionality'). Hof (1993) suggests ways of dealing with uncertainty in quantitative models in strategic planning in forest management, but these ideas are elaborated into nonlinear programming models for which there are also no efficient algorithms to enable them to be applied to large problems. Linear Programming models do not explicitly account for uncertainty. Gunn (1991) enumerates implicit ways in which uncertainty can be addressed in Linear Programming models:

- set discount rates higher than nominal interest rates;
- downgrade growth estimates;
- use the model in a rolling horizon planning framework (see also figure 3.3. in chapter three).

A recent paper on Fuzzy Programming (Mendoza, Bare & Zhou, 1993) presents some interesting ideas on how to deal with uncertainty. The approach described is complex, and cannot be elaborated here. However, it appears that further research is needed to identify how the Fuzzy Programming described by Mendoza, Bare & Zhou (1993) can be applied in a context with many variables and constraints.

The scale of the problem

Planning problems in forest management are very complex and possess a scale which can easily lead to intractible models. If forest land is defined in such a way that all spatial considerations (such as location and relationships with other pieces of land) are dealt with, and if all possible management options are included in the model, and if all possible effects are incorporated in the object function and/or in the set of constraints, then the problem would be so large that even if the time and costs of data collection were acceptable, it could not be solved because of hardware and software restrictions. On the other hand, if the problem is aggregated too much, the aggregated problem will be solvable, but the implementation of the solutions would be difficult. The exact level of aggregation will differ from case to case.

Weintraub and Cholaky (1991) dealt with the scale of the planning problem by adapting a hierarchical approach to forest planning. They developed two models. The first model they called the strategic model and the second the tactical model. The strategic model is an aggregation of the tactical model. In the strategic model decisions are taken, and these are elaborated in the tactical model. In this way the strategic model can be kept a moderate size. The strategic model is a typical mixed area-based strata-based model. The strata in this model are aggregations of the strata in the tactical model. In the strategic model the main decisions focus on land allocation and aggregate targets for inputs and outputs. At the tactical level each zone is modelled separately and in detail, using as exogenous data the strategic requirements: land allocation and aggregate levels for inputs and outputs. Because a segregated model is built for every zone, these tactical models can also be kept a moderate size. The decisions at this level refer to: detailed management of areas or management units, road building and hauling.

Problems of quantification

Another important aspect in addressing the problem of the desired future forest is how to deal with objectives that are difficult to quantify. Quantitative models (as the word indicates) can only deal with quantitative data. This means that qualitative data have to be represented quantitatively. Abstract qualitative objectives have to be operationalized into measurable quantitative objectives on a hierarchical lower level. Attempting to operationalize hard-to-quantify objectives by defining them by a set of quantitative variables brings a problem, namely how to relate the achievement of the original objective to the status of the variables (Cocklin, 1989). This problem can only partly be solved by basing this relationship on the judgment of the decision maker. Cocklin (1989) therefore concludes that certain planning criteria cannot be measured, and hence incorporating these criteria within an optimization framework would therefore seem to remain as a limitation that must be accepted. The result of this is twofold. Firstly, the solutions provided by optimization models are only optimal within the bounds imposed by the assumptions on which the model is based. This means that it is better to consider the solution provided by the model as a good alternative instead of as the best solution to the decision problem. Secondly, the qualitative consequences of the solution provided by the optimization model have to be worked out before the alternative can be judged. This means that the role of optimization models in decision making in strategic planning in forest management has to be restricted to generating alternatives and some of their consequences. Hence, their *main use is in gaining insight and not in decision making*. The quantification problem is not only restricted to the input-output relationships mentioned above, but also to the preferential relationships between different objectives, especially if one or more of the objectives is hard to quantify. Although this problem cannot be solved by the use of quantitative models, it will not be solved by eschewing quantitative models.

The preceding review of general aspects relating to modelling for decision-making in strategic planning in forest management leads to the following conclusions.

- *Sustainability* can be dealt with by means of ending inventory constraints and by means of regulation constraints. According to Dijkstra (1984) it is not wise to include both in one model, because this can easily lead to infeasible problems. On the other hand the combination of the both makes a powerful instrument to control developments in forest output and conditions. The MAXMIN approach is not preferred, because it assumes that the forest output or condition has to be maximized, which is not always true.
- According to Gunn (1991) the only way to deal with *risk and uncertainty* is by setting discount rates higher than nominal interest rates, down grading of growth estimates and usage of a rolling horizon framework. In addition, sensitivity analysis can be applied to ascertain how crucial the uncertainty of information is.
- The *scale of the problem* can hardly be dealt with and is related to the level of detail chosen in the model. The hierarchical approach chosen by Weintraub and Cholaky (1991) could in principle be applied in strategic planning, but has some shortcomings, the most important of which is that each zone is elaborated in a separate model. Strategic planning considers the whole enterprise whenever possible, and decisions are made in the light of the consequences of these decisions for the enterprise as a whole. The Weintraub and Cholaky approach does not allow this. However, their approach might be interesting for the relationship between strategic and tactical planning.
- Abstract qualitative objectives have to be operationalized into *measurable quantitative objectives* on a hierarchical lower level. If this is not possible, then alternatives generated by the model have to be assessed in terms of its contribution to the qualitative objectives that were not included.

4.4. The zoning problem

In this section attention is given to quantitative models which address the zoning problem. The first aspect considered is the way in which the mixed area-based strata-based approach of FORPLAN deals with the relationships between zoning decisions and management decisions and the second aspect is how the models deal with the spatial aspects of zoning decisions.

Zoning models

The mixed area-based strata-based approach of FORPLAN

The mixed area-based strata-based approach of FORPLAN is interesting for zoning, because FORPLAN enables the forest to be divided into zones (established outside the model) and enables alternative uses to be defined per zone. One alternative is then chosen (see Johnson and Stuart, 1987). The location of a zone and the amount of land in a zone are exogeneous variables in the model.

The description of the mixed area-based strata-based approach of FORPLAN given below is restricted to the essence of the model. For the original model description see Johnson and Stuart (1987). The way in which the zoning problem is dealt with in the mixed area-based strata-based approach of FORPLAN will be explained in two steps. The first step is restricted to the zoning problem. In the second step the relationships between zoning choices and management choices will be addressed.

First of all the forest is divided into zones z (z=1,...,Z). Then a set of feasible uses is formulated (u=1,...,U). Each zone can be assigned to each use. The objective of the zoning problem is to maximize the utility the forest owner derives from the forest. We assume that the utility can be expressed in net present value of the forest. The objective of the zoning problem is therefore to assign zones to uses in such a way that the resulting net present value of the forest (NPVUSE) is maximized. Let X_{zu} be a binary decision variable which is 1 if zone z is assigned to use u and is 0 if it is not. Let $NPVUSE_{zu}$ be the net present value of assigning zone z to use u. The net present value of the forest (NPVUSE) can now be expressed as:

$$NPVUSE = \sum_{z=1}^{Z} \sum_{u=1}^{U} NPVUSE_{zu} X_{zu} \qquad (9)$$

The problem to be solved can now be stated as:

$$\max NPVUSE = \sum_{z=1}^{Z} \sum_{u=1}^{U} NPVUSE_{zu} X_{zu} \qquad (10)$$

such that

$$\sum_{u=1}^{U} X_{zu} = 1 \qquad 1 \le z \le Z \tag{11}$$

[other linear constraints]

$$X_{zu} \text{ binary} \qquad 1 \le z \le Z; 1 \le u \le U \tag{12}$$

The zoning problem consists of dividing the forest into zones and simultaneously assigning these zones to land use objectives. In this FORPLAN model, however, the division of the forest into zones is not addressed. Furthermore, this model ignores the spatial interrelationships between decision variables.

The mixed area-based strata-based approach of FORPLAN addresses the relationships between zoning decisions and management decisions. The second step focuses on this relationship. In the mixed area-based strata-based approach the forest is divided into both zones and strata. A certain number of hectares of a stratum can be assigned to management options m if the zone in which stratum s lies is assigned to a particular use u. Let Y_{sm} be the number of hectares from stratum s assigned to management option m, and let HA_{zus} be the number of hectares from stratum s which have to be assigned to management options from subset $\mathbf{M}_{zus}$ ε {1,2,...,M} if zone z is assigned to use u. Subset $\mathbf{M}_{zus}$ consists of management options which are feasible (or preferred) on stratum s if zone z is assigned to use u. If, for example, use u means timber production, then subset $\mathbf{M}_{zus}$ consists of management options in which a considerable amount of timber is produced. The relationships between the zoning decisions and the management decisions can now be expressed as

$$\sum_{z=1}^{Z} \sum_{u=1}^{U} HA_{zus} X_{zu} = \sum_{m \in \mathbf{M}_{zus}} Y_{sm} \qquad 1 \le s \le S; \tag{13}$$

To identify the optimal management decisions the objective function of the original zoning model has to be extended. Again it is assumed that the utility the decision maker derived from management decisions can be expressed in terms of net present value. Let $NPVMAN_{sm}$ be the net present value of assigning one hectare of stratum s to management option m. The utility the decision maker derives from the forest and related management decisions can now be expressed as:

$$UTILITY = \sum_{z=1}^{Z} \sum_{u=1}^{U} NPVUSE_{zu} \; X_{zu} + \sum_{s=1}^{S} \sum_{m=1}^{M} NPVMAN_{sm} \; Y_{sm} \qquad (14)$$

All elements of the problem to be solved are now described and the problem to solve can be formulated as:

$$\max \; UTILITY = \sum_{z=1}^{Z} \sum_{u=1}^{U} NPVUSE_{zu} \; X_{zu} + \sum_{s=1}^{S} \sum_{m=1}^{M} NPVMAN_{sm} \; Y_{sm} \qquad (15)$$

such that

$$\sum_{z=1}^{Z} \sum_{u=1}^{U} HA_{zus} \; X_{zu} = \sum_{m \in \mathbf{M}_{zus}} Y_{sm} \qquad 1 \leq s \leq S \qquad (13)$$

$$\sum_{u=1}^{U} X_{zu} = 1 \qquad 1 \leq z \leq Z \qquad (16)$$

[other linear constraints]

X_{zu} binary $\quad 1 \leq z \leq Z ; 1 \leq u \leq U$

$Y_{sm} \geq 0 \quad 1 \leq s \leq S ; 1 \leq m \leq M$

An application of this approach can be found in Weintraub and Cholaky (1991).

A difficulty in applying this FORPLAN model is the lack of an efficient algorithm to solve the problem. In practice, a trial and error approach is used to obtain integer solutions for this FORPLAN model.

Zoning by means of Goal Programming

Arp and Lavigne have developed a goal programming model for hierarchical multiple land use planning of forested lands (Arp & Lavigne, 1982). Goal Programming is a special branch of mathematical programming, in which the objective function consists of weighted deviations from targets set for goals. If the problem statements consist of linear equalities and inequalities, the problem can be solved with the simplex algorithm and the problem

definition can be considered as a variant of a Linear Programming problem.
In the Arp and Lavigne model the forest has been divided into zones. The decision variables are the number of hectares in a zone to be assigned to one of the identified uses. The assignment of zones to uses contributes to the realization of goals and to a use of resources. Targets are set per goal. The problem to solve is how to assign hectares from zones to uses, in order to minimize the deviations from set targets. The model is a basic goal programming model and is described below.

$$\min \text{PENALTY} = \sum_{n=1}^{N} (W^-_n d^-_n + W^+_n d^+_n) \tag{17}$$

such that

$$\sum_{z=1}^{Z} \sum_{u=1}^{U} A_{zun} X_{zu} + d^-_n - d^+_n = \text{TARGET}_n \qquad 1 \le n \le N \tag{18}$$

$$\sum_{z=1}^{Z} \sum_{u=1}^{U} B_{zur} X_{zu} \le \text{RESTRICT}_r \qquad 1 \le r \le R \tag{19}$$

[other linear constraints]

$$X_{zu},\ d^-_n,\ d^+_n \ge 0 \qquad 1 \le z \le Z;\ 1 \le u \le U;\ 1 \le n \le N$$

in which:

PENALTY	total penalty score
W^-_n	penalty per unit of underachievement of target for goal n
W^+_n	penalty per unit of overachievement of target for goal n
X_{zu}	decision variable: number of hectares from zone z assigned use u
d^+_n	state variable: amount of overachievement of target for goal n
d^-_n	state variable: amount of underachievement of target for goal n
N	total number of goals
Z	total number of zones
U	total number of uses
R	total number of restrictions
A_{zun}	contribution to goal n if one hectare of zone z is assigned use u
B_{zur}	amount of resource r used if one hectare of zone z is assigned use u
TARGET_n	target for goal n
RESTRICT_r	amount of resource r available

The link between zoning decisions and management decisions

The mixed area-based strata-based approach of FORPLAN is the only model type I found which addressed the relationships between zoning decisions and management decisions. This model is a mixed-integer programming model. However, no existing algorithm can solve this problem efficiently, because the problem is too large (number of variables and constraints). The model does not adequately address the zoning problem (see below), but apart from this it presents an interesting solution for modelling the relationships between zoning decisions and management decisions. This relationship is addressed further in chapter five.

None of the models described above deals explicitly with the relationships between zoning decisions. In the FORPLAN model a zone is defined as an area (a contiguous heterogeneous piece of land) and the decision variables are binary (1 if zone z is assigned to use u and 0 if not). In the Arp and Lavigne goal programming model a zone is defined as a stratum (in the sense of a contiguous homogeneous piece of land) and the decision variables are continuous (number of hectares from zone z assigned to use u). The definition of a zone as a stratum assumes that the forest within a zone is homogeneous. In reality this will not be so, because a zone is not homogeneous in the sense of the same forest characteristics occuring everywhere throughout the zone, but is homogeneous in the sense of having the same land use objective throughout the zone. The result of zoning has to be a map showing the division of the forest into zones and specifying per zone the land use objectives for which the forest will be managed. The outcome of the Arp and Lavigne goal programming model cannot be displayed on a map. In this sense the FORPLAN model addresses the zoning problem more adequately. In reality the decision to assign zone z to use u does influence the location of other uses. However, in both models the location of uses in relation to each other is not considered. At this point the models do not completely deal with the spatial considerations inherent to the zoning problem.

Another point of criticism is that in both models the location and boundaries of the zones are already externally determined. The zoning problem includes the determination of the location and boundaries of the zones as well as the assignment of uses to the zones. In reality these problems have to be solved simultaneously, because they are closely related and if they are solved separately there is a chance that the optimal solution to the combination of these problems will be overlooked. In the models described above these two problems are separated and solved individually. Given the statements made above, the conclusion of Alston and Iverson (1987) that FORPLAN version 2 completely deals with the zoning problem can be questioned.

Bos (1993) describes a zoning model in which the division of the forest into zones is endogeneous. Spatial relationships between decisions are dealt with in this model by introducing quadratic terms in the object function (Quadratic Assignment Problem). This model is described in chapter six. This model seems to be more appropriate for the zoning problem than the mixed area-based strata-based FORPLAN model and the Arp and Lavigne Goal Programming model.

4.5. The problem of the desired future forest

Most quantitative models in the literature seem to be based on planning concepts in which the problem of identifying a desired future forest is not considered. Most optimization models aim at identifying the optimal scheduling in time of forest management actions. As a result, these models suffer from the fact that the state of the forest at the end of the planning horizon is not considered as a desired situation from the point of view of the objectives, but is considered to be no more than a result of management activities. In this way of thinking the problem of the desired future forest is taken as an assessment of the future consequences of current actions to ensure that these actions do not lead to unacceptable situations in the future. The basic shortcoming of this way of thinking is that the hierarchy of decisions is not dealt with correctly. Kent *et al.*(1991) say that one of the first issues to be addressed in the future use of planning models for forest management is to develop a clear understanding of the (hierarchical) level of planning (i.e. strategic, tactical or operational) (Kent *et al.*, 1991).
In this study, the desired future forest problem is taken as an assessment of the consequences of the solution to the zoning problem in the first place and not as an assessment of the consequences of management actions. Solving the desired future forest problem means deciding on which future forest is *desired*. Clearly, when making these decisions it has to be clear that this future forest can be achieved and at what costs: the transition management problem.

Below, models which address the problem of the desired future forest are discussed.

Models of the desired future forest

A multistage approach

Mitchell *et al.* (1987) developed a multistage approach for forest planning. This consists of three models: a steady state model, a model dealing solely with timber harvest scheduling, and a model combining features and results of the first two models that is the basis of the final forest plan. The steady state model is interesting to us, because the problem it addresses is related to the problem of the desired future forest. It was designed and used for screening out inferior management options from the final model. The steady state model is based on the assumption that production of outputs and effects is a function of ecosystem states (forest conditions) which could be maintained in equilibrium. This assumption provided a means for translating issues, concerns and opportunities gathered through public involvement into goals that could be used to guide the development of management options. The definition of a goal in this approach is: "a concise statement that describes a desired condition to be achieved sometime in the future". For the steady state model, a management option was composed of practices and standards for those practices necessary for maintaining the desired mix of forest conditions through time, assuming that the desired mix of forest conditions was achieved. According to Mitchell *et al.* (1987) the application of the steady state model is analogous to investigating of a full range of house plans to identify those which would meet a family's needs before going into detail of how the house will be built and the costs of construction.

A steady-state model

Dress (1975) describes an approach consisting of two models: a steady-state model and a transition model. In the steady-state model an optimal steady-state structure is determined independently of initial resource conditions by dividing the forest into homogeneous management response units (land classes), and allocating areas of land classes to specified management options. The optimal steady-state structure serves as a target for the transition model in which the current forest is transformed into the desired steady-state (Dress, 1975). Dress admits that the determination of an optimal steady-state structure independent of initial conditions is, strictly speaking, not correct, since the costs of getting to that structure starting from the current state should be accounted for in the optimization. Dress justified his choice for this approach in the following way. Because forests develop slowly (see chapter two), the time period for transition has to be long. This long period results in a high degree of uncertainty about preferred structures. In applying the models in planning the emphasis will therefore be on the transition model. The steady-state model only provides the broad guidelines for the transition model (Dress, 1975). However, if the planning horizon is taken shorter, Dress's justification fails, because the outcome of the steady-state model will restrict the degrees of freedom in the transition management.

A Goal Programming model

Field *et al.* (1981) address the following two questions:
- What is the optimal long-term steady-state structure?
- What is the optimal sequence of management activities that achieves the desired steady state?

According to them the best way to address these questions is by elaborating them into two separate problems: the steady-state problem and the transition problem. The separation is based on the fact that answers to the two questions may involve different decision criteria. The solution of the steady-state problem provides a framework which may be used to set long-term targets and constraints for the transition problem. In their paper Field *et al.* focus on the steady-state model. They did not develop a transition model, but assume that the allocation and scheduling necessary for the optimal solution

of the transition problem may be found using FORPLAN (Field *et al.*, 1981). The steady-state model of Field *et al.* is a Goal Programming model. In this model management options are defined as infinitely cycling sequences of management activities. The consequences of a management option are expressed in the model as mean periodic outputs or as characteristics of certain components of the regulated condition, such as average diameter of the harvested trees (Field *et al.*, 1981). The forest is only classified by permanent site characteristics which determine future productive capacity; existing present conditions are ignored. In the analysis of the steady-state, the optima for each criterion/objective are identified first using an LP formulation. In the second step a Goal Programming model is constructed in which the targets are derived from the optima found in the first step.
Although Field *et al.* acknowledge the fact that the wish to achieve a desired future situation influences decisions to be made in forest management, they do not construct a model for the transition problem. They only state that the link between the steady-state problem and the conversion problem is likely to require an iterative procedure, but they do not elaborate on this.

The link between desired future forest decisions and transition management decisions

From the above it becomes clear that several authors have elaborated the link between the desired future forest decisions and transition management decisions by constructing two models: a steady-state model and a transition management model. According to Mitchell *et al.* (1987) this division in two models is justified, because of a hierarchy of decisions. We must first decide where we want to get to before we start walking. Dress (1975) points out that decisions about the desired future forest cannot be made without insight in the consequences for transition management. Field *et al.* (1981) justify the construction of a separate steady-state model by pointing out that answers to the two questions may involve different decision criteria. This argument is not strong. More than one decision criterion can be represented in a model, for example as constraints or as coefficients in the object function. The inclusion of different constraints into one model is no problem. I was unable to find a model that combined decisions about desired future forest and transition management. The desired future forest models I did found in the literature all aim at identifying the optimal long-term steady-state structure. If steady-state is taken as the steady-state belonging to Land Utilization Types, we might conclude that the models of desired future forest found in the literature provide a structure which can be used as a basis for solving the problem of desired future forest. The models found in the literature are restricted to timber production. They have to be extended with the instruments to deal with multiple use (described earlier). The way in which these models relate to the zoning problem is, however, not described in the literature found.

4.6. The transition management problem

In this section attention is first given to models which address the problem of transition management. The remainder of this section focuses on the dynamic character of forest management, which becomes especially apparent in the transition management problem. The approaches discussed in this section are called transition management models. This implies that they aim at achieving a desired future forest. However, in some of these models the problem of transition management is seen as the only decision problem in strategic planning in forest management.

Transition management models

A MAXMIN model

Eriksson (1983) developed an LP model for a forest in transition. The decision variable in the model is the amount of land from land units allocated to management options. A management option consists of a schedule of activities over the whole 30-period time horizon (each period is 5 years). The model, which is based on a typical model I structure (see section 4.2), aims to optimize a combination of the discounted net revenues from timber sales and the net revenue from the period with the least net revenue. It is oriented on timber production only. The model has been applied in a case in which the annual area felled had to be reduced to comply with legal requirements. The fact that the model includes thinning as a management activity is the basis of a link with the tactical planning. The formulation of the model is given below.

$$\max \text{UTILITY} = \sum_{s=1}^{S} \sum_{m=1}^{M} \text{NPV}_{sm} \, Y_{sm} + \text{LEAST} \qquad (20)$$

such that

$$\sum_{s=1}^{S} \sum_{m=1}^{M} \text{NETREV}_{smt} \, Y_{sm} \geq \text{LEAST} \qquad 1 \leq t \leq T \qquad (21)$$

LEAST is a variable and is calculated as the net revenue of that period in which the lowest net revenue has been realized.

$$\sum_{m=1}^{M} Y_{sm} = \text{HA}_s \qquad 1 \leq s \leq S \qquad (22)$$

[other linear constraints]

In which:

Y_{sm}	decision variable: the number of hectares from stratum s assigned to management option m
NPV_{sm}	net present value if one hectare of stratum s is assigned to management option m
$NETREV_{smt}$	net revenue in period t if one hectare of stratum s is assigned to management option m
LEAST	variable: net revenue of that period in which the lowest net revenue has been realized.

A clearcut model

The conversion model Rustagi (1976) developed is part of a set of two models. In his approach he defines two decisions: clearcut and reforestation. The first model (goal programming) determines how many hectares of the forest should be reforestated according to a certain reforestation alternative. This model can be seen as a kind of desired future forest model in which the land expectation value of the forest is maximized. The second model (linear programming), the transition model, determines how the clearcut, which is to precede the reforestation, should be distributed in time and space (Rustagi, 1976). In this conversion model the optimality criterion is the net revenue from timber sales.

A clearcut plus reforestation model

The model developed by Wedershoven (1982) distinguishes two interrelated decisions: the clearcut decision and the reforestation decision. The basis of the model is that every hectare cut has to be reforestated in the same year. The model simultaneously determines the optimal clearcut schedule in combination with the optimal reforestation strategy. The optimality criterion is the sum of the net present value of the timber yields plus the land expectation value of the reforestations. The model is restricted to timber management. An important aspect of the model is that it is possible to include restrictions concerning the future forest that results from the reforestation decisions (for further information see Filius, 1983; De Wit & Gerritse, 1986; Wedershoven, 1982).

The dynamic character of forest management

In order to deal with the length of the production periods, the planning horizon is often divided into several periods of equal length. The length of the planning horizon (the number of planning periods multiplied by the length of a period is usually very long in forest management (Dress, 1975). How long it has to be is determined by the homogeneity of the forest and the number of changes that can be expected during conversion (Jöbstl, 1973). If the current forest and the desired future forest almost coincide, then a short planning horizon will suffice. If they differ considerably, then a longer planning horizon is needed, in order to transform the current forest into the desired future forest for an acceptable cost.

What happens in one period may have an important influence on decisions in subsequent periods (Cocklin, 1989). This means that addressing the dynamic character leads to additional temporal relationships such as regulation constraints being included in a model. Like non-linearities and stochastic conditions, dynamic considerations increase the complexity of optimization models and they therefore become more difficult to formulate and to solve (Cocklin, 1989).

A problem related to the dynamic character of forest management is that in reality there is no time horizon to the management of a forest. In planning and in quantitative models, however, a finite planning horizon is often used in order to reduce the complexity of the decision problem. This 'solution' gives rise to problems in valuation of the status of the forest at the end of the planning horizon. These problems can best be made clear by means of a harvest scheduling problem. If the objective of the model is to maximize net present revenue from the forest during the planning horizon, then at the end of the planning horizon, the total forest will be harvested, assuming that harvesting yields a higher net present revenue than doing nothing. This means that at the end of the planning horizon no forest will remain. The problem centres round the valuation of the status of the forest at the end of the planning horizon. According to Dijkstra (1984) there are two ways of dealing with this problem: approximate the idea of an 'infinite' horizon or include ending inventory constraints in order to achieve the desired future forest.

The approximation of an infinite horizon can be established by making the planning horizon very long, so that the model solution covers a much longer period of time than the effective planning horizon (Dijkstra, 1984). An example of this is found in the model developed by Eriksson (1983). The planning horizon in this model was set at 35 years, divided into seven five-year periods. The discounted net revenue was calculated with a 150-year horizon, i.e. 30 five-year periods. In this way the value of the ending inventory in period seven is calculated on basis of what will happen after the planning horizon and is thus included in the model. If the time horizon is really infinite, then this approach will result in a net present value based on the land expectation value.

Including ending inventory constraints means ensuring that the ending inventory comes up to some ex ante set standards. The approach is based on the assumption that the forest existing at the end of the planning period is suitable to sustainably fulfil the functions desired. The Nautiyal and Pearse (1967) model , described in section 4.3., is an example of this approach. The essence is that constraints ensure that at the end of the planning horizon the current irregular forest is transformed into a 'normal' forest.

The valuation of forest outputs and conditions in time is difficult. If the output is financial, then time preference can be expressed by means of discount rates. If the output is non-financial (i.e. non marketable) then the use of discount rates becomes difficult. For example, how do you value the fact that the desired future forest is achieved earlier or later? One could use discount rates to express time preference about the moment of the realization of the desired future forest. The discount rate to use in this case cannot be determined objectively. Here too it holds that if market prices are not available, the value system and the economic objectives of the forest owner are likely to govern the manager's decisions on forests (Gregory, 1987) (see also section 2.5).

The models described in this section are all oriented on timber production and even-aged management. The FORPLAN models were not dealt with. These models can be elaborated into transition management models. As already stated, a model I approach could be used as a basis for a transition management model.

4.7. General conclusions

The general conclusions reached in this chapter are summarized in table 4.1. From this it can be seen that the zoning problem is dealt with insufficiently, the problem of the desired future forest is dealt with reasonably and transition management is dealt with partly. The main difficulties are in the relationships between the problems. No existing model is appropriate for the zoning problem. Because of the spatial considerations, the zoning problem can only be dealt with by a non-linear integer programming model. The problem of the desired future forest and the problem of transition management are both addressed as linear problems in the literature. It must therefore be possible to combine them into one linear programming model. The fact that the criteria used to determine the optimal desired future forest differ from those used to determine the optimal transition management can be dealt with by choosing a constrained approach. As already stated in section 4.2 this model has to be based on a model I approach. The desired future forest problem and the transition management problem can be linked together into one model by defining management options as a combination of a description of a future forest and a description of a transition management which will convert the current forest into the desired future forest. From now on the model which addresses both the desired future forest problem and the transition management problem will be called the management model in this study. As already mentioned, I was not able to combine the zoning model and the management model into one model. The relationships between these two models are described in the following chapter.

Table 4.2 Map of research on forest planning models

ASPECTS OF CONCERN	HOW MODELS IN LITERATURE DEAL WITH THESE ASPECTS									
	mixed area-based strata-based approach FORPLAN	GP model of Arp and Lavigne	QAP model of Bos	Model I with constrained approach	Mitchell *et al.*	Dress	Field *et al.*	MAXMIN	Rustagi	Wedershoven
do models address ZONING problem	division in zones not included in model	division in zones not included in model	division in zones included in model							
spatial considerations	decision variables are binary		decision variables are binary, objectfunction is quadratic							
link zoning and desired future forest	zoning decisions and management decisions included in one model									
do models address DESIRED FUTURE FOREST problem				in principle suitable as basis for desired future forest model	steady-state model, screens out inferior manage-ment options	steady-state model for timber production	steady- state model (GP)			
link desired future forest and transition management				it is possible to include both in one model		sets targets for transition management model	sets long-term objectives and constraints for transition management			
do models address TRANSITION MANAGEMENT problem				in principle suitable as basis for trans-ition management model				timber produc-tion oriented	clearcut model timber production oriented	clearcut plus reforestation model

5. STAGES: AN OVERVIEW

5.1. Introduction

In the preceding chapter it was demonstrated that none of the existing quantitative models adequately addresses the decision problems in strategic planning in forest management. To redress this, I designed the blueprint of a Decision Support System (DSS) which addresses the decision problems and related aspects more adequately than existing models do.

The STrategic Alternative GEnerating System (STAGES) developed in this study is based on two interrelated decision models: a zoning model and a management model. The zoning model addresses the problem of zoning. The management model addresses the desired future forest decision problem and the transition management problem simultaneously. This chapter provides a general overview of the models; they are described in detail in subsequent chapters.

The best way to ensure that optimal solutions to the decision problems in strategic planning will be identified is to construct a single model in which all the decision problems and all the related aspects are dealt with adequately and simultaneously. I was unable to find any model in the literature that satisfies this requirement. Furthermore, as my study progressed I discovered that it is impossible to address strategic planning in forest management in a single model encompassing all decision problems, because the decisions about the optimal desired future forest and the transition management depend on the decisions about zoning and the way the zoning problem is solved determines which management problems have to be solved.

5.2. The purpose of STAGES

The STrategic Alternatives GEnerating System (henceforth called STAGES) was developed for decision support in strategic planning in forest management. Its main task is to generate strategic alternatives and their financial, social and environmental consequences, thereby helping overcome the deficiencies in strategic planning in forest management mentioned in the introduction (chapter 1) (no alternatives, no consequences, no justification).

STAGES enables possible objectives to be identified; this identification can only be done well if the consequences of these objectives are known. STAGES does not aim at decision making itself, but at providing the insight needed to support decisions. It first gives insight in the problem to be solved. In each application of the models comprising STAGES, the way the problems are formulated in the format of these models is part of the planning process and sheds light in the actual planning problem. The problem cannot be solved unless it is correctly formulated.

The actual collection and analysis of the data needed to run the STAGES models is also very informative, because in this process the potentials of the different parts of the forest, the feasibility of allocation options and the consequences of allocating parts of the forest to one of the identified allocation options all become clear.

The third way in which STAGES leads to insight is via the generation of alternatives. Each alternative generated sheds more light on the feasibility of objectives and their implications. Furthermore, each alternative gives insight in trade-offs between objectives. The model's output can make the decision maker aware of objectives that have not yet been included. For example, consider a situation in which a constraint has been included in the management model which states that no more than twenty percent of the forested area may be coniferous forest. The effect of this could be to raise the costs of managing the forest. In this case the decision maker can become aware of the fact that he should not allow the costs to rise above a certain level. This results in the formulation of another, financial, constraint. Thus, the application of STAGES reveals how decisions or consequences are related to each other. A constraint for a certain part of the forest, can influence decisions in other parts of the forest. For example, if no more than twenty percent of the total forest area will be coniferous forest, in the next run another constraint may be added, namely that in a specific part of the forest eighty percent has to be coniferous forest, so the insight gained can be used to generate other alternatives.

STAGES is also useful because it enables the decision maker to keep track of all the partial decisions that have been made. And it helps to make decision making more consistent, because conflicting decisions will lead to solutions that are not feasible.

STAGES can be used in a planning process in several ways. In STAGES, variables can be divided into decision variables (internally determined, output of the model) and parameters (externally determined, input to the model: constraints, growth parameters etc.). Analysing how the solutions change in response to a change of non-decision variables also sheds light on the system. Only the implications of changes in the constraints were mentioned above, but the implications of changes in the technical coefficients such as growth and yield parameters can also be analysed. Scenarios can be analysed in this way. For example: the consequences of a decline in growth induced by air pollution. In this way, insight can also be gained about the importance of certain information in the model. For example, if a change in growth rates does not really change the decisions made and a change in discount rate does change decisions considerably, it can be inferred that the assessment of the discount rate is more important than the assessment of the growth rate. From the foregoing it is clear that STAGES is intended to be used interactively.

STAGES also can be used to identify the impact of regional and national policies, by assessing their implications for the forest enterprise. The policies can be simulated in STAGES by including additional constraints that represent regulations of the government, or by including financial incentives.

5.3. The zoning model

The first problem of strategic planning is the zoning of the forest. None of the existing quantitative models for zoning in forest management addresses the zoning problem adequately, they merely focus on the allocation of land use objectives to zones, but do not divide the forest into zones (see chapter 4). In the zoning model developed in this study the complete zoning problem is addressed. This means that the forest is divided into zones and simultaneously land use objectives are allocated to these zones. This formulation provides more opportunities dealing with spatial considerations than the common LP formulations do (see chapter six for the mathematical formulation of the zoning model).

Zoning a forest for different uses is a complex problem. Land of a particular suitability and location has to be assigned to land use objectives in such a way that the highest value is derived from zoning. The land use objectives are assigned to a tract of forest land on the basis of that land's suitability for these land use objectives and also on the resulting location of land use objectives in respect to each other and the forest environment.

In the zoning model, forest land is represented by cells in a grid. Land use objectives are represented by uses. A use is a description of land use objectives in terms of functions to be fulfilled. Each grid cell has to be assigned a particular use. Decision variables in the zoning model are binary (zero or one). Hence a particular grid cell is assigned to a particular use (decision variable is 1) or not (decision variable is 0).

The assignment of grid cells to uses is partly based on the suitability of a grid cell for a certain use. If the suitability of a grid cell for a certain use is the only decision criterion, the best solution is to assign each grid cell to the use for which it is most suitable. A decision maker can, however, give one use more weight than another. Multiplying the suitability of the grid cell by the weight of the use yields a score for each type of use of a grid cell. In principle, the best decision is the one that assigns the grid cell to the use with the highest score.

The suitability of a grid cell for a particular use is influenced by decisions on the use of adjacent grid cells. If, for example, a grid cell is assigned to a use "nature conservation" and the adjacent grid cells also have this use, then the suitability of that grid cell for "nature conservation" is higher than if all the adjacent grids are being assigned to recreation. Certain uses attract each other while others conflict. In the model this is represented by means of an attraction coefficient. If two uses attract each other, the attraction coefficient between them is positive; the more the two uses attract each other, the higher the attraction coefficient. If two uses conflict with each other the attraction coefficient is negative; the more the two uses conflict, the more negative the attraction coefficient.

The model will assign each grid cell to a use in such a way that the resulting score (sum of values from the point of view of suitability/preference and value from the point of view of the spatial location of uses) is maximized. The relative score from the point of view of the suitability/preference in relation to the score from the point of view of the spatial location of uses is balanced by a non-negative weighting parameter M. The higher the M, the more the assignment of grid cells to uses is determined by spatial location of uses with respect to each other. The lower the M, the more the assignment of grid cells to uses is determined by the suitability of grid cells for uses. So the parameter M can be used to achieve a compromise between the influence of suitabilities of grids for uses and the influence of the spatial location of uses with respect to each other.

In the model it is possible to put restrictions to the number of grid cells assigned to a particular use. For example, assign no more than ten and no less than four grid cells to the use "timber production and dispersed recreation".

When deciding about zoning, the relationships between a specific forest use and the socio-economic and natural environment of the forest have to be considered. The distance between the location of uses within the forest and certain land utilization types outside the forest is important in zoning. The distance from population centres is, for example, considered important in recreational forest functions and the distance from other natural elements in the landscape is important for nature conservation (LNV, 1990b).

There are at least two ways of dealing with the relationship between the forest and its environs. The first is to take these relationships into consideration when determining the suitability of a forest area for a particular forest use. The second is to take the environs of the forest as a border of grid cells that surround the grid cells representing the forest and to make these relationships part of the problem to be solved. I opted for the second way, because it makes an essential part of the problem clearer and no information is lost. In the first procedure all the information on the environs is aggregated into one suitability. In the second, this information is explicitly incorporated into the problem.

Grid cell representing the environs of the forest are assigned to a particular use. This use can be a forest land utilization type or another land utilization type such as agriculture, residential area or lake. Grid cells representing the environs will influence the assignment of grid cells belonging to the forest as if they themselves were grid cells that belonged to the forest. However, the zoning model does not make decisions about the use assigned to "environs" grid cells, because such decisions are not made in forestry strategic planning. Hence, the uses of grid cells belonging to the environs are determined outside the model.

Summarizing the zoning model needs the following information (see figure 5.1):
- location of grid cells in a grid;
- per grid cell a suitability rating for each use;
- preference score;
- attraction coefficients;
- weighting parameter M;
- constraints about the minimum or maximum number of grid cells permitted to be assigned to a particular use.

The user of the model can influence the outcome of the model. To do this he or she can use one (or a combination) of the following techniques (see figure 5.1):
1. Changing the value attached to a certain use (change preference scores);
2. Changing constraints about the minimum or maximum number of grid cells that are permitted to be allocated to a certain use;
3. Changing the value of the weighting parameter M.

The output of the zoning model consists of a map showing the zones of the forest. A zone is defined as a cluster of adjacent grid cells which are all assigned to the same use. The zoning map is a grid in which each grid cell has been assigned to a certain use.

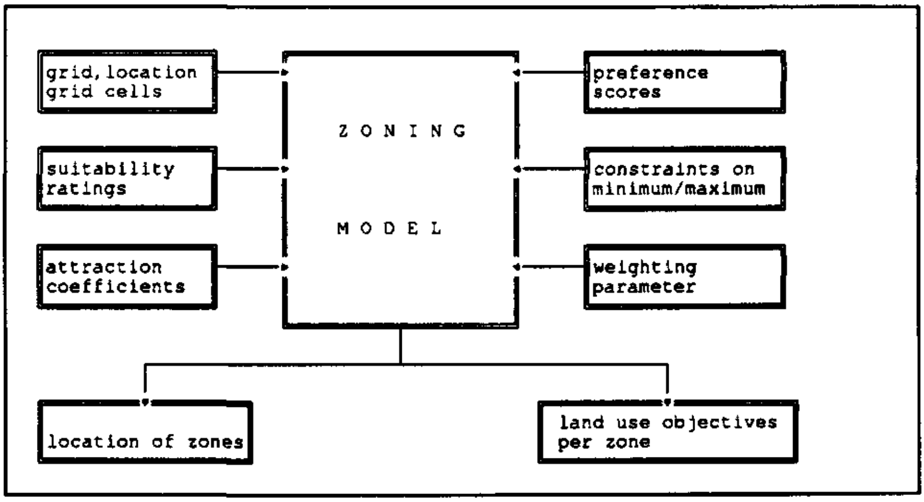

Figure 5.1 The input and output of the zoning model

5.4. The management model

The second and third problems of strategic planning are the decision about the desired future forest and the decision about transition management. Both are included in the management model. This model is based on a model I formulation, because that formulation is flexible (all kinds of management options can be included), and deals with multiple use by means of the constrained approach, because this allows land use objectives to be translated into constraints about forest characteristics (see chapters three and four).

The management model assigns forest land to management options in such a way that the uses chosen in the zoning model are achieved. A management option consists of a transition management strategy that converts the current forest into a desired future forest, a description of the consequences of this transition management strategy, a description of the management in the desired future forest and a description of the consequences of that management to maintain the desired future forest (characteristics of the forest and the financial and economic consequences). In a management option the desired future forest is described in terms of a forest land utilization type. In this way a management option can be linked to a land use objective (outcome zoning model), as we will see later on. The consequences are primarily forest characteristics and financial consequences. Social and environmental consequences have to be derived from the forest characteristics.

In the management model the forest is represented by zones and by stands within a zone. A zone is an area of the forest that is homogeneous in respect to use. A stand is an area of the forest which is homogeneous with respect to growing conditions and characteristics (stand type) of the current forest. The division of the forest into zones is needed in the management model, because management aims at the achievement of uses and the uses differ between zones. The division into stands is needed because the consequences of assigning land to a certain management option depend on the growing condition and the current situation of the forest. The decision variables in the management model are the amount of land from a certain stand from a certain zone assigned to a certain management option.

A land use objective is specified by the needs of society that will be fulfilled (in terms of forest functions), a description of the forest structure and composition needed to achieve a forest that is suitable to fulfil these functions and a set of forest land utilization types that are feasible in the context of this land use objective. In the management model the land use objectives per zone are translated into constraints to the realization of forest characteristics in that zone and into values attached to the realization of forest characteristics in that zone. The set of forest Land Utilization Types constitutes the basis for the formulation of management options, because the description of the desired future forest in a management option is actually a description of a forest land utilization type in terms of management activities and consequences.

The management model generates a desired future forest and a related transition management by assigning all available hectares per stand per zone to management options. The allocation depends on several factors, which are determined by the user of the model.

The user of the model can influence the outcome of the model. He or she can do so by one (or a combination of) the following techniques:

1. Appraising certain characteristics in the future forest per zone. For example, each hectare of a zone under a forest type can be valued. The model will allocate the available hectares per stand in such a way that the resulting total value is as high as possible.
2. Formulating constraints to the characteristics of the future forest. These constraints can be formulated for the entire future forest (for example not less than 300 m^3 timber harvest per year) or per zone (for example in zone four no more than 10 hectares may be under even-aged managed forest). The model will allocate the available hectares per stand to management options in such a way that the consequences of the resulting desired future forest and transition management fulfil these constraints.
3. Appraising certain consequences in a certain period during transition. For example the net cash flow in the first period is valued at three points per guilder (140 guilders leads to a score of 420 points), to ensure the liquidity of the organization in the first period. The model will allocate the available hectares per stand in such a way that the resulting score is as high as possible.
4. Formulating constraints to the minimum or maximum allowable number of units of particular consequences in a certain period during transition. For example, in period 3 no more than 23 hectares of forest may be clearcut. The model will allocate the available hectares per stand to management options in such a way that the consequences of the resulting desired future forest and transition management fulfil these constraints.
5. Restricting fluctuations in consequences in sequential periods, by means of a constraint. For example, the number of hectares transformed in period t may not differ by more than five hectares from the number of hectares transformed in period t-1. The model will allocate the available hectares per stand to management options in such a way that the consequences of the resulting desired future forest and transition management fulfil these constraints.
6. Minimizing fluctuations in consequences in adjacent periods, by means of penalizing deviations between periods. The model will allocate the available hectares per stand to management options in such a way that the total penalty realized is as low as possible.
7. Determining the relative value of the consequences during transition in relation to the value of the consequences in the desired future forest by means of a weighting parameter (W). The higher the W, the more the allocation is determined by the optimization of total score of the consequences during the transition period. The lower the W, the more the allocation is determined by the optimization of the total score of the consequences in the future forest situation.

The available hectares per stand are allocated to management options in such a way that all constraints are satisfied and the sum of the scores realized is maximum. The latter sum consists of the score of the consequences during transition (1 above) plus the score of consequences in the desired future forest (3 above) minus the total penalty on fluctuations in the number of units of a characteristic during transition (6 above).

The output of the model consists of:
- a distribution of forest land utilization types in the desired future forest, specified per zone;
- a description of the resulting consequences, including characteristics of the future forest, specified per zone;
- a description of transition management in terms of number of hectares per stand that have to be transformed per period into the desired future forest;
- a description of the resulting consequences and characteristics of these decisions for the transition management, specified per period.

In figure 5.2 the input and output of the management model is represented graphically.

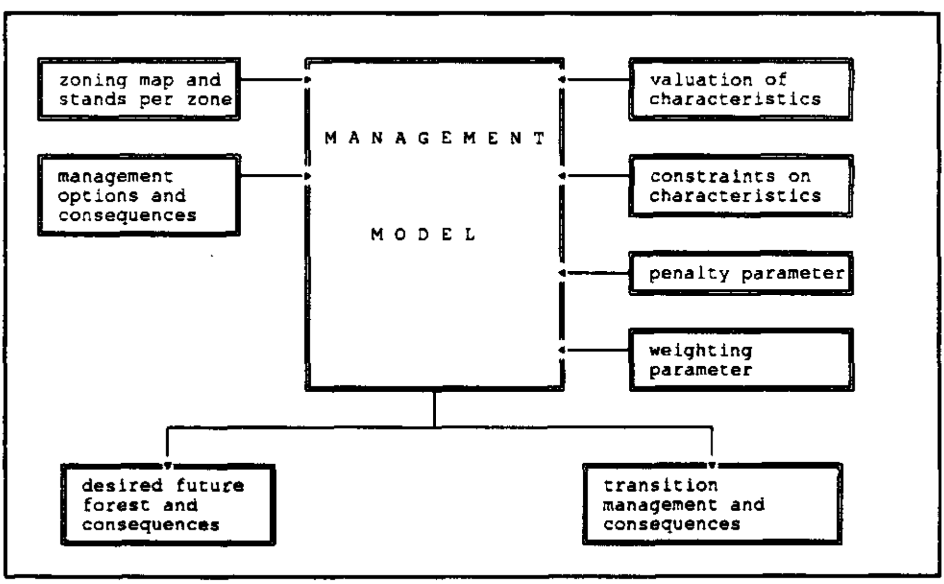

Figure 5.2 The input and output of the management model

5.5. The link between zoning and management

Zoning results in a map showing the division of the forest into zones. In combination with additional information about stands, this map forms the basis of the representation of the forest in the management model. In that model the land use objectives per zone, which are also specified as a result of zoning, are translated into constraints and valuations. Forest Land Utilization Types which are feasible in the context of the land use objectives chosen are represented in the management model by means of management options. Thus the output of the zoning model is the basis of the input of the management model. In addition to the information from the zoning model, the management model also needs additional information (see also appendix D). The relationships between the zoning model and the management model discussed above are shown in figure 5.3.

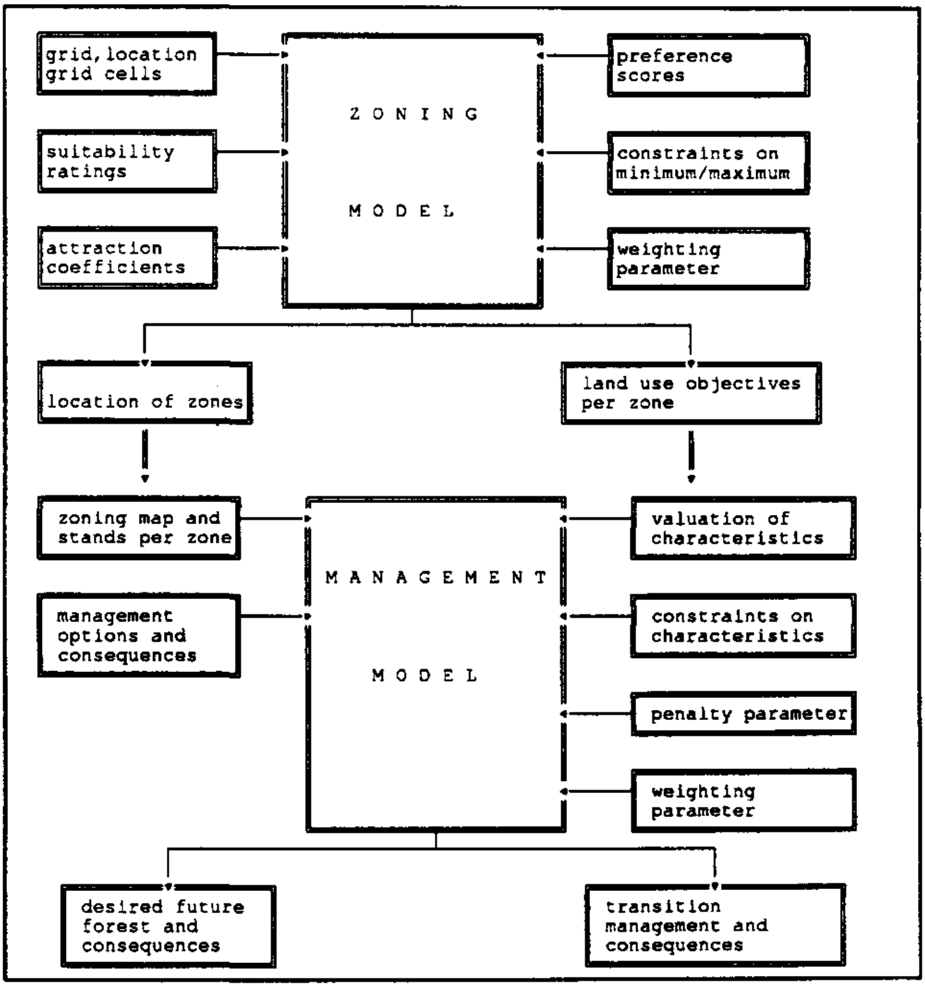

Figure 5.3 The output of the zoning model determines the input of the management model

In the zoning model, land of a particular suitability and location is assigned to land use objectives in such a way that the highest value is derived from zoning. Not only the output of the zoning model is important in this valuation, but also the financial, social and economic consequences of this zoning. However, the latter consequences are assessed in the management model. Hence, there is a danger that zoning decisions will be based on only part of the information needed. The best way to avoid this is to combine zoning, the desired future forest and transition management into one all encompassing model. However, no algorithm is available to solve this problem within an acceptable amount of time. The second best option is to relate the models to each other in such a way that each takes the output of the other in consideration in making decisions iteratively. This option is elaborated below.

In the zoning model the value of assigning a certain grid to a certain use is based on the suitability rating of the grid cell for that use and the weight of the use (preference score). If the value of assigning a grid cell to a use is also based on the expected consequences of management in assigning this grid cell to this use, then management decisions can be anticipated in the zoning model. In this way zoning decisions can be based on a valuation of the resulting zoning in which the financial, social and economic consequences of resulting management are also considered. The consequences of resulting management activities can be predicted from information generated by the land evaluation process in which the suitability of the grid cells for a certain forest land utilization type is assessed. When matching the land use requirements of the forest land utilization type (LUT) with the land qualities (LQ) of the grid cell (a grid cell is here considered as a Land Management Unit LMU), the following two questions have to be answered:

1. What are the financial consequences of achieving this forest land utilization type (LUT) on this grid (LMU)? The answer to this question reveals the financial consequences of transition management.
2. What are the consequences of maintaining this forest land utilization type (LUT) on this grid cell (LMU). The answer to this question gives some indications of consequences of the desired future forest.

After answering these questions, the consequences of the resulting management are known per combination of grid cell and forest LUT.

A land use objective is specified by a set of forest land utilization types that are feasible in the context of that land use objective. The suitability rating of a grid cell for a certain land use objective is an aggregation of the suitability of this grid cell for the different LUTs belonging to the set of feasible forest land utilization types. In the same way the expected consequences of management activities resulting from a grid cell being assigned to a certain use can be based on an aggregation of the expected consequences of management per forest LUT belonging to the set of feasible forest LUTs. This is graphically represented in figure 5.4.

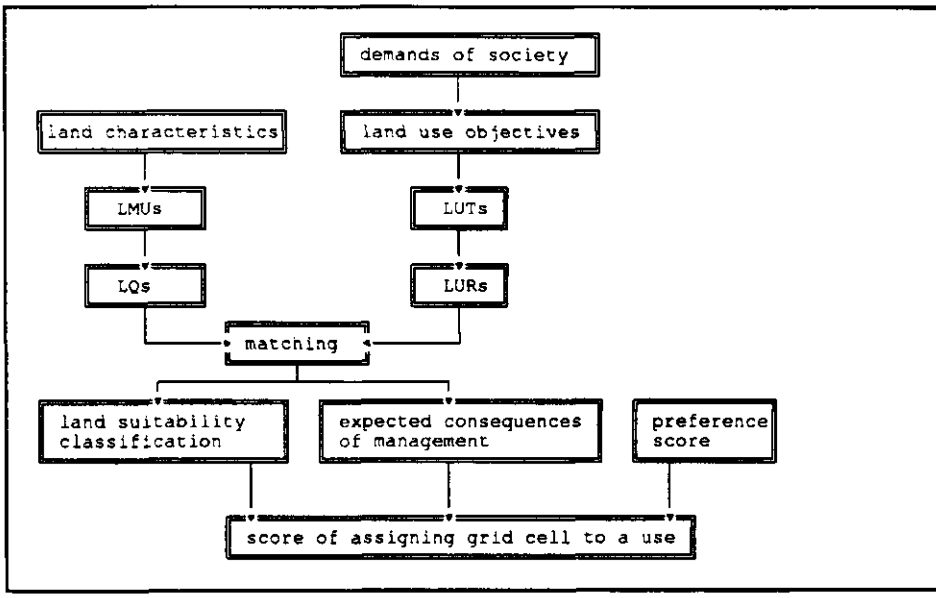

Figure 5.4 Assessment of value of grid cell use combination

However, there is no guarantee that the expected consequences of management assumed in the zoning model (input to the zoning model) will equal the "real" consequences of management (output of the management model). If there is a difference, the user will have to decide whether the differences between the expected and "real" consequences are acceptable. If he deems the differences acceptable, then zoning decisions have been made on a correct estimation of consequences of management. Because the resulting zoning is optimal and the management decisions based on these zoning decisions are also optimal and the consequences of these management decisions are weighted when making the zoning decisions, then the combined zoning decisions and management decisions are considered to be consistent.

If the user of the models deems the differences between the expected consequences and the "real" consequences to be unacceptable, he has two options for proceeding:

- change the parameters of the zoning model;

or

- change the input of the management model.

Changing the parameters of the zoning model means replacing the current estimation of expected consequences of management by the current "real" consequences of management, and rerunning the zoning model. In certain situations it is not necessary to rerun the zoning model (e.g. when the change in the expected consequences of management are not large enough to justify changing the output of the zoning model). In this situation the combination offered by solutions of the zoning model and the management model is optimal, because the differences between the expected consequences of management on which the zoning decisions are based and the "real" consequences of management are acceptable (they are negligable). If the rerunning of the zoning model results in an alternative zoning, then the management model has to be run again. The expected consequences of management have to be compared with the "real" consequences of management and if the differences between them are deemed acceptable, the combination of solutions is consistent and the algorithm stops. If the differences are not deemed acceptable, the current expected consequences of management have to be replaced by the current "real" consequences of management again and the zoning model has to be run again. This process will continue until a stable solution has been found (see figure 5.5). The algorithm has been elaborated and illustrated with a numerical example in appendix B.

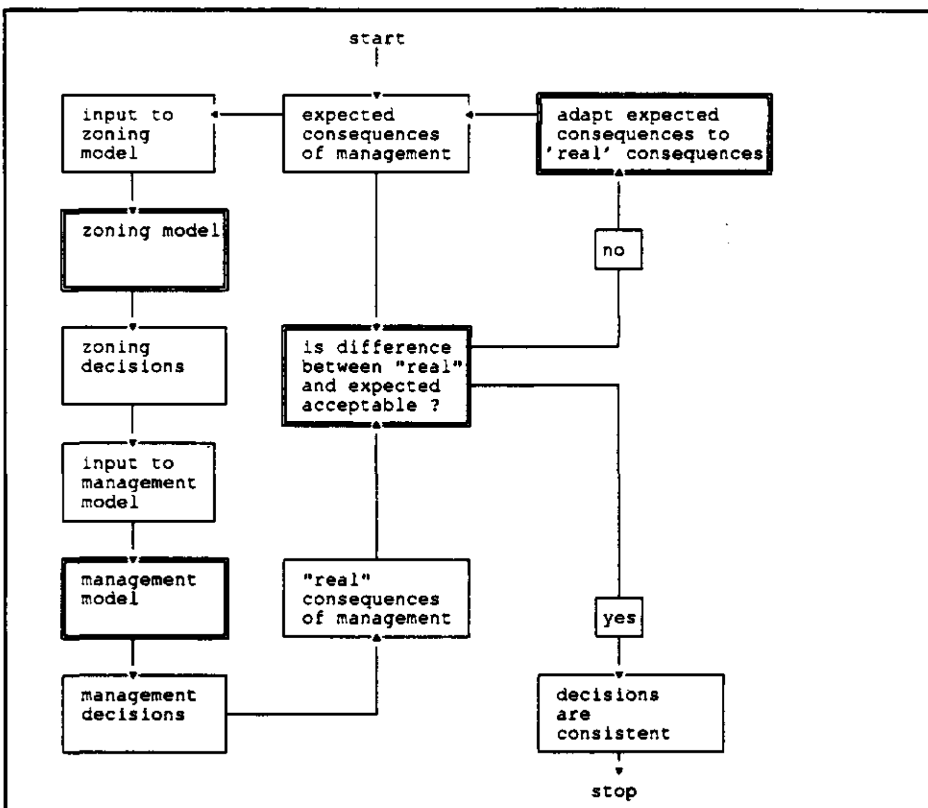

Figure 5.5 Flow chart of combination of zoning model and management model

Changing the input of the zoning model means that the data used in that model are adjusted in the light of information gained in running the models. In this way more attention is given to the consequences for management in making decisions. In most cases changing the input of the management model means that the problem to be solved is changed (other constraints or other right-hand side values for existing constraints or other management options). The effect of this is that the resulting solution and consequences of management cannot be compared with the original solution and consequences of management, because the problems solved are different. Therefore it is not advisable to change the input of the management model.

To link the zoning and the management models in this way the constraints in the management model must be formulated per grid cell, not per zone. Each grid cell is considered as a zone. In this way the "real" consequences of management are known per grid cell and the expected consequences of management in the zoning model, which are formulated per grid cell, can be replaced by the 'real' consequences of management (see appendix B).

6. THE ZONING MODEL

6.1. Introduction

In this chapter the zoning model is described mathematically. Inevitably, there will be some overlap with the qualitative description presented in chapter 5. As well as describing the mathematical problem to be solved in the zoning model, the algorithm used to solve the zoning problem is discussed. This chapter draws heavily on previous work (Bos, 1993).

6.2. The formulation of the problem

In the zoning model demands of society are represented by uses. A use is a description of land use objectives in terms of functions to be fulfilled. Examples of uses are:

- timber production;
- nature conservation;
- recreation;
- dispersed recreation and timber production.

The forest is represented by cells in a grid (see figure 6.1). In a grid cell the suitability for a certain use is everywhere the same. Each grid cell has to be assigned a particular use.

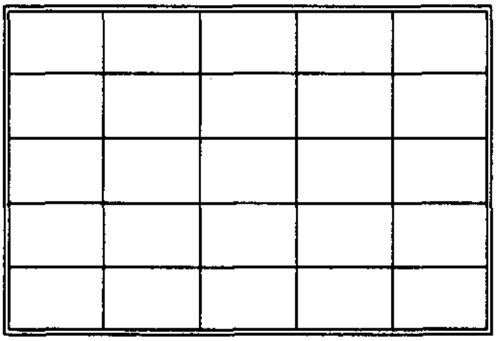

Figure 6.1 Cells in a grid

For each grid cell (g) a use (u) has to be assigned. Decision variables are X_{gu}. The binary variable X_{gu} is 1 if grid cell g is assigned to use u and 0 if not.

A grid cell can only be assigned once. The decisions are, therefore, restricted by the following constraints:

$$\sum_{u=1}^{U} X_{gu} = 1 \qquad 1 \leq g \leq G$$

in which:

G	total number of grid cells
U	total number of uses

The object function in the zoning model consists of two parts. The first expresses the appraisal of decisions from the point of view of suitability of grid cells for uses. The second expresses the appraisal of the decisions from the point of view of the spatial location of uses in relation to each other.
As already stated in chapter 5 (section 5.3) if the suitability of a grid cell for a certain use is the only decision criterion, the best solution is to assign each grid cell to the use for which it has the highest suitability rating ($SUIT_{gu}$). A decision maker can however, weight one use more than another. This can be expressed by means of a preference score (WGT_u). By multiplying the suitability rating of the grid cell by the weight of the use, a value ($SUIT_{gu}$ WGT_u) per combination of grid cell and use can be established. Now the best decision is to assign the grid cell to the use with the highest value ($SUIT_{gu}$ WGT_u).

The first part of the object function is therefore:

$$\max \sum_{g=1}^{G} \sum_{u=1}^{U} SUIT_{gu}\ WGT_u\ X_{gu}$$

The second part of the object function expresses the appraisal of the decisions from the point of view of the spatial location of uses in relation to each other.
In the model, the "attraction" of certain uses (see section 5.3) is represented by means of an attraction coefficient ATT_{uf} between uses u and f. If use u attracts use f, ATT_{uf} is positive. The stronger this attraction, the more positive ATT_{uf} will be. If use u and use f conflict, ATT_{uf} is negative. The stronger the conflict, the more negative ATT_{uf} will be. If use u and use f are neutral to each other, ATT_{uf} is zero. If use u is the same as use f

and the attraction coefficient is positive, then ATT_{uu} will act as a concentration coefficient (clustering of u).

In the spatial location of uses it is better to locate conflicting uses (negative attraction coefficient) far from each other. It is also better if the spatial location of uses that attract each other (positive attraction coefficient) are located closer together.

If grid cell g is assigned to use u ($X_{gu}=1$) and grid cell h is assigned to use f ($X_{hf}=1$) and the distance between grid cell g and grid cell h is $DIST_{gh}$ then:

$$(ATT_{uf}/DIST_{gh})\ X_{gu}\ X_{hf}$$

is an expression of the relative value of these assignments from the point of view of the spatial location of use u in relation to the spatial location of use f. If there is a positive attraction coefficient the value rises with decreasing distance between grid cell g and grid cell h. In the case of a negative attraction coefficient, the value is less negative as the distance between grid cell g and grid cell h increases.

Thus the second part of the object function is to maximize the sum of all these relative values. This can be stated as:

$$\max \sum_{u=1}^{U} \sum_{f=1}^{U} \sum_{g=1<}^{G} \sum_{h=1}^{G} (ATT_{uf}/DIST_{gh})\ X_{gu}\ X_{hf}$$

So the object function consists of a linear term and a quadratic term both of which have to be maximized. The object of the decisions is to maximize the total combined value (V) of these two parts. To be able to balance the contribution of the first part to V with the contribution of the second part to V, the second part is multiplied by a non-negative weighting parameter M. The object function can, therefore, be stated as:

$$\max V = \sum_{g=1}^{G} \sum_{u=1}^{U} SUIT_{gu}\ WGT_u\ X_{gu} + M \sum_{u=1}^{U} \sum_{f=1}^{U} \sum_{g=1}^{G} < \sum_{h=1}^{G} ATT_{uf}/DIST_{gh}\ X_{gu}\ X_{hf}$$

in which :

V	total value of forest
$SUIT_{gu}$	suitability rating of grid cell g for use u
WGT_u	preference for use u
ATT_{uf}	attraction coefficient between use u and use f
$DIST_{gh}$	distance between grid cell g and grid cell h
M	non-negative weighting parameter with which the second term of the object function can be weighted in relation to the first term

The higher the M, the more the assignment of grid cells to uses is determined by spatial location of uses with respect to each other. The lower the M, the more the assignment of grid cells to uses is determined by the suitability rating of grid cells for uses. The parameter M can thus be used to achieve a compromise between the influence of suitability rating of grid cells for uses and the influence of the spatial location of uses with respect to each other.

The number of grid cells assigned to a particular use can be restricted. For example, assign no more than 10 and no less than 4 grid cells to use "timber production and dispersed recreation". The decisions, therefore, have to satisfy the following constraints:

$$MIN_u \leq \sum_{g=1}^{G} X_{gu} \leq MAX_u \qquad 1 \leq u \leq U$$

in which MIN_u minimum number of grid cells that have to be assigned to use u.
MAX_u maximum number of grid cells that can be assigned to use u.

When deciding about zoning, the relationships between a specific forest use and the socio-economic and natural environment of the forest also have to be taken into consideration. The distance between the location of uses within the forest and certain land utilization types outside the forest is important in zoning. The distance from population centres is, for example, considered important in recreational forest functions and the distance from other natural elements in the landscape is important for nature conservation (LNV, 1990).

Figure 6.2 shows how the environs of the forest are taken as an extra border of grid cells around the grid cells representing the forest (see section 5.3 too).

E	E	E	E	E	E	E
E						E
E						E
E						E
E						E
E						E
E	E	E	E	E	E	E

Grid cells with an **E** belong to the environs of the forest. They influence decisions but they are not assigned: their use is determined externally.

Figure 6.2 The setting of the forest

Grid cells that belong to the setting of the forest, are assigned to a particular use. This can be a forest utilization type or another land use type such as agriculture, residential area or lake. Because the setting can influence the functioning of the forest, the evaluation of assigning grid cell g to use u is influenced by the location of grid cell g vis-à-vis the location of grid cells belonging to the setting and the relationship between the use u and the type of use of the environs.

Grid cells belonging to the environs will influence the assignment of grid cells belonging to the forest as if they themselve were grid cells which belonged to the forest. Decisions about the use assigned to grid cells belonging to the environs, however, are not taken within the model. Decisions on how the environs are to be used are not made in strategic planning in forest management and uses assigned to grid cells belonging to the environs are, therefore, fixed outside the model. This is represented by the following constraints.

$X_{gu} = 1$ for g ε **ENVIR** and certain u

in which: **ENVIR** ε {1,2,...,G} (see figure 6.2) where G is the total number of grid cells distinguised in the model and **ENVIR** is a sub-set of grid cells belonging to the environs of the forest.

This last set of constraints completes the description of the zoning problem as a Quadratic Assignment Problem (QAP)

6.3. The algorithm

Combinatorial problems such as Quadratic Assignment Problems are difficult to solve, especially when they are large. This is because all the exact methods known for determining an optimal solution (for example the Branch and Bound method, Benders Decomposition etc.) require a computing effort that increases exponentially with n (n = G x U) (Kirkpatrick *et al.*, 1983). Heuristics do not have this problem, but there is no guarantee that a heuristic procedure for finding near-optimal solutions for one type of problem will be effective for another (Kirkpatrick *et al.*, 1983).

There are two types of heuristics: "divide and conquer" and "iterative improvement" (Kirkpatrick *et al.*, 1983). In "divide and conquer" heuristics the problem is split into smaller problems and the smaller problems are solved. The solution to the whole problem is the sum of the solutions to the smaller problems. Heuristics of the type "iterative improvement" use a different approach. Starting from a known solution (configuration) a better solution (configuration) for the whole problem is sought. Simulated annealing is an "iterative improvement" method.

Simulated annealing was chosen for the zoning model in STAGES because it is a heuristic method that gives good results in solving Quadratic Assignment Problems (Burkard, 1984; Burkard & Rendl, 1984; McLaughlin, 1989; Kirkpatrick *et al.*, 1983; Connolly, 1990). It is well documented by the aforementioned authors, so only the main lines of the algorithm are presented below.

The origin of Simulated Annealing has been described by McLaughlin (1989, p. 28) as follows:

> "The term annealing originally referred to a process employed in the fabrication of objects constructed of metal or glass. When these materials are shaped, small, often microscopic, regions of stress develop in response to deformations at the atomic level and cause the object to be prone to fracture. Annealing corrects this defect. From a chemical standpoint, regions of stress have relatively high energy and thus are "almost fractured" already. An object would be more stable (of lower energy) if the stress were absent. However, atoms and molecules in a solid, at room temperature, do not have enough energy, on average, to move about and relieve the stress (If they did, the object would not be very solid). When an object is annealed, it is first heated enough to provide the constituent atoms with sufficient energy to relax any stress but not enough to initiate melting. It is then cooled very slowly. During the cooling phase, the atoms are gradually "frozen" in place. If the annealing is done properly, the resulting object will be without stress. If the

cooling is too rapid, there will be insufficient time for atomic structure to relax completely, and the object will end up with excess energy and fracture too easily."

The energy distribution that is most likely to occur (configuration that leads to lowest energy) at a certain temperature can be calculated. Furthermore, if the temperature decline is simulated, the whole process can be simulated. This simulation model can be used to determine an optimal annealing scheme.

This model can also be used as an algorithm to solve combinatorial problems. The combinatorial problem is taken as an object. The possible solutions to the problem are taken as possible configurations of the object. If the score of a combinatorial problem is associated with energy, such that minimizing energy means optimizing score, the algorithm used in simulated annealing to identify the most likely state of the system (i.e. lowest energy c.q. highest score) at a certain temperature also serves well as an algorithm to solve combinatorial problems.

In simulated annealing the problem to be solved is seen as an object which can take more configurations (choose 1 or 0 for each X_{gu}; this leads to 2^n possible configurations with n = G x U). Each configuration is associated with a certain energy level (score of object function). Temperature can be seen as a parameter that allows skipping from a current configuration to a worse configuration. Such moves are less likely to occur as temperature declines (see below). The effect of this is that it is possible to move away from a local optimum. "Normal" iterative improvement heuristics stop at a local optimum. In the case of simulated annealing this can be avoided.

The main algorithm used in the zoning problem is described below. The algorithm is a further development of the basic algorithm described by Burkard and Rendl (1984).

Starting from a current configuration (S), a grid cell is at random determined. The next step is to change the current assignment of this grid cell to a randomly determined use. The resulting configuration is called S'. The change in object function (DELTA) is calculated. If DELTA is positive, then S' becomes the new current configuration S. If DELTA is negative there still is a chance that S' will become the new S. S' is accepted if the following relationship holds:

x < P(DELTA)
In which x is a number chosen at random between 0 and 1 and
P(DELTA) = exp(DELTA/T)

The chance that a worse configuration will be accepted increases with increasing T (temperature). The algorithm starts with a high T and T is reduced during the algorithm. At each value of T new configurations are looked for. At a certain moment, the system "freezes" in a current configuration (a local optimum). In the numerical example presented in the next section the decline of T is constant. This is not necessary. The decline of T can be altered during the cooling curve, such that a problem-specific cooling curve is obtained.

In the algorithm used to solve the zoning problem, the selection of grid cells is not totally random. Not every configuration satisfies all the minimum and maximum constraints. The basic procedure is that a grid cell is selected at random and that this grid cell is assigned to a new use at random. If the maximum allowed number of grid cells assigned to this new use is exceeded, the grid cell is assigned to another use. In the event that the current number of grid cells assigned to the current use of the grid cell equals the minimum allowable number of grid cells assigned to this use or the sum of all the maxima or the sum of all the minima equals the total number of assignable grid cells, a different procedure is followed. Then two grid cells are selected at random and the use of the first grid cell becomes the use of the second grid cell and the use of the second grid cell becomes the use of the first grid cell: the uses are transposed.

Optimality of solutions

The simulated annealing algorithm is a heuristic algorithm. This means that it cannot be guaranteed that the solution generated by Simulated Annealing to a certain problem always coincides with the optimal solution. In order to say something about the quality of the solutions generated by Simulated Annealing, they have to be compared with the exact optimal solution to the problem. This can only be done for small-scale problems, however.

By introducing $Y_{guhf} = X_{gu} \cdot X_{hf}$ the Quadratic Assignment Problem (QAP) can be reformulated as an Integer Linear Programming problem (ILP), which is equivalent to the original QAP. This conversion is established by replacing the expression $X_{gu} \cdot X_{hf}$ in the object function by Y_{guhf}. Note that $Y_{guhf} = \mathrm{MIN}\ \{ X_{gu}, X_{hf} \}$.

To force the equality $Y_{guhf} = \mathrm{MIN}\ \{ X_{gu}, X_{hf} \}$ the following three sets of constraints have to be added to the problem

(1)

$$Y_{guhf} \leq X_{gu}$$
$$1 \leq g < h \leq G; 1 \leq u \leq U; 1 \leq f \leq U$$

(2)

$$Y_{guhf} \leq X_{hf}$$
$$1 \leq g < h \leq G; 1 \leq u \leq U; 1 \leq f \leq U$$

(3)

$$Y_{guhf} \geq X_{gu} + X_{hf} - 1$$
$$1 \leq g < h \leq G; 1 \leq u \leq U; 1 \leq f \leq U$$

The optimal solution to this integer LP problem can be found by applying the Branch and Bound method (see Hillier & Liebermann (1990) or Winston (1991)). The performance of the simulated annealing algorithm can be assessed by comparing the solutions it has generated with solutions to the same problem generated by the Branch and Bound method. I carried out this test; the results are given in table 6.1.

In practice, the Branch and Bound method cannot be applied to large problems because of complexity problems. The test was, therefore, done on small problems (25 grid cells and 2 uses). Each of these problems was solved by Branch and Bound to identify the optimum. Resolving the same problem several times (10 times) with simulated annealing not only enabled the solution provided by Simulated Annealing to be compared with the optimum, but also allowed the coefficient of variation (σ/μ) could be calculated from the mean Simulated Annealing solution. This coefficient of variation gives valuable information about how well the algorithm performs. The lower it is, the more stable the performance of the algorithm.

In table 6.1 the results of the tests are summarized. In the first column the problem identification number is stated. In the second column the object value of the ILP optimum is given. In the third column the mean object value (μ) of 10 runs of the Simulated Annealing algorithm is given. In the fourth column the mean object value of the Simulated Annealing solutions is presented in percentages of the object value of the ILP optimum. In the fifth column the coefficient of variation (σ/μ) from the mean solution of the Simulated Annealing solutions is given.

From this test it is concluded there is no guarantee that the simulated annealing algorithm finds the optimal solution in all cases, but that it is likely that it gives acceptable solutions for problems so large that mathematical programming methods which guarantee identification of the optimal solution can no longer be applied because of hardware restrictions. In addition it can be concluded that simulated annealing is a stable solution technique.

Table 6.1 Results of tests for optimality

problem no.	value of the ILP solution	mean of 10 runs from SA absolute	% of ILP solution	coefficient of variation from mean solution SA
1	128.652707	128.116900	99.58	0.0057974
2	386.470850	386.421880	99.99	0.0000000
3	791.214493	784.979280	99.21	0.0035767
4	92.745814	91.647182	98.82	0.0008581
5	88.900001	87.346797	98.25	0.0111660
6	116.758801	116.514210	99.79	0.0054196
7	-154.111930	-154.161570	99.97	0.0000000
8	79.321674	79.347190	100.03 1)	0.0000000
9	20.348406	19.866405	97.63	0.0262331

1) rounding error

6.4. Discussion and conclusions

This chapter addressed zoning in forest management as a quadratic assignment problem. This formulation led to an approach to zoning which enables land quality, interactions with management goals in other grid cells and interactions with the environs of the forest to be taken into account when deciding to assign a particular grid to a particular use. Figure 6.3 gives an overview of the mathematical formulation of the model.

It was demonstrated that the simulated annealing algorithm is capable of solving the problem and providing acceptable solutions. The algorithm can also handle much larger problems efficiently. Connolly (1990) describes an improved annealing scheme. This refinement could, in some cases, lead to a better algorithm. Further research is needed to identify whether this would be the case in the application described here.

Although the model developed in this study can be considered as a step forward, it is only a first step. Much research has to be done before the zoning problem is addressed in all its aspects. At present it is not possible to constrain the size of a zone. For certain uses a minimum size of zones might be needed. Research is needed to extend the model with constraints about the minimum or maximum size of resulting zones. Another issue for research is how to deal with a town situated beyond the boundaries of the grid, which nevertheless influences zoning decisions.

Although the model presented was developed for forest management it could in principle, be used for a wider range of zoning problems in land use planning generally.

$$\max V = \sum_{g=1}^{G} \sum_{u=1}^{U} SUIT_{gu}\, WGT_{u}\, X_{gu} + M \sum_{u=1}^{U} \sum_{f=1}^{U} \sum_{g=1}^{G} < \sum_{h=1}^{G} ATT_{uf}/DIST_{gh}\, X_{gu}\, X_{hf}$$

such that:

$$\sum_{u=1}^{U} X_{gu} = 1 \qquad 1 \leq g \leq G$$

$$MIN_{u} \leq \sum_{g=1}^{G} X_{gu} \leq MAX_{u} \qquad 1 \leq u \leq U$$

$X_{gu} = 1$ for $g \in$ ENVIR and certain u

X_{gu} binary

Figure 6.3. Overview of the mathematical formulation of the zoning problem

7. THE MANAGEMENT MODEL

7.1. Introduction

In this chapter the management model is described mathematically. Inevitably, there will be some overlap with the description of the management model in chapter five (section 5.4.). The management problem involves selecting the desired future forest and the transition management. Although these are included in one (linear programming) model and are solved simultaneously, they are described separately in this chapter because this makes it easier to explain the model. The management model is described in three parts: the basis of the model, the desired future forest decision problem and the transition management decision problem.

7.2. The basis of the management model

The basis of the management model consists of decision variables and constraints. They are described in this section.

As denoted in section 5.4, the major aim of the management model is to assign forest land to management options in such a way that the land use objectives chosen in the zoning model are achieved. A management option consists of a transition management strategy that converts the current forest into a desired future forest, a description of the consequences (financial, social and environmental) of this transition management strategy, a description of management in the desired future forest and a description of the consequences of that management to maintain the desired future forest (characteristics of the forest and the financial and economic consequences).

In the management model the division of the forest into zones is obtained from the zoning model. As explained in section 5.4 each zone consists of one or more stands. The decision variables in the management model are the amount of land from a certain stand from a certain zone assigned to a certain management option. They are defined as:

Y_{zsm} = the number of hectares from stand s of zone z assigned to management option m

All the available hectares per stand have to be assigned to management options. The decisions are, therefore restricted by the following area constraints:

area constraints (1)

$$\sum_{m=1}^{M} Y_{zsm} = HA_{zs} \qquad 1 \le z \le Z;\ 1 \le s \le S_z$$

in which:	Z	total number of zones
	S_z	total number of stands in zone z
	M	total number of management options
	HA_{zs}	total number of hectares in stand s of zone z

A management option consists of a description of the characteristics of the future forest. The characteristics of the desired future forest play a role in fulfilling the functions targeted by the land use objectives. Not every combination of forest characteristics is desired in every land use objective. The land use objectives differ from zone to zone, so not every management option is feasible in every zone. Management options describe how the current forest has to be maintained or has to be transformed into the desired future forest. The current forest assumed in the management option does not exist in every stand, thus management options need not be feasible for every stand. This has been formulated in the following feasibility constraints:

feasibility constraints (2)

$Y_{zsm} = 0$ for certain combinations of z, s and m

This completes the description of the basis of the management model. The following section describes how the desired future forest is included in the model. The first part of the object function is also described.

7.3. The desired future forest decision problem

The desired future forest decision problem is incorporated in the management model by including additional constraints to the constraints that underlie the model. These additional constraints and the first part of the object function are addressed below.

It has already been noted (section 5.4) that a land use objective is specified by the needs of society that will be fulfilled (in terms of forest functions), a description of the forest structure and composition needed to achieve a forest that is suitable to fulfil these functions and a set of forest land utilization types that are feasible within this land use objective.

The realization of the desired forest structure can partly be achieved by restricting the assignment of forest land to a limited set of management options (see feasibility constraints of section 7.2) and by putting constraints on the management and forest-related characteristics which result from the assignment decisions. These constraints are based on translating land use objectives into restrictions to the achievement of characteristics of the forest in a certain zone. In this way the constraints can not only restrict the realization of characteristics of the forest, but also the output of management options in general. Examples of output are standing stocks, mean annual harvest, net discounted cash flow, mean annual increment. These constraints are formulated per zone and restrict output, therefore they are called zone level output constraints. In the model, zone level output constraints are formulated as:

zone level output constraints (3)

$$LCZ_{cz} \leq \sum_{s=1}^{S_z} \sum_{m=1}^{M} OUT_{czsm} \, Y_{zsm} \leq UCZ_{cz} \qquad 1 \leq c \leq C;\ 1 \leq z \leq Z$$

in which:

	C	total number of outputs
	LCZ_{cz}	parameter: lower limit to the number of units of output c realized in zone z
	UCZ_{cz}	parameter: upper limit to the number of units of output c realized in zone z
	OUT_{czsm}	coefficient: number of units of output c realized if one hectare of stand s of zone z is assigned to management option m.

The linearity of the relationships puts some restrictions on the definition of the outputs. Outputs have to be defined in such a way that output per hectare can be summarized as output per zone (or per forest).

For the sake of risk aversion, constraints can be put on the maximum number of hectares assigned to a certain management option. From the standpoint of desired profitability, there can be constraints on minimum level of revenue etc. All these constraints are constraints on output and are formulated at the forest level. In the model, forest level output constraints are formulated as:

forest level output constraints (4)

$$LCF_c \leq \sum_{z=1}^{Z} \sum_{s=1}^{S_z} \sum_{m=1}^{M} OUT_{czsm} \, Y_{zsm} \leq UCF_c \qquad 1 \leq c \leq C$$

in which: LCF_c parameter: lower limit to the number of units of output c realized in the forest

UCF_c parameter: upper limit to the number of units of output c realized in the forest

In addition to constraints on outputs, constraints on inputs (i) can also be formulated. They include limiting the availability of capital or labour. They do not have to be upper limits to inputs. Political decisions on, for example, employment, can result in a constraint that puts a lower limit to labour needed. It is assumed that all input factors can be implemented throughout the forest. Constraints on input factors are therefore only formulated on forest level. There is one exception to this rule. Land is an unmovable input factor and is addressed separately in this model by means of area constraints (see section 7.2). In the model, forest level input constraints are formulated as:

forest level input constraints (5)

$$LIF_i \leq \sum_{z=1}^{Z} \sum_{s=1}^{S_z} \sum_{m=1}^{M} INP_{izsm} \; Y_{zsm} \leq UIF_i \qquad 1 \leq i \leq I$$

in which:

I total number of inputs

LIF_i parameter: lower limit to the number of units of input i needed in the forest

UIF_i parameter: upper limit to the number of units of input i needed in the forest

INP_{izsm} coefficient: number of units of input i needed if one hectare of stand s in zone z is assigned to management option m.

In the management model, land use objectives per zone are translated not only into constraints on the realization of forest characteristics in a certain zone, but also into values attached to the realization of forest characteristics in a certain zone. Not only characteristics of the land (and forest) but also other forms of output such as net financial revenues can be considered valuable. Thus all the different kinds of output have to be valued. The weight of a particular output factor in a particular zone is represented by V_{cz}.

V_{cz} parameter: value of one unit of output c realized in zone z

If U_t is the total combined value of the outputs, the best decision is to assign the available forest land to management options in such a way that the following object function is maximized.

first part of object function (6a)

$$\max U_1 = \sum_{c=1}^{C} \sum_{z=1}^{Z} \sum_{s=1}^{S_z} \sum_{m=1}^{M} V_{cz} \; OUT_{czsm} \; Y_{zsm}$$

The costs of input factors are represented in the object function by means of net financial output, which is considered to be an output factor. This object function forms the first part of the object function of the management model.

This completes the description of the part of the model that deals with the desired future forest problem. The constraints described in section 7.2 form the basis of the management model and are obligatory. The constraints and part of the object function described in this section deal with the desired future forest decision problem. In the next section the constraints and part of the object function which deal with the transition management decision problem are described. If the constraints and the part of the object function which deal with the desired future forest decision problem are omitted, the management model will change into a purely transition management model.

7.4. The transition management decision problem

The transition management decision problem has been incorporated into the management model in the same way as the desired future forest decision problem, namely by including additional constraints to the obligatory constraints underlying the model. These additional constraints and the second part of the object function are addressed below.

Transition management focuses on converting the current forest into the desired future forest. A management option consists of a transition management strategy that converts the current forest into a desired future forest, a description of the consequences of that management (forest characteristics and financial, social and economic consequences), a description of management in the desired future forest and a description of the consequences of that management to maintain the desired future forest (characteristics of the forest and the financial and economic consequences). This means that consequences of transition management (financial, social and environmental) of assigning stands to management options can be assessed. These consequences have to be considered over time. The length of the planning horizon comprises several decades. The planning horizon is therefore divided into periods (t=1,...T), each of several years (normally a decade). To be able to trace the consequences in time the following (state) variables are introduced:

OCT_{ct} = number of units of output c realized in period t
ICT_{it} = number of units of input i needed in period t
OCT_{ct} is related to the decision variables in the following way:

definition of state variables for output of transition management (7)

$$OCT_{ct} = \sum_{z=1}^{Z} \sum_{s=1}^{S_z} \sum_{m=1}^{M} OUTT_{ctzsm} \; Y_{zsm}$$

$1 \le c \le C; \;\; 1 \le t \le T$

in which:	$OUTT_{ctzsm}$	coefficient: number of units of output c realized in period t if one hectare of stand s from zone z is assigned to management option m.
	T	total number of periods

ICT_{it} is related to the decision variables in the following way:

definition of state variables for input of transition management (8)

$$ICT_{it} = \sum_{z=1}^{Z} \sum_{s=1}^{S_z} \sum_{m=1}^{M} INPT_{itzsm} \; Y_{zsm}$$

$1 \le i \le I; \;\; 1 \le t \le T$

in which:	$INPT_{itzsm}$	coefficient: number of units of input i needed in period t if one hectare of stand s from zone z is assigned to management option m.

In the management model the consequences of assigning land to (transition) management options can be valued. For example, one unit of net financial output in the first period can be valued higher than one unit of net financial output in the next period. The weight of a particular output factor in particular zone is represented by VT_{ct}.

VT_{ct} parameter: value of one unit of output c realized in period t

If U_2 is the total combined value of transition management, the best decision is to assign the available forest land to management options in such a way that the following object function is maximized.

second part of object function (6b)

$$\max\ U_2 = \sum_{c=1}^{C} \sum_{t=1}^{T} VT_{ct}\ OCT_{ct}$$

Input factors are not directly valued in this object function. Their value is represented as costs and costs are included in the financial output, which is an output factor.

To ensure sustainability it can be desirable to condition the transition process. With help of the state variables defined above the transition process can be conditioned in three ways:

- A. Periodic output and input constraints;
- B. Even flow constraints;
- C. Including production smoothing in the object function;

A. Periodic output and input constraints

The transition process is conditioned by putting lower or upper limits to the number of units of output c realized or number of units of input i needed in period t.

periodic output constraint (9)

$LCT_{ct} \leq OCT_{ct} \leq UCT_{ct}$ $\qquad 1 \leq c \leq C;\ 1 \leq t \leq T$

in which:

	UCT_{ct}	parameter: Upper limit to number of units of output c realized in period t
	LCT_{ct}	parameter: Lower limit to number of units of output c needed in period t

periodic input constraint (10)

$LIT_{it} \leq ICT_{ct} \leq UIT_{it}$ $\qquad 1 \leq i \leq I;\ 1 \leq t \leq T$

in which:

	UIT_{it}	parameter: Upper limit to number of units of input i realized in period t
	LIT_{it}	parameter: Lower limit to number of units of input i needed in period t

Periodic output and input constraints are "hard". The inclusion of these constraints can imply infeasibility. On the other hand, the effect of including periodic output and input constraints is that the resulting consequences per period will be sure to lie within given boundaries. This is not always the case with the other ways to control the transition process (see below).

B. Even flow constraints

Even flow constraints are used in (among others) FORPLAN to restrict fluctuations in the number of units of output realized or number of units of input needed in the course of time. Even flow constraints are a way of production smoothing. The difference between OCT_{ct} and $OCT_{c,t-1}$ has to be smaller than a certain fixed value. The formulation of even flow constraints is:

even flow constraint on output (11)

$$LEOF_c \leq OCT_{ct} - OCT_{c,t-1} \leq UEOF_c \qquad 1 \leq c \leq C;\ 2 \leq t \leq T$$

in which:

$LEOF_c$	parameter: Lower limit to the difference between the number of units of output c realized in period t and the number of units of output c realized in period t-1
$UEOF_c$	parameter: Upper limit to the difference between number of units of output c realized in period t and the number of units of output c realized in period t-1

even flow constraint on input (12)

$$LEIF_i \leq ICT_{it} - ICT_{i,t-1} \leq UEIF_i \qquad 1 \leq i \leq I; 2 \leq t \leq T$$

in which:

$LEIF_i$	parameter: Lower limit to the difference between the number of units of input i needed in period t and the number of units of input i needed in period t-1
$UEIF_i$	parameter: Upper limit to the difference between the number of units of input i needed in period t and the number of units of input i needed in period t-1

Although the inclusion of even flow constraints can lead to infeasible constraints, they are less "hard" than periodic output and input constraints. The advantage of even flow constraints is that the user of the model does not have to formulate as many constraints as in the case of periodic output and input constraints.

C. Including production smoothing in the object function

Even flow constraints are hard constraints: the solution space is restricted. This restriction can lead to an infeasible problem. This can be avoided by penalizing differences in output or input between periods in the object function instead of restricting them by constraints. The core of the approach is that differences between the number of units of output c realized in period t and the number of units of output c realized in period t-1 are penalized in the objectfunction. The difference between production smoothing included in the object function and even flow constraints is that when production smoothing is included in the object function the maximum in difference between periods is not constraint, but larger differences are penalized more. The advantage of this approach is that the solution space is not restricted, and thus controlling fluctuations during the transition process by including production smoothing in the object function cannot lead to an infeasible problem.

If P is the total penalty on fluctuations in output, the best decision is to assign forest land to management regimes in such a way that the following objectfunction is minimized.

Third part of the object function (6c)

$$\min P = \sum_{c=1}^{C} (PPOD_c \sum_{t=2}^{T} PDOF_{ct} + PNOD_c \sum_{t=2}^{T} NDOF_{ct}) + \sum_{i=1}^{I} (PPID_i \sum_{t=2}^{T} PDIF_{it} + PNID_i \sum_{t=2}^{T} NDIF_{it})$$

such that

$$OCT_{ct} - OCT_{c,t-1} - PDOF_{ct} + NDOF_{ct} = 0 \qquad 1 \le c \le C;\ 2 \le t \le T \qquad (14)$$

$$ICT_{it} - ICT_{i,t-1} - PDIF_{it} + NDIF_{it} = 0 \qquad 1 \le i \le I;\ 2 \le t \le T \qquad (15)$$

$$PDOF_{ct} \ge 0 \qquad 1 \le c \le C;\ 1 \le t \le T \qquad (16)$$

$$PDIF_{it} \ge 0 \qquad 1 \le i \le I;\ 1 \le t \le T \qquad (17)$$

$$NDOF_{ct} \ge 0 \qquad 1 \le c \le C;\ 1 \le t \le T \qquad (18)$$

$$NDIF_{it} \ge 0 \qquad 1 \le i \le I;\ 1 \le t \le T \qquad (19)$$

[other model constraints]

in which:

$PDOF_{ct}$ state variable: positive difference between the number of units of output c realized in period t and the number of units of output c realized in period t-1

$NDOF_{ct}$ state variable: negative difference between the number of units of output c realized in period t and the number of units of output c realized in period t-1

$PPOD_c$ parameter: penalty for the sum over all periods of positive differences between the number of units of output c realized in period t and the amount of output c in period t-1.

$PNOD_c$ parameter: penalty for the sum over all periods of negative differences between the number of units of output c realized in period t and the number of units of output i realized in period t-1.

$PDIF_{it}$ parameter: positive difference between the number of units of input i needed in period t and the number of units of input i needed in period t-1

$NDIF_{it}$ state variable: negative difference between the number of units of input i needed in period t and the number of units of input i needed in period t-1

$PPID_i$ parameter: penalty for the sum over all periods of positive differences between the number of units of input i needed in period t and the number of units of input i needed in period t-1.

$PNID_i$ parameter: penalty for the sum over all periods of negative differences between the number of units of input i needed in period t and the number of units of input i needed in period t-1.

This object function forms the third part of the object function of the management model.

This approach is related to Goal Programming. In Goal Programming targets are set per goal. Deviations from the targets are minimized by penalizing these deviations in the object function. For more information about Goal Programming see Winston (1991) and also section 4.2.

Production smoothing constraints are 'soft' constraints. They will never lead to infeasibility. Production smoothing constraints included in the object function will perform well in combination with even flow constraints. The even flow constraints will roughly mark the hard boundaries of the ideal path, and production smoothing constraints will tune the solution so that the ideal path is followed as closely as possible. Periodic output and input constraints can be added to obtain a good absolute starting point.

7.5. Overview of the mathematical formulation

In this section the parts of the management model described in this chapter are combined into a complete description of the management model. This complete description consists of a complete list of all relationships described in this chapter. The only difference is that the three parts of the object function are combined into one combined object function. In this combined object function (see relationship 6) a weighting factor W is introduced ($W \geq 0$). The inclusion of W does not change the model, but makes it easier to attune the model to certain planning concepts. If, for example, the focus is on the desired future forest, then W will have a high value, if on the other hand focus is on the transition management, then W has a low value. The total combined object function is described below.

object function (6)

$$\max \ UTOT = U_1 + W\, U_2 - P$$

In the remainder of this section, the complete mathematical description of the management model is given (figure 7.1), including a list of indices (table 7.1), a list of variables (table 7.2), a list of coefficients (table 7.3), and a list of parameters (table 7.4).

Table 7.1 List of Indices in the management model of STAGES

z	index for zones
s	index for stands
m	index for management options
c	index for outputs
i	index for inputs
t	index for periods

Table 7.2 List of variables in the management model of STAGES

Y_{zsm}	decision variable: the number of hectares from stand s of zone z assigned to management option m
U_1	total value of desired future forest
U_2	total value of transition management
P	total penalty in transition management
OCT_{ct}	number of units of output c realized in period t
ICT_{it}	number of units of input i needed in period t
$PDOF_{ct}$	state variable: positive difference between the number of units of output c realized in period t and the number of units of output c realized in period t-1
$NDOF_{ct}$	state variable: negative difference between the number of units of output c realized in period t and the number of units of output c realized in period t-1
$PDIF_{it}$	state variable: positive difference between the number of units of input i needed in period t and the number of units of input i needed in period t-1
$NDIF_{it}$	state variable: negative difference between the number of units of input i needed in period t and the number of units of input i needed in period t-1

Table 7.3 List of Coefficients in the management model of STAGES

V_{cz}	value of one unit of output c realized in zone z
VT_{ct}	value of one unit of output c realized in period t
OUT_{czsm}	number of units of output c realized if one hectare of stand s of zone z is assigned to management option m
INP_{izsm}	number of units of input i needed if one hectare of stand s in zone z is assigned to management option m
$OUTT_{ctzsm}$	number of units of output c realized in period t if one hectare of stand s from zone z is assigned to management option m
$INPT_{itzsm}$	number of units of input i needed in period t if one hectare of stand s from zone z is assigned to management option m

Table 7.4 List of Parameters in the management model of STAGES

Z	total number of zones
S_z	total number of stands in zone z
M	total number of management options
C	total number of outputs
I	total number of inputs
T	total number of periods
W	weighting factor between value of desired future forest and value of transition management
V_{cz}	value of one unit of output c realized in zone z
VT_{ct}	value of one unit of output c realized in period t
HA_{sz}	total number of hectares in stand s of zone z
LCZ_{cz}	lower limit to the number of units of output c realized in zone z
UCZ_{cz}	upper limit to the number of units of output c realized in zone z
LCF_c	lower limit to the number of units of output c realized in forest
UCF_c	upper limit to the number of units of output c realized in forest
LIF_i	lower limit to the number of units of input i needed in forest
UIF_i	upper limit to the number of units of input i needed in forest
UIT_{it}	upper limit to number of units of input i realized in period t
LIT_{it}	lower limit to number of units of input i needed in period t
UCT_{ct}	upper limit to number of units of output c realized in period t
LCT_{ct}	lower limit to number of units of output c needed in period t

Table 7.4 List of Parameters: continued

$LEOF_c$	lower limit to the difference between the number of units of output c realized in period t and the number of units of output c realized in period t-1
$UEOF_c$	upper limit to the difference between number of units of output c realized in period t and the number of units of output c realized in period t-1
$LEIF_c$	lower limit to the difference between the number of units of input i needed in period t and the number of units of input i needed in period t-1
$UEIF_c$	upper limit to the difference between the number of units of input i needed in period t and the number of units of input i needed in period t-1
$PPOD_c$	penalty for the sum over all periods of positive differences between the number of units of output c realized in period t and the amount of output c realized in period t-1.
$PNOD_c$	penalty for the sum over all periods of negative differences between the number of units of output c realized in period t and the number of units of output i realized in period t-1.
$PDIF_{it}$	positive difference between the number of units of input i needed in period t and the number of units of input i needed in period t-1
$PPID_i$	penalty for the sum over all periods of positive differences between the number of units of input i needed in period t and the number of units of input i needed in period t-1.
$PNID_i$	penalty for the sum over all periods of negative differences between the number of units of input i needed in period t and the number of units of input i needed in period t-1.

object function (6)

$$\max \quad UTOT = U_1 + W\,U_2 - P$$

such that

first part of object function (6a)

$$U_1 = \sum_{z=1}^{Z} \sum_{c=1}^{C} \sum_{s=1}^{S_z} \sum_{m=1}^{M} V_{cz}\, OUT_{czsm}\, Y_{zsm}$$

second part of object function (6b)

$$U_2 = \sum_{c=1}^{C} \sum_{t=1}^{T} VT_{ct} \sum_{z=1}^{Z} \sum_{s=1}^{S_z} \sum_{m=1}^{M} OUTT_{ctzsm}\, Y_{zsm}$$

third part of the object function (6c)

$$P = \sum_{c=1}^{C} (PPOD_c \sum_{t=2}^{T} PDOF_{ct} + PNOD_c \sum_{t=2}^{T} NDOF_{ct}) + \sum_{i=1}^{I} (PPID_i \sum_{t=2}^{T} PDIF_{it} + PNID_i \sum_{t=2}^{T} NDIF_{it})$$

BASIS OF MODEL

area constraints (1)

$$\sum_{m=1}^{M} Y_{zsm} = HA_{zs} \qquad 1 \le z \le Z;\ 1 \le s \le S$$

feasibility constraints (2)

$Y_{zsm} = 0$ for certain combinations of z,s and m

DESIRED FUTURE FOREST

zone level output constraints (3)

$$LCZ_{cz} \le \sum_{s=1}^{S_z} \sum_{m=1}^{M} OUT_{czsm}\, Y_{zsm} \le UCZ_{cz} \qquad 1 \le c \le C;\ 1 \le z \le Z$$

forest level output constraints (4)

$$LCF_c \le \sum_{z=1}^{Z} \sum_{s=1}^{S_z} \sum_{m=1}^{M} OUT_{czsm}\, Y_{zsm} \le UCF_c \qquad 1 \le c \le C$$

forest level input constraints (5)

$$LIF_i \le \sum_{z=1}^{Z} \sum_{s=1}^{S_z} \sum_{m=1}^{M} INP_{izsm}\, Y_{zsm} \le UIF_i \qquad 1 \le i \le I$$

Figure 7.1 Overview of the mathematical formulation of the management model

TRANSITION MANAGEMENT

definition of state variables for output of transition management (7)

$$OCT_{ct} = \sum_{z=1}^{Z} \sum_{s=1}^{S_z} \sum_{m=1}^{M} OUTT_{ctzsm}\, Y_{zsm} \qquad 1 \le c \le C;\ 1 \le t \le T$$

definition of state variables for input of transition management (8)

$$ICT_{it} = \sum_{z=1}^{Z} \sum_{s=1}^{S_z} \sum_{m=1}^{M} INPT_{itzsm}\, Y_{zsm} \qquad 1 \le i \le I;\ 1 \le t \le T$$

periodic output constraint (9)

$$LCT_{ct} \le OCT_{ct} \le UCT_{ct} \qquad 1 \le c \le C;\ 1 \le t \le T$$

periodic input constraint (10)

$$LIT_{it} \le ICT_{it} \le UIT_{it} \qquad 1 \le i \le I;\ 1 \le t \le T$$

even flow constraint on output (11)

$$LEOF_c \le OCT_{ct} - OCT_{c,t-1} \le UEOF_c \qquad 1 \le c \le C;\ 2 \le t \le T$$

even flow constraint on input (12)

$$LEIF_i \le ICT_{it} - ICT_{i,t-1} \le UEIF_i \qquad 1 \le i \le I;\ 2 \le t \le T$$

definition of state variables for output in production smoothing (14)

$$OCT_{ct} - OCT_{c,t-1} - PDOF_{ct} + NDOF_{ct} = 0 \qquad 1 \le c \le C;\ 2 \le t \le T$$

definition of state variables for input in production smoothing (15)

$$ICT_{it} - ICT_{i,t-1} - PDIF_{it} + NDIF_{it} = 0 \qquad 1 \le i \le I;\ 2 \le t \le T$$

non-negative constraints

(16)

$$PDOF_{ct} \ge 0 \qquad 1 \le c \le C;\ 1 \le t \le T$$

(17)

$$PDIF_{it} \ge 0 \qquad 1 \le i \le I;\ 1 \le t \le T$$

(18)

$$NDOF_{ct} \ge 0 \qquad 1 \le c \le C;\ 1 \le t \le T$$

(19)

$$NDIF_{it} \ge 0 \qquad 1 \le i \le I;\ 1 \le t \le T$$

Figure 7.1 Overview of the mathematical formulation of the management model: continued

8. THE WATERBLOEM CASE STUDY

8.1. Introduction

The STAGES models described in earlier chapters were applied in a case study, to validate them and to demonstrate their applicability. This case study is described below.

In this case study, the emphasis is on the models and not on the data needed to run the models. The reliability of the data used is not considered. However, to get a clear picture of the potential of the models, the data used must resemble real world data as much as possible. To achieve this, the data used in my case study were taken from the "Waterbloem" management plan (SBB, 1990). Waterbloem is a national forest (of about 180 hectares) in the southern part of the Netherlands (see figure 8.1.). If real-world data were lacking (could not be derived from the Waterbloem management plan), best professional judgment was used to supply the missing data. Because the models are emphasized, not the data, there will be no discussions on the constraints included and on parameters used.

The models were implemented on a DEC VAX 4200 (see sections 8.2 and 8.3 below). In the application of the management model one of the solutions of the application of the zoning model was taken as input. However, the feedback link between the zoning model and the management model was not elaborated further in this application, because the algorithm to provide the feedback between the two models had not been developed sufficiently to enable it to be applied in this case study (see appendix B).

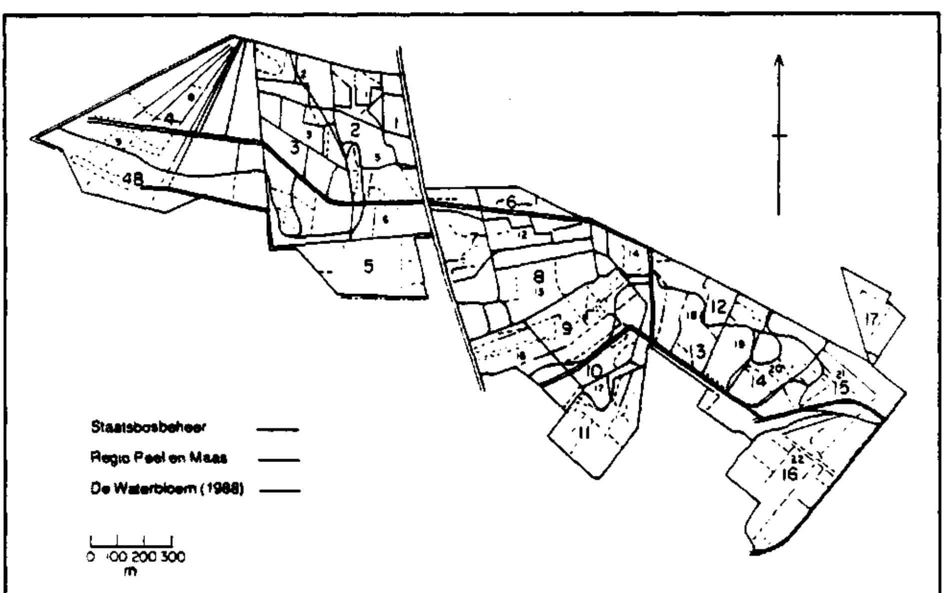

Figure 8.1 Map of Waterbloem source: SBB, 1990

8.2. Case study using the zoning model[1]

8.2.1. Data concerning Waterbloem

In the zoning model the Waterbloem forest is represented by 85 grid cells and the environs of Waterbloem by 80 grid cells (see Figure 8.2). For the sake of simplicity it is assumed that each grid cell is 1 ha. In Waterbloem the following uses are considered important:

1. timber production;
2. nature conservation;
3. recreation;
4. timber production and dispersed recreation.

The land use objectives of the grid cells belonging to the environs of the forest are determined externally. They are:

5. residential area;
6. other forest managed for timber production and nature conservation
7. agriculture;
8. road.

Their location is given in Figure 8.2.

.	.	7	7	7	7	7	7	7	7	.	.	.	.	.	.	.	.	.	.	.	.	.
7	7	7	0	0	0	0	0	0	7	.	.	.	.	.	.	.	.	.	.	.	.	.
7	0	0	0	0	0	0	0	0	7	.	.	.	.	.	.	.	.	.	.	.	.	.
7	0	0	0	0	0	0	0	0	7	8	7	7	6	.	.	.	.	.	.	.	.	.
7	7	0	0	7	0	0	0	0	0	0	0	0	6	6	.	.	.	.	.	.	.	.
.	7	7	7	7	7	0	0	0	0	0	0	0	0	6	6	6	6	.	6	6	6	.
.	.	.	.	.	7	7	0	0	0	8	0	0	0	0	0	0	6	6	6	0	6	6
.	.	.	.	.	.	7	7	7	7	8	0	0	0	0	0	0	0	0	6	6	0	6
.	.	.	.	.	.	.	.	.	.	8	0	0	0	0	0	0	0	0	0	0	0	6
.	.	.	.	.	.	.	.	.	.	8	7	7	0	0	5	5	0	0	0	0	0	6
.	.	.	.	.	.	.	.	.	.	.	.	7	7	0	5	5	5	0	0	0	5	6
.	.	.	.	.	.	.	.	.	.	.	.	.	7	5	5	.	5	0	0	5	5	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	0	0	5	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	5	5	5	.	.

Figure 8.2 Representation of Waterbloem and its environs by means of grid cells and uses

[1]The case study described in this section in which the zoning model is applied has already been published (see Bos, 1993).

The relationships (ATT_{uf}) between the uses are given in table 8.1. These relationships are based on a translation and an extension of the "degree of compatibility among various forest uses" (Clawson, 1974). The more compatible the uses are, the more they attract each other. If use u attracts use f ATT_{uf}=1: in the case of strong attraction ATT_{uf}=2. If use u and use f conflict, ATT_{uf}=-1: in the case of strong conflict ATT_{uf}=-2. If use u and use f are neutral to each other ATT_{uf}=0.

Table 8.1 Relationships (ATT_{uf}) between uses

USE u	USE f							
	1	2	3	4	5	6	7	8
1	1	-1	0	1	0	0	0	0
2	-1	2	-2	-1	-2	1	-2	-2
3	0	-2	1	0	2	1	-1	2
4	1	-1	0	2	2	1	-1	2
5	0	-2	2	2	0	0	0	0
6	0	1	1	1	0	0	0	0
7	0	-2	-1	1	0	0	0	0
8	0	-2	2	2	0	0	0	0

As can be seen from table 8.1 ATT_{uf}=ATT_{fu}. This means that if recreation conflicts with nature conservation, nature conservation also conflicts with recreation. In reality the recreational experience does not have to be negatively influenced by the presence of nature, whereas nature can be negatively influenced by the presence of recreationists. These kinds of relationships are not directly represented in the model, but in determining the value of ATT_{uf} the decision maker must take them into account. An example of how this can be done in a formal way is presented in appendix C.

As can be seen from table 8.1, timber production (use 1) is neutral to most other uses. Most uses conflict with nature conservation (use 2). Recreation (use 3) and timber production and dispersed recreation (use 4) do not conflict with other uses, apart for nature conservation (use 2). Agriculture (use 7) conflicts with recreation. For the sake of simplicity I have omitted the suitability rating per combination of grid cell uses. All the suitability ratings are within the range 0 - 9.

8.2.2. Description of alternatives

In this example 7 runs are presented. The differences between these runs are given in table 8.2. Each row in the table represents an alternative run. The first column denotes the number of the alternative. The second column contains the value of the weighting parameter M. Columns three to six give the weights per use. Columns seven to ten give the right-hand side values of the constraints concerning the minimum number of grid cells that have to be assigned to a particular use. Constraints concerning the maximum number of grid cells that are permitted to be assigned to a particular use are not included in this case study.

Table 8.2 Differences between the seven runs of the zoning model

run	M	WGT_u				min. no. of grid cells			
		1	2	3	4	1	2	3	4
1	0.00	0.25	0.25	0.25	0.25	15	15	15	15
2	100.00	0.25	0.25	0.25	0.25	15	15	15	15
3	0.05	0.25	0.25	0.25	0.25	15	15	15	15
4	0.05	0.40	0.20	0.20	0.20	30	15	15	15
5	0.05	0.20	0.40	0.20	0.20	15	30	15	15
6	0.05	0.20	0.20	0.40	0.20	15	15	30	15
7	0.05	0.20	0.20	0.20	0.40	15	15	15	30

All the runs have the same basis: at least 15 grid cells have to be assigned to every use ($MIN_u = 15$ for $1 \leq u \leq U$) and there are no restrictions on the maximum number of grid cells assigned to a particular use.

In the first three runs all uses are equally weighted. The runs differ in the value of M. The first two runs aim at identifying the best zoning from the point of view of suitability rating (first run) and the best zoning from the point of view of the location of uses in respect to each other (second run). In the first run M = 0.0. This means that the second term of the object function is eliminated and the problem can be taken as a simple linear assignment problem: the assignment is based purely on suitability of grid cells for uses. In the second run M = 100, for the Waterbloem case this is very high. It means that the first term of the object function is practically eliminated: the assignment is based purely on location of uses in relation to each other. In the third run a solution is sought which is based partly on suitability rates and partly on location of uses. The value for M that would lead to this result was chosen after rerunning the model several times with different values of M. The parameter M was chosen high and, with each run, M was lowered until the clustering of grid cells assigned to a certain use u started to loosen up, because the suitability rating of grid cells for a particular use started to play a determining role in the assignment. This happened around M = 0.05. The solution to this third run is thus based partly on the suitability ratings of grid cells and partly on the location of uses with respect to each other.

The last five runs are all based on M = 0.05 and differ in the weights assigned to the uses and the minimal number of grids that have to be assigned to a certain use (see table 8.2). In run number 4 the emphasis is on timber production, in run number 5 it is on nature conservation, in run number 6 it is on recreation and in run number 7 it is on timber production and dispersed recreation. If in a certain run the emphasis is on use u, this means that the weight assigned to use u is double the weight assigned to other uses and that the minimum number of grid cells that have to be assigned to use u is double the number that have to be assigned to other uses.

8.2.3. Description of results

Figure 8.3 presents the solutions to the problems described in table 8.2 The solutions will be discussed.

The two main differences between the first three runs (run 1: M=0.0, run 2: M=100.0 and run 3: M=0.05) are the differences in clustering of uses and the location of the nature conservation zone; west in runs 1 and 3, and east in run 2. The strong clustering of grid cells assigned to a certain use stems from increasing values for M. The location of the nature conservation zone in runs 1 and 3 is due to high suitability ratings for nature conservation in that part of the grid. The shift from the nature conservation zone can be explained as a result of the high M. In run 2, M is so high that suitability ratings no longer play a role in the assignment process. From table 8.1 it can be seen that nature conservation conflicts with every use except with other forest (use 6). Hence, from this point of view it is logical to locate a nature conservation zone in a part of the grid where it is surrounded by forest.
When runs 3, 4, 5, 6 and 7 are compared it can be concluded that in all the runs the nature conservation zone is mainly located in the west part of the forest. Recreation is always located near the residential area, whilst timber production and dispersed recreation are always located around the road. Timber production is often located on the south side and the west side of the nature conservation zone.
The emphasis on timber production mainly affects the amount of grid cells assigned to 'timber production and dispersed recreation' (use 4). The emphasis on nature conservation leads to a situation in which there is a long (interrupted) zone used for nature conservation on the north side of the forest and a zone used for nature conservation on the west side of the forest. The emphasis on recreation leads to a situation in

which 39 grid cells are assigned to *recreation* (9 more then necessary). Most of these grid cells constitute one big zone between town and road. Emphasis on timber production and dispersed recreation gives a solution similar to the one in which there was no emphasis on any use (run 3).

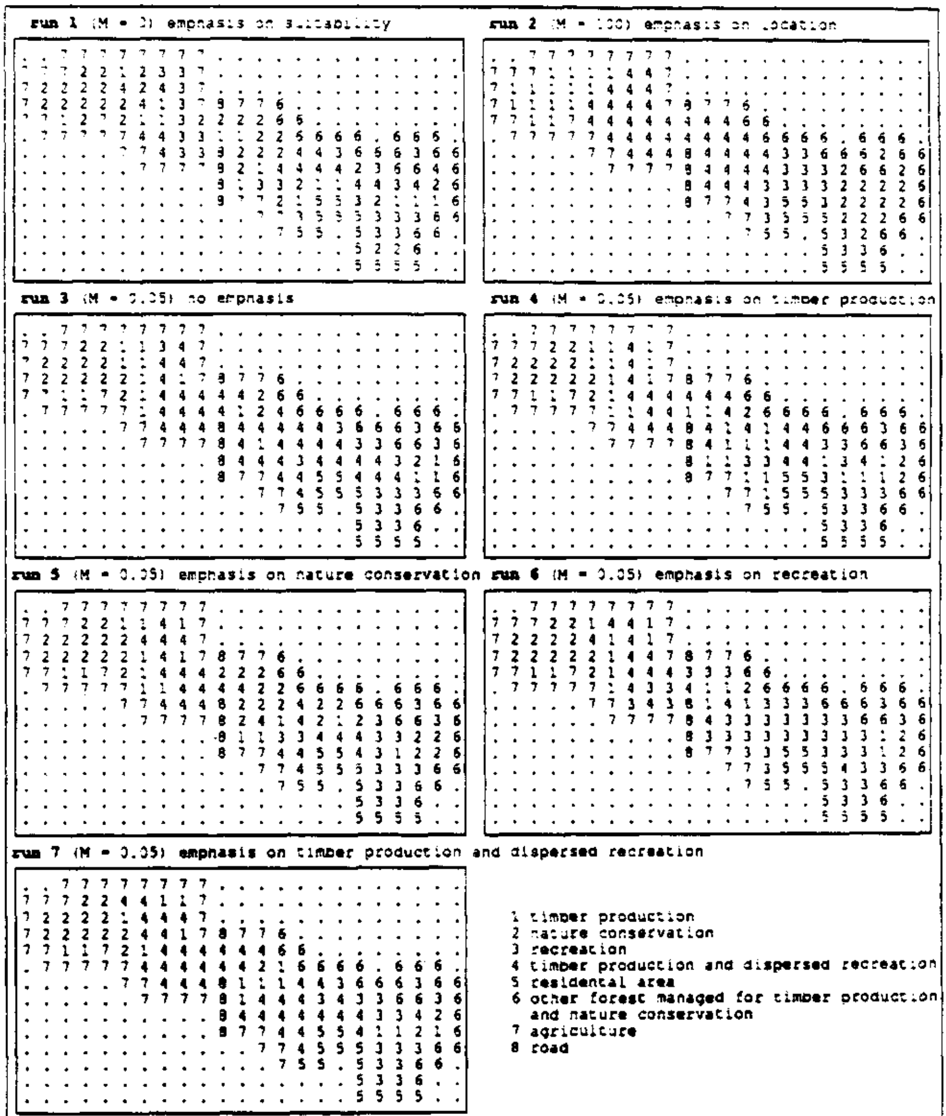

Figure 8.3 Solutions to the problems described in table 8.2

8.3. Case study using the management model[2]

8.3.1. Operationalization of land use objectives per zone

One of the alternatives generated by the zoning model was chosen, to demonstrate the management model. It is the alternative in which M=0.05 and in which all uses are equally weighted (see section 8.2). The division of the forest into zones is based on this alternative. Each zone consists of one or more stands. In figure 8.4 it is shown that the numbering of the zones is based on the output of the zoning model.

land use objectives per grid

```
. . . . . . . . . . . . . . . . . . . . . . .
. . . 2 2 1 1 3 4 . . . . . . . . . . . . . .
. 2 2 2 2 1 1 4 4 . . . . . . . . . . . . . .
. 2 2 2 2 2 1 4 1 . . . . . . . . . . . . . .
. . 1 1 . 2 1 4 4 4 4 4 2 . . . . . . . . . .
. . . . . . 1 4 4 4 4 1 2 4 . . . . . . . . .
. . . . . . . 4 4 4 . 4 4 4 4 4 3 . . . 3 . .
. . . . . . . . . . . 4 1 4 4 4 4 3 3 . . 3 .
. . . . . . . . . . . 4 4 4 3 4 4 4 4 3 2 1 .
. . . . . . . . . . . . . 4 4 . . 4 4 4 1 1 .
. . . . . . . . . . . . . . 4 . . . 3 3 3 . .
. . . . . . . . . . . . . . . . . . 3 3 . . .
. . . . . . . . . . . . . . . . . . 3 3 . . .
. . . . . . . . . . . . . . . . . . . . . . .
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zones

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. . . . . . . . . . . . . . . . . . . . . . .
. . . 1 1 2 2 3 4 . . . . . . . . . . . . . .
. 1 1 1 1 2 2 4 4 . . . . . . . . . . . . . .
. 1 1 1 1 1 2 4 5 . . . . . . . . . . . . . .
. . 1717. 1 2 4 4 4 4 4 7 . . . . . . . . . .
. . . . . . 2 4 4 4 4 6 7 8 . . . . . . . . .
. . . . . . . 4 4 4 . 8 8 8 8 8 11. . . 15. .
. . . . . . . . . . . 8 9 8 8 8 8 1111. . 15.
. . . . . . . . . . . 8 8 8 101212121212111614.
. . . . . . . . . . . . . 8 8 . . 1212121414.
. . . . . . . . . . . . . . 8 . . . 131313. .
. . . . . . . . . . . . . . . . . . 1313. . .
. . . . . . . . . . . . . . . . . . 1313. . .
. . . . . . . . . . . . . . . . . . . . . . .
```

Figure 8.4 Location of zones in the Waterbloem forest as generated by the zoning model and as used in validating the management model

For demonstration purposes it is assumed that each grid cell consists of one stand of 1 ha. In table 8.3 the land use objectives and the number of stands are given per zone. The location of the zones is given in figure 8.4.

[2]Backgrounds of the case study are described in Bos *et al.* (1994). In this section only the headlines are presented.

Table 8.3 Description of zones featured in the alternative generated by the zoning model

Zone	Use	Number of stands
1	nature conservation	12
2	timber production	7
3	recreation	1
4	timber production and dispersed recreation	16
5	timber production	1
6	timber production	1
7	nature conservation	2
8	timber production and dispersed recreation	17
9	timber production	1
10	recreation	1
11	recreation	4
12	timber production and dispersed recreation	7
13	recreation	7
14	timber production	3
15	recreation	2
16	nature conservation	1
17	timber production	2

The four uses were operationalized into constraints concerning characteristics of the desired future forest as described in chapter three.

Timber production

For timber production the harvest (m^3 per ha per year) is assumed to be the most important objective. In addition, the standing stock is important, because it determines the sustainability of production. These two characteristics were valued in the object function. In zones assigned to timber production the assignment of hectares to management options had to satisfy the following constraints:

- No more than 25% of the available hectares to be assigned to mixed broadleaf coniferous forest;
- No less than 4.5 working hours per hectare per year in the desired future forest.

The first constraint was formulated to avoid loss of profitability, and the second to ensure quality. It was assumed that the quality of the timber would increase with the number of working hours. However, this contention is questionable; quality is not related to the number of working hours, but to management activities. It would have been better to exclude management options that would yield timber of poor quality. Every constraint formulated can be questioned, but as already stated in the introduction to this chapter, the emphasis in this validation exercise is not on the data, but on the models. As clearly shown above, the management model provides several instruments to include the wishes of the decision maker.

Nature conservation

A number of criteria (more than 20, see Hekhuis, De Molenaar and Jonkers, 1994) determine the suitability of forest for nature conservation. In this case study, these criteria are represented by a set of constraints on forest characteristics, for demonstration purposes. In zones assigned to nature conservation the assignment of hectares to management options had to satisfy the following constraints:

- Average rotation period no less than 120 years;
- Average number of tree species in a zone no less than 2;
- No less than 50% of available hectares to be assigned to mixed broadleaf conifereous forest;
- No less than 70% of available hectares to be assigned to broadleaf species;
- No less than 35% of available hectares to be assigned to tree species that belong to Natural Potential Vegetation (NPV);
- No more than 4 working hours per hectare per year in desired future forest;
- No less than 40% of available hectares to be assigned to shade tolerant species.

The average number of tree species in a zone was calculated by multiplying the number of tree species in a management option by the number of hectares assigned to that option. The resulting value was added to the scores of the other management options for average number of tree species and was divided by the total number of hectares within that zone. The resulting figure is the average number of tree species. The average number of tree species was taken as a proxy variable for the horizontal structure and diversity of the forest. The constraint concerning the shade-tolerant species was formulated to ensure that the forest would have a vertical structure.

Recreation

In the Netherlands the suitability of forest for recreation is determined by the following criteria:

- diversity (De Nil, 1974; L&V, 1986; Sissingh, 1978; Filius, 1983; Zonneveld, 1977; Van der Kloet, 1963);
- age of trees (Van den Berg & Coeterier, 1980; Sissingh, 1978);
- shelter (De Jonge, 1969; De Nil, 1974; Den Hertog, 1986);
- naturalness (Van den Bos, 1969; Katteler & Kropman, 1975).

In this case study these criteria were represented by means of a restricted set of constraints on forest characteristics. In zones assigned to recreation the assignment of hectares to management options had to satisfy the following constraints:
- Average rotation period no less than 120 years;
- Average number of tree species no less than 2;
- No less than 50% of available hectares to be assigned to mixed broadleaf confiereous forest;
- No less than 30% and no more than 70% of the available hectares to be assigned to broadleaf species;
- No more than 4 working hours per hectare per year in desired future forest;
- No less than 25% of available hectares to be assigned to shade tolerant species.

The constraints are operationalizations of the diversity criterion, which is important for recreation. The constraint "no more than 4 working hours per hectare per year" was included to avoid too much noise in the forest.

Timber production and dispersed recreation

The forest was deemed to be suitable to be used for the combination of timber production and dispersed recreation, if it satisfied criteria concerning timber production and criteria concerning recreation. Therefore in zones assigned to timber production and dispersed recreation the assignment of hectares to management options had to satisfy the following constraints:
- Average rotation period no less than 120 years;
- Average number of tree species no less than 2;
- No less than 25% and no more than 50% of available hectares to be assigned to mixed broadleaf confiereous forest;
- No less than 30% and no more than 50% of the available hectares to be assigned to broadleaf species;
- No more than 4 working hours per hectare per year in desired future forest ;
- No less than 4.5 m^3 harvest per hectare per year.

In addition to the constraints for specific zones mentioned above, constraints for the whole forest were included, to ensure the economic sustainability of the management organization (that the organisation may not go bankrupt). These constraints were also formulated on forest level:

- financial yield may not be less than 250 units per hectare per year in desired future forest (to ensure income);
- no more than 7 working hours per hectare per year in desired future forest (to restrict costs);
- average number of tree species no less than 2 (to avert risk);
- no less than 30% of available hectares to be assigned to mixed broadleaf coniferous forest (to ensure stability of the forest and avert risk).

All alternatives developed were based on the set of constraints formulated in this section. This set of constraints is therefore referred to as the basic alternative. In this case study the focus was on demonstrating the validity of the models and not on ascertain the correctness of the constraints.

8.3.2. Management options

A management option consists of a desired future forest in terms of forest land utilization types, a transition management strategy that converts the current forest into this desired future forest and a description of the implications of the desired future forest and transition management strategy. Six forest land utilization types were identified in the Waterbloem case study. They were selected from the list of Dutch forest land utilization types given in L&V (1986) (see table 8.4). It was assumed that the current forest has to be transformed into the desired future forest within 50 years. This planning horizon was divided into 5 10-year periods. Hence in principle, there were five alternatives per forest land utilization type: transform the current forest in the first period, in the second period and so on. This means that per stand 30 management options (6 forest land utilization types times 5 periods) can be formulated (30 times 85 stands makes 2550 management options in total). In the case study, 2306 management options were formulated (not every management option of the 2550 possible options appeared to be feasible).

Table 8.4 LUTs used in the Waterbloem case study to validate the management model

Code of LUT	Distribution of tree species		
5	pm (100)		
9	ps (100)		
12	ag (70)	fs (30)	
14	qr (100)		
15	fs (100)		
25c	qr (33)	bp (33)	ps (33)

Explanation: ag(70), fs(30) means 70 % of total basal area consists of *Alnus glutinosa* and 30% of total basal area consists of *Fagus sylvatica*

Key:
ag = *Alnus glutinosa* (L.) Gaertner.
bp = *Betula pendula* Roth.
fs = *Fagus sylvatica* L.
pm = *Pseudotsuga menziesii* (Mirb.) Franco.
ps = *Pinus sylvestris* L.
qr = *Quercus robur* L.

An example of a management option is given below. The implications of a type of management depend on the soil type of the grid cell and the current forest in that grid cell. Therefore the consequences of a management option have to be described per grid cell. Below, they are described for grid cell 1.

Management option: future forest type 25c and transition in period 5

Description of management
This management option transforms a stand into forest land utilization type 25c, which is a forest type described in L&V (1986) consisting of the following tree species: *Quercus robur*, *Pinus sylvestris* and *Betula pendula*. Management can be described as uneven-aged management (groups), the forest regenerates naturally.

Because the tree species of the current forest do not fit in the forest land utilization type of this management option, they have to be removed. This can be done in several ways. Furthermore, because the tree species desired in the future forest are not present in the current forest, this management option transforms the current forest into the desired future forest in period five, by clearcutting the old stand and reforestating with the tree species desired in the future forest. Note that this is only one of the possible types of transition managements. The consequence of this transition management strategy is that there is zero reforestation by means of natural regeneration during the transition period.

Table 8.5 shows the consequences of this management option for the desired future forest. The "rotation period" of 190 years is the rotation period of the oldest trees harvested. The discount rate used in this case study is zero. Table 8.6 shows the consequences of this management option during transition.

Table 8.5 Consequences in desired future forest if 1 ha of grid cell 1 is assigned to management option 25c

rotation period (years)	190
average number of tree species	3
percentage mixed forest	80
percentage broadleaf	66
percentage Natural Potential Vegetation	0
number of working hours (per ha per year)	2
harvest (m^3 per ha per year)	2.5
cash flow in guilders per ha per year	125
percentage of species which are shade tolerant	0

Table 8.6 Consequences per period (of 10 year) during transition management if 1 ha of grid cell 1 is assigned to management option 25c

Period	Standing stock in m^3/ha	harvest from thinning and clearcut in m^3/ha	Cash flow in guilders per period
1	91.00	19.00	0.00
2	128.00	23.00	0.00
3	163.00	26.00	0.00
4	196.00	28.00	0.00
5	82.00	155.00	1627.00

8.3.3. Description of alternatives

In this case study the following alternatives and their consequences were generated:
A: money
B: nature
C: production
D: recreation
E: multiple use

The differences between these alternatives are presented in two tables. The first table (table 8.7) presents the valuation of forest characteristics in the desired future forest. The second table (table 8.8) presents the valuation of the forest characteristics during transition management. The sum of values given to realization of units of outputs is 1000, as can be seen from the tables. This was done to enable the outcome of the alternatives to be compared. Each cell in the table contains the value attached to one achieved unit of output in a zone (table 8.7) or in a period (table 8.8). In this case study there was no difference in valuations per zone or per period.

In the "money" alternative financial returns are valued highest (664 points see table 8.7) in the desired future forest. Of the characteristics during transition management financial returns are also highly valued (625 points see table 8.8). In the "nature" alternative the percentage of natural potential vegetation is valued most (450 points see table 8.7) in the desired future forest and of the characteristics during transition, natural generation and standing volume are valued highest (respectively 750 points and 125 points, see table 8.8). In the "production" alternative the harvest in m^3 per ha per year is valued most (855 points see table 8.7) in the desired future forest, and of the characteristics during transition the harvest in m^3 per ha per period are also valued most (750 points, see table 8.8). In the "recreation" alternative the characteristics of rotation (in years), average number of tree species, percentage of mixed broadleaf/coniferous forest and percentage of shade-tolerant species (all 210 points, see table 8.7) are valued equally in the desired future forest, and in the transition management, transition by means of clearcut has a zero value. The fact that transition is valued high (487.5 points, see table 8.8) is not meaningful, because all hectares already have to be transformed. The only effect is that decisions are determined more by the values attached to the characteristics of the future forest (meaningful valuations add up to 1000) than by the characteristics of the transition management (meaningful valuations add up to 1000-487.5). Finally, in the "multiple use" alternative all characteristics are equally valued in the desired future forest (see table 8.7) as well as during transition management (see table 8.8).

Table 8.7 Alternative weight sets as used in the case study for valuation of characteristics for the desired future forest

Consequences	Weight sets				
	A money	B nature	C production	D recreation	E multiple use
Rotation	42	130	25	210	111.11
Species	42	100	25	210	111.11
Mixed forest	42	120	25	210	111.11
Broadleaf	42	150	15	156	111.11
Nat. Pot. Veg.	42	450	0	1	111.11
Working hours	42	0	25	1	111.11
Harvest	42	1	855	1	111.11
Financ.	664	1	15	1	111.11
Shade tol. species	42	48	15	210	111.11
Total	1000	1000	1000	1000	999.99

Tables 8.7 and 8.8 also give an overview of the outputs (and inputs) that were included in this application of the management model. Table 8.8 lists the outputs (and inputs) distinguished when deciding on the transition management and table 8.7 lists the outputs (and inputs) distinguished when deciding on the desired future forest.

The management model was run three times for each alternative. The differences between these runs were caused by assigning a different value to the weighting parameter W. In the first run, the emphasis was on the characteristics of the future desired forest (W=0.00001). In the second run, the valuations of the characteristics of the future desired forest and of the characteristics during transition interacted (W=1.4). In the third run the emphasis was on the characteristics during transition (W=10000). When W=10000 the choices made in transition management set the context for the decisions made about the desired future forest. When W=0.0001 the choices made in the desired future forest set the context for the decisions reached in the transition management. For the first run in which the emphasis was on the desired future forest, W=0.0001 was chosen instead of W=0, because with W=0 all choices would have been equally valued in the transition management (the value of each choice was multiplied by W). The value of W=1.4 in the run in which decisions about the desired future forest and about the transition management influence each other was determined similarly as the value of the weighting parameter M of the zoning model, by rerunning the model several times with different values of W and studying the outcome. The results of these runs are given in the following section.

Table 8.8 Alternative weight sets used in the case study for valuation of characteristics during transition

Consequences	Weight sets				
	A money	B nature	C production	D recreation	E multiple use
Standing stock	75	125	200	150	166.65
Harvest	75	50	750	150	166.65
Transition	75	75	0	487.5	166.65
Clearcut	75	0	50	0	166.65
Nat. Regeneration	75	750	0	150	166.65
Financ.	625.4784	0.6254	0.625	62.547	166.794
Total	1000.478	1000.625	1000.625	1000.047	1000.044

8.3.4. Description of results

The aim of this case study was to validate the models and to demonstrate their potential. Therefore it is not necessary to give a complete analysis of the consequences of the alternatives. Such an analysis can be found in Bos *et al.* (1994).

Results concerning the distribution of forest types in the desired future forest situation

The available hectares per stand were allocated to the forest land utilization types in such a way that all constraints were met and the score of the object function (based on multiplying the value per unit of a certain characteristic and the number of units achieved; see also chapter seven) was maximised.

From figure 8.5 it can be seen that shifts in distribution of forest types within a certain alternative caused by another value of W are marginal. The following facts became clear. Forest type 9 appears at high values for W and disappears at low values for W. Forest type 25c constitutes a major part of the forest (34-44%). This is plausible because this forest type contains many tree species and has a long rotation period. These characteristics are often highly valued or demanded (because of constraints). The only exception is in the multiple use alternative, where forest type 5 changes from 14% to 28% (if W increases).

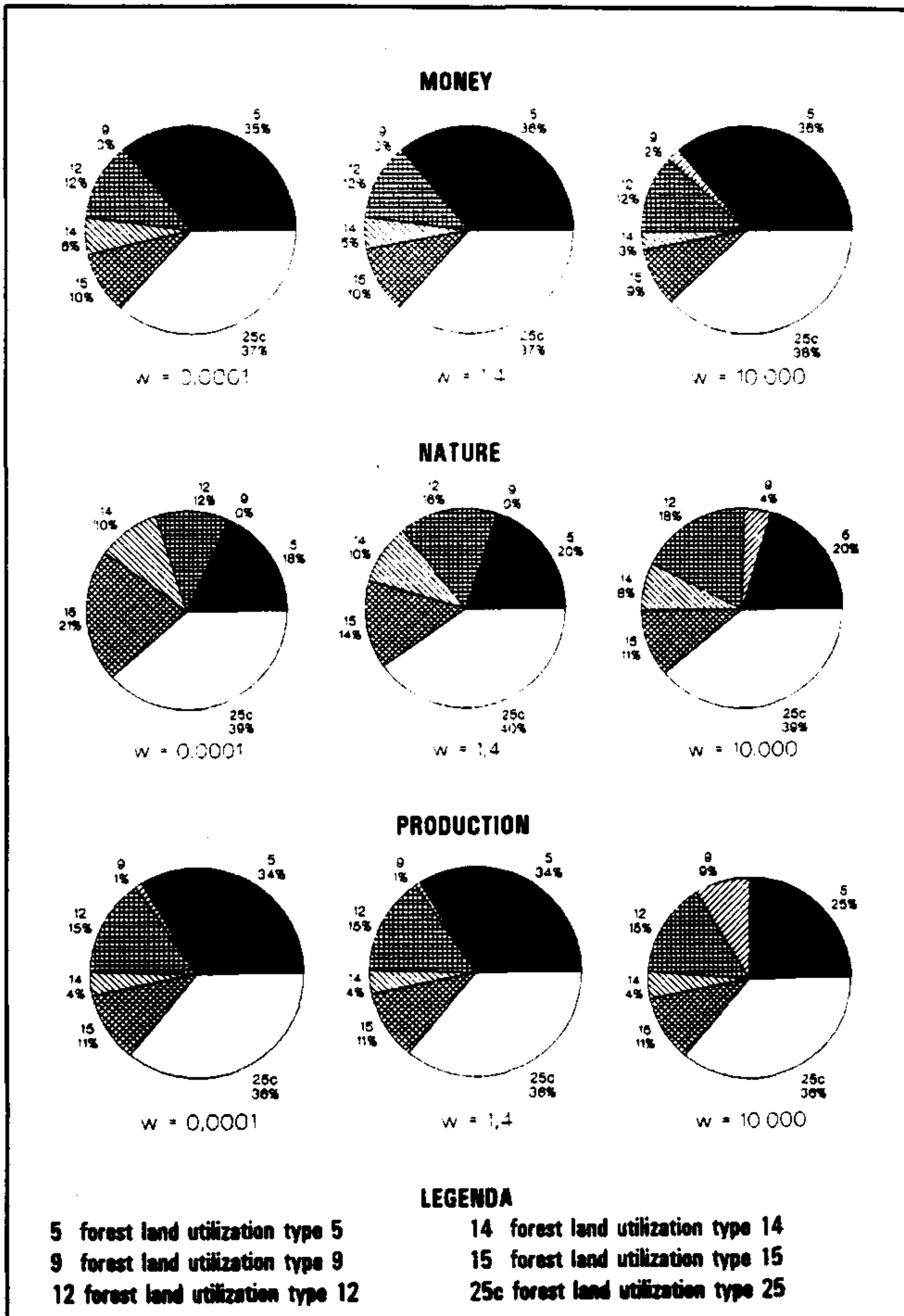
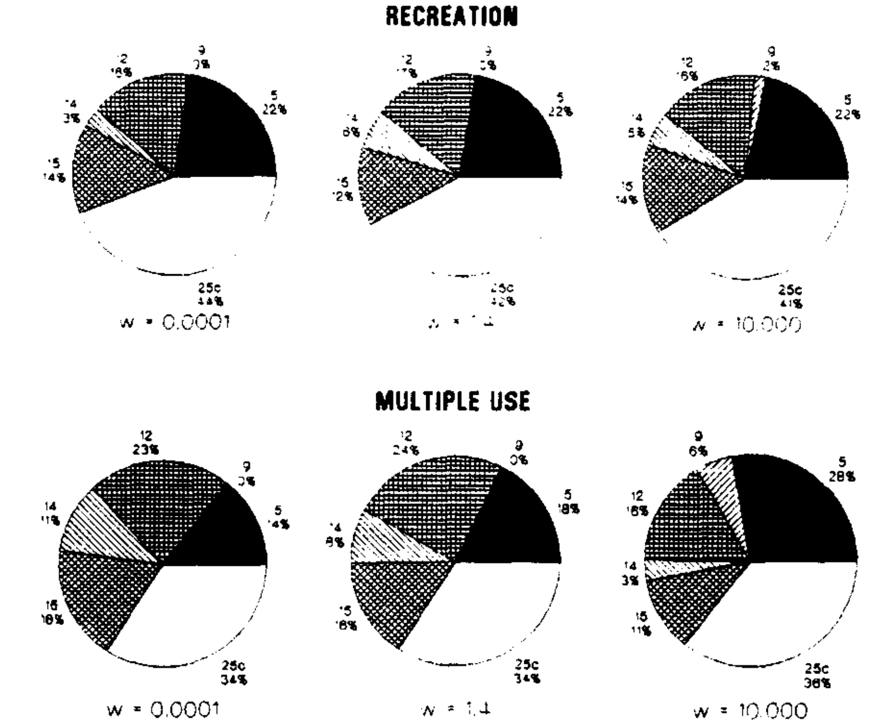


Figure 8.5 Distribution of forest land utilization types in desired future forest per alternative generated by the management model



LEGENDA

5 forest land utilization type 5	14 forest land utilization type 14
9 forest land utilization type 9	15 forest land utilization type 15
12 forest land utilization type 12	25c forest land utilization type 25

Figure 8.5 Distribution of forest land utilization types in desired future forest per alternative generated by the management model: continued

Results concerning the characteristics of the desired future forest

Before the management model was run, statements about the expected consequences of alternatives were made (see Bos *et al.*, 1994). In most cases the results of the runs matched these expectations. When they did not, the results could be explained after more thorough analysis.

Looking at the consequences in the desired future forest (figure 8.6) it becomes clear that within a run the number of working hours, the m^3 of harvest and the financial returns in guilders per ha per year are correlated. Furthermore the effect of the weighting parameter W is clear. If a characteristic is given a high value, the realized number of units of this characteristic is highest if W is small (a small W means an emphasis on the characteristics of the future desired forest). However, this explanation does not hold for all consequences in all runs. The reason for this might be the influence of other values for certain parameters. However, this was not examined further in this case study.

In situations in which a certain characteristic is not valued or is not valued equally to other characteristics, there is no clear relationship between the value of the parameter W and the number of units of that characteristic achieved. This means that the model concentrates on the characteristics which are valued highest. The characteristics assigned a low value are only achieved if this does not conflict with the achievement of characteristics valued highest.

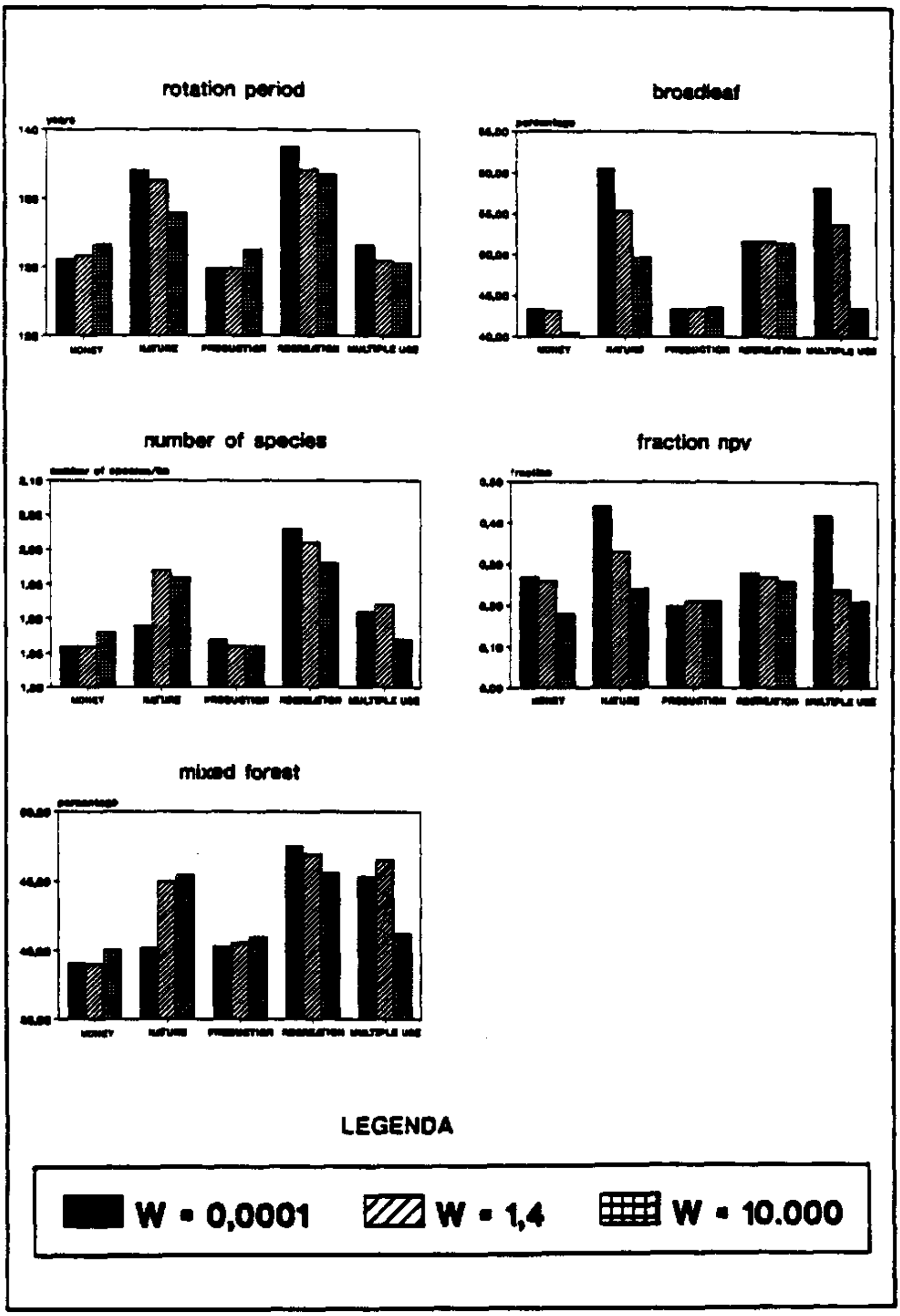


Figure 8.6 Characteristics of the desired future forest per alternative as generated by the management model

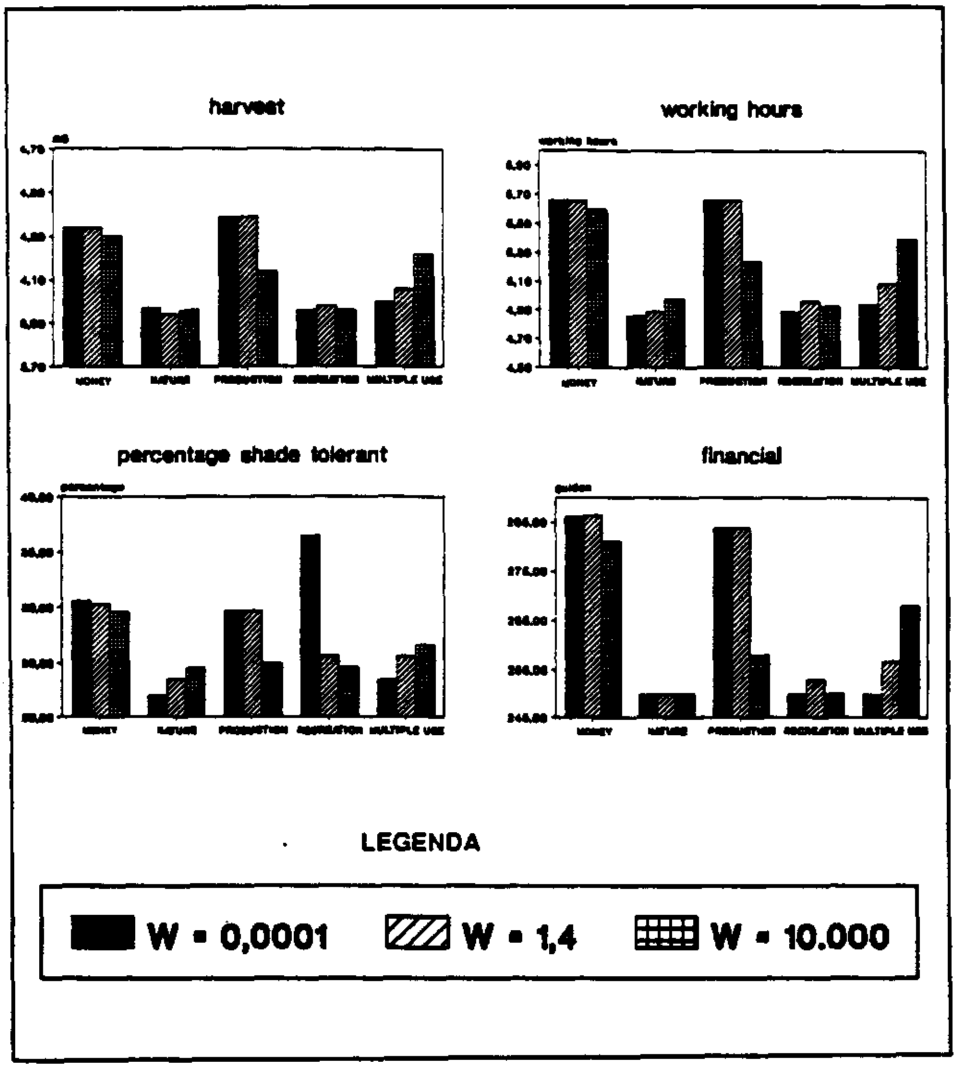


Figure 8.6 Characteristics of the desired future forest per alternative as generated by the management model: continued

Results on the characteristics of the transition management

In figures 8.7 to 8.11 the consequences of transition management per period are represented graphically for the five alternatives. It is clear that the results for the transition management are not equally distributed among the different periods. In period 5 there is an upsurge in activity. This is because the harvest is large if it is delayed until the fifth period, which is when the maximum harvest is possible. Thus in this period many hectares are transformed by clearcutting. Another contributory factor is the fact that the discount rate was set at 0. The result of this activity boom is a very small standing stock and very high financial returns in the fifth period. The activity boom in the fifth period was unintended, but reveals that it is plausible. Certain restrictions (instruments) can be included in the model to avoid these kinds of activity booms. These instruments were tested, and the results are described below.

The instruments tested and compared were: the formulation of constraints to the realization of characteristics in a certain period; the formulation of "even flow constraints" (fluctuation in realization of characteristics between two periods is restricted); and the penalization of fluctuations in realization of characteristics between two periods. From the tests it can be concluded that by penalizing fluctuations, the activity boom can be almost completely excluded without risking infeasibility. However, if the penalty on fluctuations is set too low, the effect will be marginal. The results of these computations are represented graphically in figure 8.12. In figure 8.12 the transition per period in the multiple use alternative (and W=1.4) is given as reference.

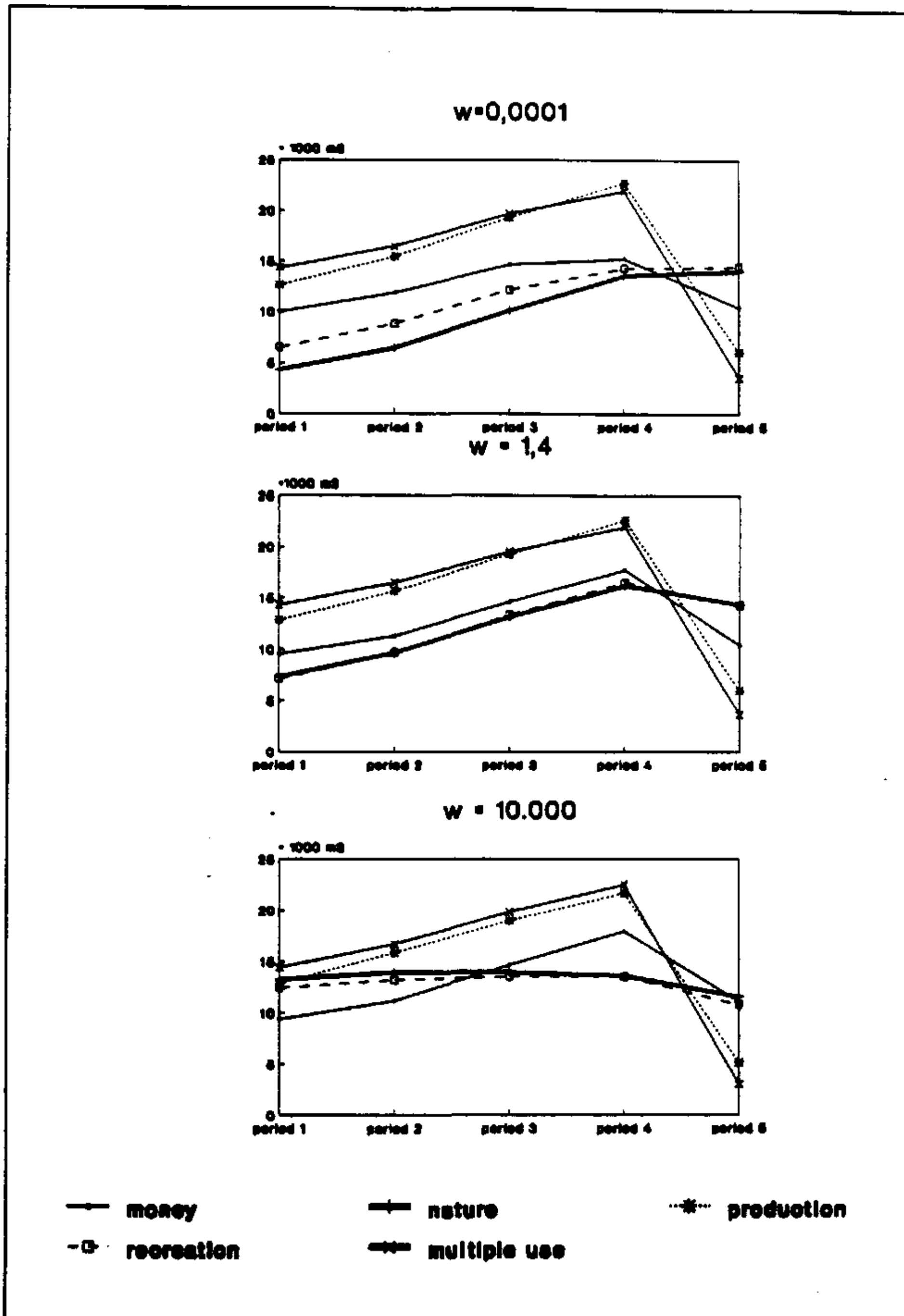


Figure 8.7 Standing stock per period per alternative as generated by the management model

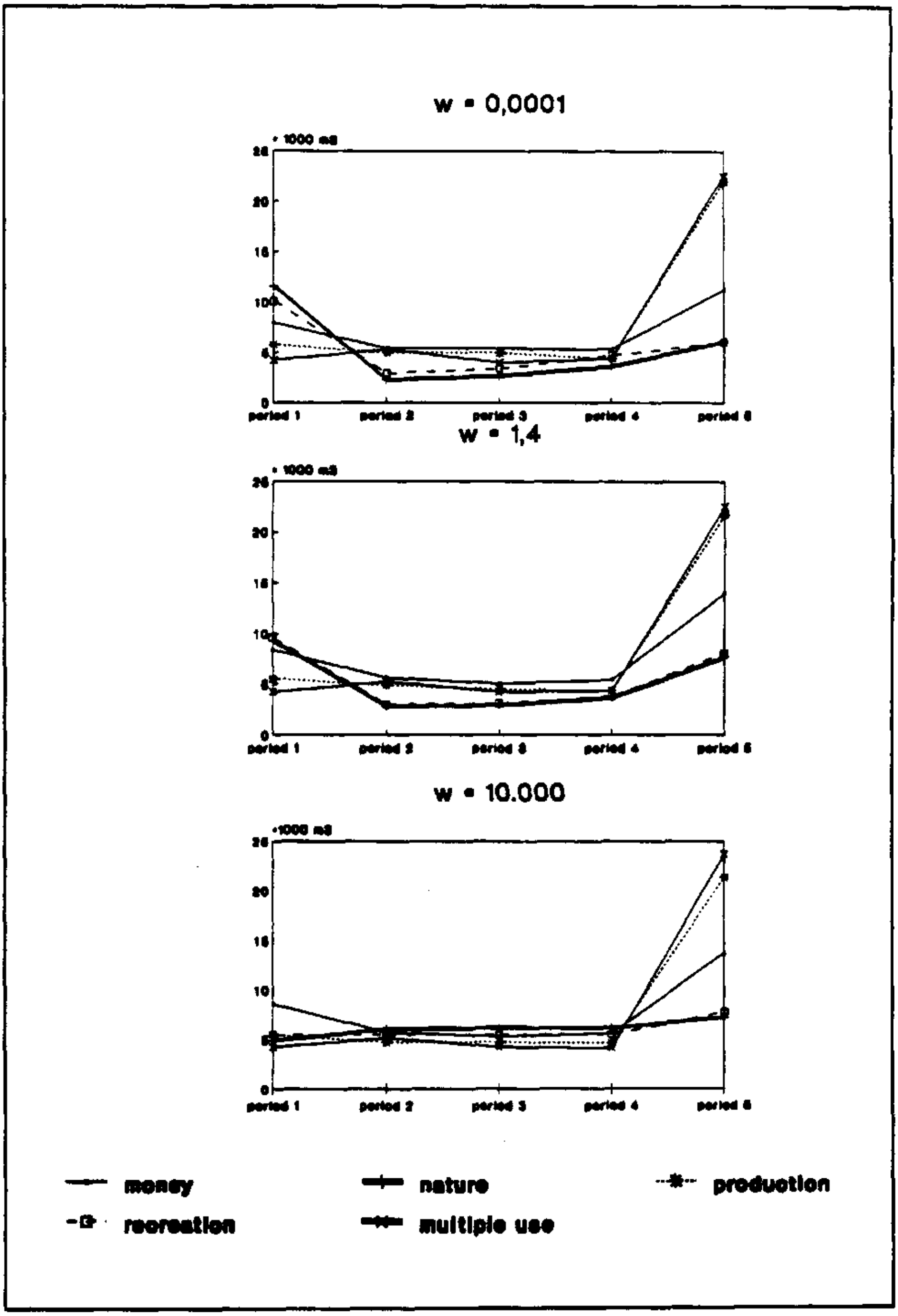


Figure 8.8 Harvest per period in m^3 per alternative as generated by the management model

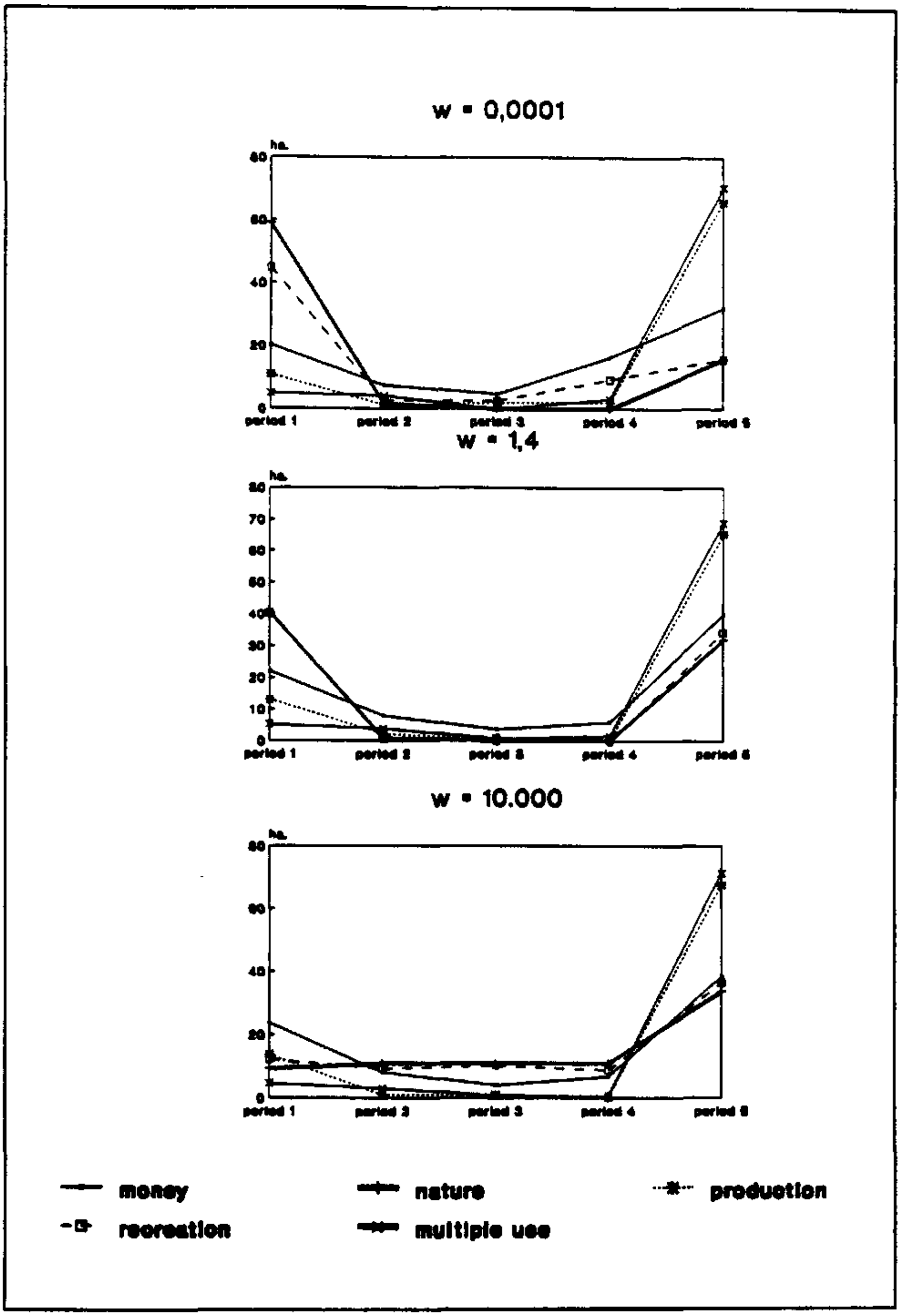


Figure 8.9 Number of hectares transformed per period per alternative as generated by the management model

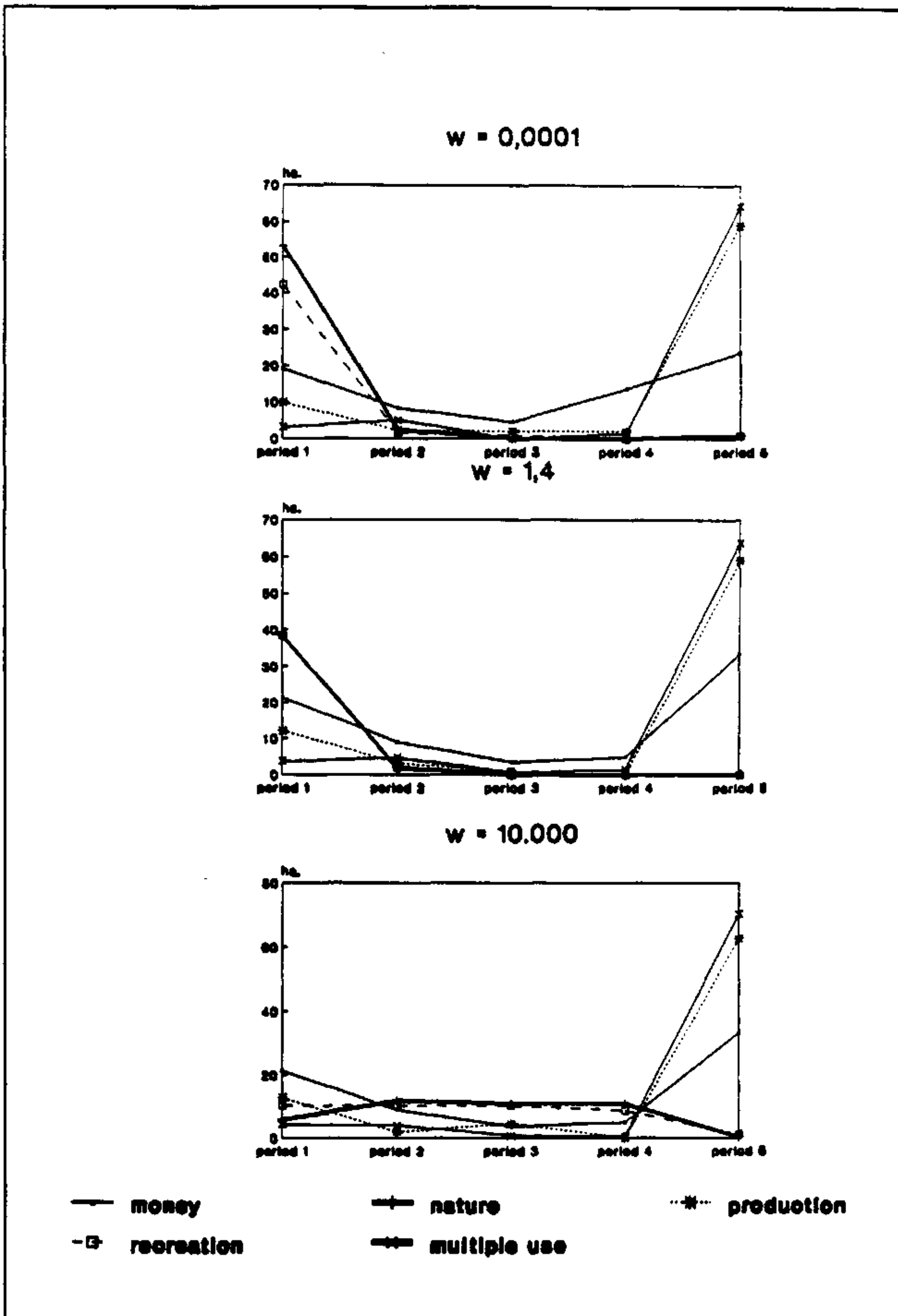


Figure 8.10 Number of hectares clearcut per period per alternative as generated by the management model

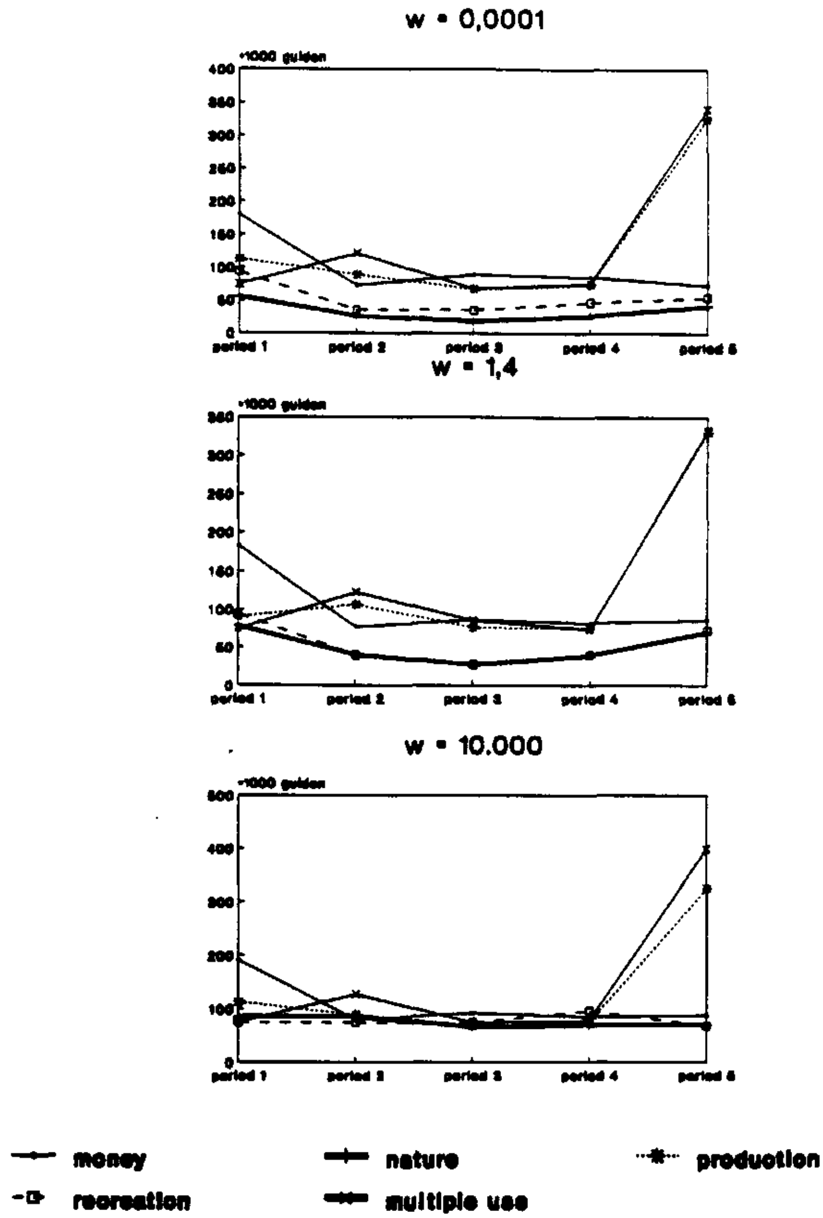


Figure 8.11 Financial results (cash flow) per period per alternative as generated by the management model

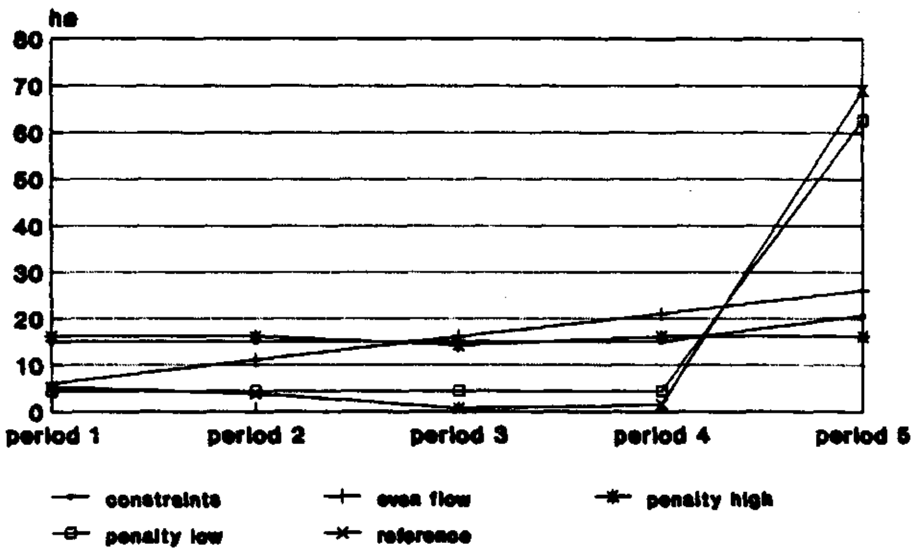


Figure 8.12 Effects of instruments used to control transition management

8.4. Conclusions drawn from the case studies

While executing the case studies it became clear that the models force the planner to structure the problem and to structure the data available. This reveals shortcomings in the data and also forces the decision maker to be specific about his or her objectives. The constraints put on land use objectives and forest characteristics and the valuations of them cannot be vague.

The aim of the case studies was to validate the models and to demonstrate their applicability. The validation was achieved: no failures in outcome were found. It can therefore be concluded that the models work as anticipated. However, the second part of the aim (demonstration of the model's applicability) was not wholly achieved. The potential of using the models for sensitivity analyses or for identifying trade-offs between characteristics, or for assessing the effects on future desired forest and transition management of lengthening the planning horizon in which the forest has to be transformed into the future desired forest, was not been demonstrated.

Not all the output of the management model was presented in this chapter (e.g. distribution of tree species, developments in distribution of age classes from period to period etc.). This output merely illustrates variations in the way in which the models are used; it is basically no different to the working and the kind of output demonstrated in the case studies in this chapter. The only difference is the purpose for which the model is used. For example, a sensitivity analysis could be performed by systematically changing one of the parameters (for example, restriction of labour). Trade-off relationships between forest characteristics could be identified in the same way and could be used to identify trade-off relationships between different kinds of uses (provided the quantitative relationship between the functioning of the forest and the characteristics of the forest is known).

If we look at the results of the case study for the zoning model and the management model separately, the following conclusions can be drawn.

The zoning model

The outcome of the runs seems to be correct and according to the expectations. It can therefore be concluded that the zoning model seems to be working properly. In the case study it was demonstrated that the quadratic part of the object function can take spatial effects into consideration.

The simulated annealing algorithm proved to be capable of solving the problem described in chapter six and of providing acceptable solutions. The algorithm can also handle much larger problems efficiently. Connolly (1990) describes an improved annealing scheme. His suggested refinement could, in some cases, lead to a better algorithm. Further research is needed to identify whether this would be the case in the application described in this study.

The zoning model proved to be capable of identifying alternatives. These provided a deeper insight into possible zoning and the related consequences of the forest considered.

Clearly, the parameter M is chosen rather arbitrarily. Research needs to be done to refine the process of finding "good" values for M.

The management model

No failures in the outcome of the runs were found. This indicates the management model works properly. The management model was shown to be capable of handling complex problems and of generating alternatives and their consequences efficiently. Its use provided insight into this complex problem of deciding on an appropriate management strategy.

9. DISCUSSION OF THE RESEARCH METHODOLOGY

9.1. Introduction

The activities carried out in this study came forth from the research questions and the methodology proposed in chapter one to realize the objectives of this study. The methodology applied consisted of:

1: an analysis of the decision situation in strategic planning in forest management.
2: a literature review of forest management models suitable for solving the decision problems described in part 1.
3: the development of mathematical models to support decisions in strategic planning in forest management.
4: the validation and implementation of these models.

In this chapter the methodology used in this research is discussed. Did this methodology yield the desired results? Would another methodology have yielded better results? What could have been done in a better way?

9.2. The methodology used in this study

The Forest Service of the US Department of Agriculture uses the FORPLAN computer system for developing linear programming models to support the planning of national forests. When discussing FORPLAN, Bare and Field (1987) conclude that before any attempt is made to extend, improve, correct or change the existing analytical apparatus, the relationship between the hierarchical nature of planning and decision making in the US Forest Service must be completely and satisfactorily resolved. Thus, the right planning questions have to be formulated before instruments can be developed to support answering them. This was the approach pursued in this study.

The methodology chosen in this study means that models to support the decisions to be made in strategic planning are derived from a global concept of forest management and within this concept a vision on the role of strategic planning in forest management. Decisions to be made in strategic planning in forest management are derived from this vision, and the relationships between these decisions are elaborated. In this way a consistent concept of strategic planning in forest management forms the basis of STAGES.

Another possible - more practical - approach would have been to develop models that support the actual way in which strategic planning is carried out in current forest management practice. However, this approach would have led to poor results, because strategic planning is not always carried out theoretically correctly in current management practice. For example, the transition management decision problem is seldom addressed. This is partly caused by the lack of quantitative models to deal adequately with the complexity of decision making. If the models developed in this study had been based on current planning practice, they would have ignored transition management. Therefore, the approach used in this study not only yields models that support strategic planning based on a consistent concept of strategic planning, but also provide opportunities to overcome certain shortcomings in current planning practice.

The methodology chosen in this research also enables the concept of strategic planning adopted in this study to be used for a broad range of categories of forest ownership, and therefore the models developed to support strategic planning which are based on this concept do so too. A disadavantage is that the models will have to be refined and fine-tuned per ownership category if they are to be implemented. The more practical approach would have yielded models that are more specifically attuned to one of the categories of forest ownership, hence the aim of developing models suitable for different types of forest ownership would not have been realized.

9.3. Strategic planning in forest management

In this section the first part of the methodology is addressed: the analysis of decision making in strategic planning in forest management. That analysis was carried out as a stepwise refinement of broad concepts found in literature.

The advantages and disadvantages of this approach have already been discussed in the preceding section. The approach yielded a planning system consisting of three planning processes:
- strategic planning;
- tactical planning;
- operational planning.

Strategic planning is divided into three decision problems:
- zoning;
- the desired future forest;
- transition management.

In this study, the transition management problem was taken as a strategic decision problem and was included in strategic planning. The decision to include transition management in tactical planning instead of in strategic planning can also be defended. Transition management means deciding on how the other strategic objectives (land use objectives and desired future forest) will be realized, and from this point of view can be seen as tactical planning. However, transition management was included in the strategic planning process because the desired future forest decision problem and the transition management decision problem have to be solved simultaneously to identify the optimal decisions for both decision problems (see also chapter four).

The bringing forth of forest-related products and services is the primary process of the forest enterprise. All plans have to support this process. The most important planning process in this respect is the planning of management objectives. In addition to forest management, other functions of the organization also have to be planned; for example marketing, personnel management and bookkeeping. The planning of management objectives is related to all of these other planning processes. In this study, however, these relationships were not explicitly included, because strategic planning in forest management must be clear, before relationships with other planning processes can be identified. Further research is needed to reveal the relationships between strategic planning in forest management and the planning processes concerning marketing, personnel, book keeping etc. However, this research cannot be carried out if first strategic planning in forest management has not been analysed.

9.4. Search for suitable management models

The methods used in the search for suitable forest management models were a literature review and a study trip to the USA to discuss the modelling of strategic planning in forest management with experts. Both methods proved useful. Aspects of models found in literature were incorporated in STAGES. The results of the discussions with experts are more intangible; they relate to the thinking process that lead to STAGES.

9.5. Stages

The third part of the methodology, the development and implementation of mathematical models to support decisions in strategic planning in forest management, resulted in STAGES. The two quantitative models in STAGES, the zoning model and the management model, are both optimization models.

The decision to opt for optimization models

Like simulation models, optimization models are quantitative models. Quantitative models do have limitations; they are restricted to analytical aspects of decisions and do not address aspects such as the acceptance of decisions by the general public. Bare and Field (1987) conclude that the optimization models used by the Forest Service of the US

Department of Agriculture do not recognize or comfortably fit the real process of making decisions about National Forests, which is more political than analytical. In my opinion this is not a shortcoming of the models, but simply a limitation. Models can be used to gain insight into the "technical" aspects of the decisions. Insight into the social acceptability of the decisions has to be gained from other sources. This means that STAGES cannot guarantee that the outcome of the models are the optimal decisions, because not all the information needed to decide if the decision is optimal is included. STAGES therefore focuses on the generation of strategic alternatives. Which alternative is optimal in the real world situation depends on many factors not included in STAGES.

Instead of optimization models, simulation models could have been developed in this study. The difference between optimization and simulation is that in simulation the effect of decisions is evaluated, whereas in optimization models the decisions that lead to a desired effect are determined. Hence, in optimization models not only the problem has to be modelled, but also an algorithm to solve the problem. The latter often restricts the possible ways in which the problem can be described. In simulation this restriction plays no role. As a result, simulation models often describe reality better than optimization models. In this study I opted for optimization models because the problem to be solved involves so many decisions that the number of possible alternative solutions to the problem is too large. Therefore an instrument (read algorithm) to identify "good" alternatives in an efficient way is required. A decision maker is not in the first place interested in the *effect* of his decisions, but in *which* decisions he has to make. Insight into the effect of decisions is only needed to identify the best decision.

Because of risk and uncertainty the models do not have to precisely describe the characteristics of the forest at a point 100 years from now. They have to indicate the direction in which the forest will develop and what the consequences will be. As already mentioned, they must point in a direction and give a global description of the consequences of choosing that direction. Hence the advantage of simulation models - more precise modelling of reality - becomes less important from this point of view. However, this does not mean that simulation models play no role in strategic planning in forest management. Many of the data needed to run STAGES can be provided by means of simulation models. For example, the consequences of assigning one hectare of a certain stand type to a certain management option can be assessed by means of simulation models. The output of simulation models is then taken as input for STAGES.

The zoning model

Certain specific aspects which specially relate to the zoning model developed in this study have to be discussed. The most important is the fact that many parameters can only be assessed subjectively. This means that the zoning model is not a technical model, but serves as a framework in which all decisions, objectives and opinions of the decision maker can be combined and made consistent with one another. The model has to provide information about the zoning alternatives for the forest. It has to help the decision maker to make up his mind. The case study demonstrated that the model is suitable to efficiently generate alternative zonings. Whether the model also helps the decision maker to make up his mind cannot be proven on the basis of the case study. However, it is clear that the model will not run before the decision maker has provided the information needed (and thus has thought about his objectives).

Quadratic assignment problems are what is called NP-complete[1]. This means that the time needed to solve the problem increases exponentially as the number of decision variables increases. The NP-completeness of quadratic assignment problems can partly be overcome by the algorithm used in this study, because the algorithm can be adjusted to the problem. This involves setting parameters in such a way that much less time is needed to find a solution (fast annealing scheme). However, the shorter the time spent attempting to find a solution, the less likely it is that the solution will be optimal. For further reading on NP-completeness see Garey and Johnson (1979).

The management model

The management model was formulated to be flexible. Thus the decision maker can decide how many forest characteristics to include in the model and what these should be. He or she can also decide which constraints to include and to what extent decisions made in the model should be based on consequences for the desired future forest or on consequences for the transition management. It is even possible to focus exclusively on the desired future forest or on the transition management. This means that the model can be adapted to a variety of circumstances. Because the management model is an LP model, the decision problem it is intended to solve must be formulated according to certain requirements, the most important of which is the restriction to linear relationships. The assumption underlying linear programming is that only linear relationships exist between variables. Clearly, this assumption is an oversimplification. For example, the consequences of assigning one ha of forest land to a management option are determined externally. This information must be input in the management model in order to determine the combination of values for decision variables that maximizes the score of the object function. In doing this it is assumed that each combination of feasible values for decision variables has a score equal to the sum of the effects of each of these decisions individually. In other words, the model can only deal with a static unchanging marginal value of consequences. It arrives at the value of one extra hectare of broadleaf forest independent of the number of hectares already assigned to broadleaf and also independent of the number of units assigned to other uses that have consequences deemed to be important. On the other hand the restriction to linearity means that only the

[1]An intractable problem is a problem so hard that no polynomial algorithm can possibly solve it. NP is a class of decision problems that can be solved in polynomial time by a nondeterministic computer. Most of the apparently intractable problems encountered in practice, when phrased as decision problems, belong to this class. NP-complete problems are the "hardest" problems in NP (Garey and Johnson, 1979).

salient aspects of the decision problem are considered. This is essential in strategic planning. Linear programming has the advantage of being a well known and often used technique for which a number of standard software packages exist. Hence, the modelled decision problem can be solved, although it has to be forced into a format which permits linear relationships only.

The link between zoning model and management model

The decision problems to do with strategic planning in forest management were divided between two optimization models because the combination of problems is too complex to describe and solve in one model. If decision problems are solved sequentially there is a chance that sub-optimal solutions to the original problem may be obtained, because not all the aspects related to the problem can be taken into consideration when solving one of the decision problems. On the other hand, formulating strategic planning as a family of decision problems is probably the only way to solve the original problem. One benefit of this approach is that the hierachical structure of decisions in forest management becomes clearer and this can lead to a better understanding and acceptance of decisions. The problem of suboptimality is partly overcome by linking the zoning model and the management model. However, this linking does not completely solve the problem, because so far no algorithm has been found that efficiently identifies the optimal combined solution to the problems. The algorithm developed in this study provides consistent combined solutions to the decision problems of strategic planning in forest management.

The use of weighting parameters

The STAGES models contain several weighting parameters which were included to attune the models to the circumstances specific to an actual problem and to facilitate the generation of alternatives (change the value of the weighting parameter and the model will yield an alternative solution). In practice, however, there is a risk attached to the use of weighting parameters. If there are no objective sources on which to base the value of the parameters, the models can easily be manipulated by choosing values for the parameters that preclude the generation of certain alternatives. In this situation the integrity of the planner/analyst (who operates the models) and the communication between that planner/analyst and the decision maker (who chooses which alternative has to be implemented) becomes important.

9.6. The usefulness of the case studies

To ascertain that the models work properly they were applied in case studies. To be useful in practice the models must be sound, operational and relevant (Navon, 1986).

The models were demonstrated to be sound in several ways: they are consistent with the concept of strategic planning described in this study and the software is free from errors in logic and programming. From the case studies it was concluded that the models work properly (any errors in the software had been corrected) and it was demonstrated that the outcome of the models is correct. Thus the models must be considered as valid.

The way the models were developed influences the way they can be used. The software was developed on a mainframe computer. The advantage of this is that a mainframe computer puts fewer restrictions on the size of LP models that can be run. However, to enable the models to be operated in situ, the next step in the research should be to adapt the models so they can be run on a personal computer.

When the models were applied in the case studies it was discovered that not all the data required were available. There is a particular lack of information about relationships between the functioning of the forest and forest characteristics. However, even if this kind of information is lacking, the models can be still used. In this situation the decision maker cannot derive the number of units per characteristic needed from a research report, but has to decide himself how many units of a particular forest characteristic are needed and must also make a subjective judgement on trade-offs between characteristics.

The case study excercise demonstrated that the models only require information that is also needed in a strategic planning process which does not use quantitative models. If a land evaluation procedure forms part of the strategic planning process, then most of the information needed to run the models can be obtained from the results of that land evaluation procedure (see also appendix D).

The next step in ascertaining the relevance of the models is to measure their impact on decision making in practice. If strategic planning in practice does not considerably change as a result of using the models (in terms of effectiveness and efficiency) then the impact of the models and therefore their relevance is considered to be small. At the moment no information is available to enable the relevance of the models for practice to be assessed, but this information could be obtained by conducting parallel case studies. This means drawing up a strategic plan without using STAGES in one case study and doing the same exercise with help of STAGES in a second case study. The results of the case studies in terms of decisions made, quality of decisions and means (time and information) needed to prepare the plans could then be compared and conclusions could be drawn.

9.7. Conclusions

One of the basic features of the methodology used in this research was that decisions about forest management to be solved in strategic planning were identified from the starting point of a global concept of forest management and in the context of a vision on the role of strategic planning. Based on this, models were developed to support these decisions.

Another approach would have been to develop models that support the actual way in which strategic planning in forest management is carried out in current forest management. However, this approach would not help overcome some serious shortcomings in current planning practices, because instead of yielding models that would correct current planning, it would yield models adapted to current planning.

The conclusion from this chapter is therefore that the methodology used in this study yielded models that not only support strategic planning based on a consistent conception of strategic planning, but also provide opportunities for overcoming some serious shortcomings that have arisen in current planning practice because of the lack of any such models. In addition, the methodology chosen in this research allowed the concept of strategic planning adopted in this study to be used for a broad range of categories of forest ownership, and therefore the models to support strategic planning developed on the basis of this concept can also be applied to this broad range. However, the models have to be refined and fine-tuned per ownership category before they can be implemented. A more pragmatic approach would have yielded models that were more specifically attuned to one of the categories of forest ownership. However, the objective of this study was to develop models that are suitable for different types of forest ownership.

In the next (and final) chapter of this thesis the main conclusion outlined above will be expanded on.

10. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

10.1. Introduction

In this final chapter the conclusions to be drawn from the research will be discussed in relation to the questions posed at the outset of the research. The main question was:

> Is it possible to develop a model or a system of models that supports the identification and selection of strategic objectives in forest management planning in the Netherlands on the level of the forest enterprise by generating alternatives and assessing the consequences of these alternatives?

As noted in chapter one, that question was broken down into five sub-questions:

1. What are the characteristics of forest management planning in the Netherlands?
2. What is the role and position of strategic planning in forest management?
3. What decisions have to be made in strategic planning in forest management?
4. What requirements must a system for generating strategic alternatives fulfil in order to be suitable for supporting decision making in strategic planning in forest management in the Netherlands?
5. How can the decisions that have to be made in strategic planning in forest management in the Netherlands be modelled so that they constitute the basis of a system for generating strategic alternatives?

10.2. Analysis of strategic planning in forest management

In this section the conclusions relating to the first three research questions are addressed, together, because the combined answer to them achieves the first objective of this research - an analysis of strategic planning in forest management.

What are the characteristics of forest management planning in the Netherlands?

The basic concepts of forest management and other characteristics related to the object of forest management (the adjustment of forest ecosystem and society) make forest management a complex decision-making process. These basic concepts and complicating factors were analysed in this study. Even at an early stage of this research it was concluded that forest management is one of the few decision-making processes in which all these complicating factors actually are taken into consideration in making decisions. These factors are not unique for forest management, but other management processes do not recognize them. If, for example, the environmental effects of decisions were to be incorporated in industrial management processes, most of the complicating factors mentioned for forest management would (all other things being equal) also become important in industrial management processes.

It was concluded that the characteristics of forest management that are special to the Netherlands are that it is multiple-use and small-scale and that it deals with a transition from managing plantation forests to managing forests which are more "natural".

What is the role and position of strategic planning in forest management?

The conclusions reached in relation to this question are largely based on the literature study. In decision making in forest management a large amount of information is needed and all kinds of relationships between decisions have to be dealt with. Decisions in forest management cannot therefore be taken ad hoc, but have to be incorporated into a planning system based on three planning processes: strategic planning, tactical planning and operational planning.

Because of the shift to multiple use and the maturing of the forest ecosystem itself, forest management planning not only needs to allocate means, it also needs to search for objectives. This calls for strategic planning in forest management, because strategic planning deals with decisions on objectives and strategies (ways and means) to realize the objectives. In tactical planning the emphasis is on the planning of management activities. In operational planning the emphasis is on planning the actual execution of management activities.

What decisions have to be made in strategic planning in forest management?

Strategic planning in forest management is a complex planning process in which the following decision problems have to be solved:
- the zoning decision problem;
- the desired future forest decision problem;
- the transition management decision problem.

The identification of these three related decision problems was the best possible way of tackling the analysis of strategic planning, because it links the external adjustment of the organization to the internal adjustment of the organization. In addition to this it yielded a consistent concept of strategic planning. This concept was shown to be suitable to function as the basis of a system for generating alternatives for strategic planning in forest management.

10.3. Conclusions relating to the basis of a system for generating strategic alternatives

In this section the fourth and fifth research questions are addressed.

What requirements must a system for generating strategic alternatives fulfil in order to be suitable for supporting decision making in strategic planning in forest management in the Netherlands?

Solving the decision problems mentioned in the preceding section involves dealing with a large number of variables, their interrelationships and a large volume of data. Hence, the generation of alternatives and their consequences in strategic planning in forest management is difficult and very time-consuming. However, the effectiveness and efficiency in generating alternatives and their consequences can be increased if strategic planning is supported by computer-based quantitative decision supporting models.

Models intended to support zoning decisions have to fulfil the following requirements:
- they have to deal with spatial relationships between decisions;
- decisions to divide the forest into zones must be made simultaneously with decisions about land use objectives per zone.

Models intended to support decisions about the desired future forest have to fulfil the following requirements:
- they have to deal with the allocation of forest land to forest land utilization types;
- they have to be able to show the consequences of these allocations.

Models intended to support decisions about transition management have to fulfil the following requirements:
- they have to deal with the allocation of forest land to transition managements;
- they have to be able to show the consequences of these allocations in time.

How can the decisions that have to be made in strategic planning in forest management in the Netherlands be modelled so that they constitute the basis of a system for generating strategic alternatives?

The zoning problem

Because of spatial considerations the zoning problem can only be dealt with by a non-linear integer programming model. In this study it was shown that the zoning problem can be formulated as a quadratic assignment problem. This formulation leads to an approach to zoning in which it is possible to take into account land quality, interactions with management goals in other grid cells and interactions with the environs of the forest in deciding to assign a particular grid cell to a particular use.

The simulated annealing algorithm was shown to be capable of solving the problem and providing acceptable solutions. The algorithm can also handle much larger problems efficiently.

The management problem

The future desired forest decision problem and the transition management decision problem were addressed together as the management problem. It became clear that the desired future forest decision problem can not be seen apart from the transition management decision problem: to identify optimal decisions, both decision problems have to be solved simultaneously. In this study it has been shown that it is possible to address them together in one single linear programming model.

Whether a model I or a model II approach in combination is chosen and the way in which multiple use is dealt with (combined, constrained or Goal Programming) is crucial to the features of the resulting model. It has also been shown that the model I approach in combination with the constrained approach is most advisable in the Dutch context.

The management model has a very flexible structure. It can be attuned to planning approaches which tend to blueprint planning or planning approaches which tend to process planning. Furthermore, it can be used to decide on the desired future forest or on transition management or on a management strategy including both of these.

The two models presented were developed for forest management, but can, in principle, be used for zoning and management problems in natural resource planning in general, in land use planning in general and in regional planning.

10.4. The development of a STrategic Alternatives GEnerating System

As this thesis has demonstrated it is possible to develop a STrategic Alternatives Generating System (STAGES), that supports decision making in strategic planning in forest management. It has been demonstrated that STAGES can be implemented on a computer, STAGES has been validated in small-scale case studies. The answer to the main question that triggered the research described in this thesis must be a resounding "yes".

10.5. Recommendations for further research

The recommendations for further research can be grouped into three categories:
- research concerning the improvement of existing technical aspects of the current models in STAGES;
- research concerning the further development and implementation of STAGES in forest management planning;
- research concerning the applicability of STAGES in planning processes other than forest management.

Research concerning the improvement of existing technical aspects of the current models of STAGES

It has already been noted (chapter 9) that the weighting parameters M and W in respectively the zoning model and the management model were chosen rather arbitrarily and that the use of weighting parameters opens the door to manipulation. Therefore further work needs to be done to refine the process of finding objective values for M and W.

The basis for an operational link between the zoning model and the management model has been laid in this study. It is formed by the relationship between the functioning of the forest and measurable forest characteristics. These relationships are used to operationalize land use objectives (the output from the zoning model) into constraints and valuations about the measurable forest characteristics in the management model and to determine land suitability ratings on the basis of forest characteristics (output from the management model). At the moment not enough is known to be able to quantify the relationships between the functioning of the forest and the forest characteristics. Therefore further research is needed to assess these relationships. The results could be used to refine or reformulate the STAGES models.

The algorithm developed to link the zoning model and the management model (see appendix B) is only a first step. It has not been fully tested. It seems a promising approach, but further research is needed to develop this basic idea into an operational algorithm. One of the main topics in this research should be the development of a procedure to test optimality (of the combination of solutions produced by both models). In addition, research is needed on identifying and dealing with the cycling of the algorithm (see appendix B) and on the starting values for $REAL_{gu}$ that should be used in order to get the best results when applying the algorithm.

The Simulated Annealing could be improved. Connolly (1990) describes an improved annealing scheme which might, in some cases, lead to a better algorithm. However, further research is needed to identify whether this would be the case in the application in this study.

The management model includes several ways in which transition management can be controlled. The effects of these control mechanisms were marginally tested (see chapter eight), but further research is needed to assess the effects of applying them separately or in combination. This would reveal which control mechanism or combination of control mechanisms should be used in which situations.

The management model deals with risk and uncertainty in a very modest way. Recently (1993), however, Mendoza, Bare and Zhou published a paper on Fuzzy Programming. Their paper presents some interesting ideas on dealing with uncertainty. Further research is needed to identify how the Fuzzy Programming approach described by Mendoza, Bare and Zhou (1993) can be applied in a context with many variables and constraints. For more information about how to deal with risk and uncertainty in forest management models see, among others, also Gong (1993) and Lohmander (1987).

The scale of the problem in strategic planning in forest management has not been completely resolved. Aggregating the problems into fewer problems could be an effective approach. Further research is needed to confirm this.

Research concerning the further development and implementation of STAGES in forest management planning

At the moment, the user interfaces of the models (the way in which the user of the model can communicate with the models and the way in which the output of the models is represented to the user) are poorly developed. Furthermore, the models are intended to be run on a mainframe computer. Before any attempts are made to develop more sophisticated user interfaces or to implement them on a personal computer it must first be clarified how the models will be used, by whom, and for what purposes. Further research is needed to provide answers to these questions. It mainly consists of conducting case studies. This will enable the models to be fine-tuned to the demands of the forest management planners, and will reveal the requirements the user interface should meet.

When the case study described in this report was being done, the data concerning management options were generated manually (by screening growth and yield tables, norms etc.). The lack of an interface with simulation or optimization models at the level of the stand was apparent. Therefore, further research is needed to select an existing model or develop a new model at the stand level that is suitable for generating stand-specific data on the consequences of management. The important consequences can be derived from the results of the research concerning the quantification of the relationships between the functioning of the forest and the forest characteristics. After a suitable model has been selected or developed, research needs to be done to find out how this model should be incorporated into STAGES in order to facilitate the generation of alternatives at stand level (management options).

Although the zoning model developed in this study can be considered as a step forward, it is only a first step. Much research has to be done before all aspects of the zoning problem are addressed. At the moment it is impossible to constrain the size per zone. For certain uses minimum sized zones might be needed. Research should be done to extend the model with constraints on the minimum or maximum size of resulting zones. Not only the size of a zone, but also its shape can be important (for example, a corridor linking two nature conservation areas). Another research topic is how to deal with a residential area situated beyond the boundaries of the grid, which nevertheless influences zoning decisions.

STAGES deals with data which have a spatial aspect. Geographic Information Systems (GIS) are intended to process this kind of data. They provide procedures for storing this kind of data, transforming data into information and representing this information on a map (see further Burrough, 1986). Before the STAGES database is further developed, research should be done on the possibilities, of linking STAGES to a GIS and the pros and cons of doing so.

As already mentioned in chapter nine, the relationships between strategic planning in forest management and planning processes concerning marketing, personel, finance etc. need to be investigated further. In addition, the relationships between strategic planning and tactical planning have to be studied further, because they determine how the output of the strategic planning process has to be formulated to give clear directions to the tactical planning process. In this way a further step along the path of the development of adequate planning systems for forest management can be taken.

STAGES is only one of the instruments needed in strategic planning in forest management. The application of STAGES results in the generation of some promising alternatives and their consequences. These alternatives have to be compared with each other by means of a multi-criteria evaluation method, before the most preferred alternative can be determined and elaborated into a strategic plan. This, however, is beyond the scope of this study. STAGES is restricted to the generation of strategic alternatives and assessing their consequences.

Research concerning the applicability of STAGES in planning processes other than forest management

Although STAGES was primarily developed for decision support in strategic plannning in forest management in the Netherlands, the models also seem to be applicable in other planning processes. For example, the zoning model could be used on a regional scale to select locations for afforestation projects or for nature development projects. In this way it could support land use planning and regional planning.

The management model could be used to assess the most efficient way of managing natural resources in which certain objectives concerning the characteristics of the vegetation have to be achieved under restricted availability of means. This also applies to the planning and management of green areas in residential areas.

Finally, research is needed to identify if the STAGES models can be applied to support the planning processes mentioned above, how they can be applied and the benefits of doing so. Here too, case studies could be carried out to identify the applicability of STAGES in planning processes other than forest management.

SUMMARY

The topic of this study is strategic planning in forest management. The goal of the research was to develop decision models for this planning.

Chapter one introduces the changes in forest management which made this research necessary. There has been an increase in the possible objectives of forestry, and hence in management options and therefore forest management planning not only has to allocate means, but must also search for goals. If forest management wishes to be equipped to incorporate these changes in its tasks, planners not only have to be aware of these changes, but must also have the instruments to bring this about. These instruments are lacking. As a result we can conclude that:
- alternatives seldom are identified;
- insufficient attention is given to the long-term consequences of decisions;
- decisions made in strategic planning are difficult to justify.

The identification of alternatives and their consequences is an important part of a planning process. The reasons for choosing a certain alternative are the justification of a decision. These reasons are based on comparing of the consequences of the various alternatives with decision criteria, intentions, ends or preferences. The identification of alternatives (with their consequences) is unquestionably a crucial part of a planning process. Therefore, the lack of instruments to generate and assess alternatives is a serious shortcoming in forest management planning.

The model this research set out to develop is a STrategic Alternatives GEnerating System (henceforth referred to as STAGES) for decision support in strategic planning in forest management. Its main task is to generate strategic alternatives and their financial, economic, social and environmental consequences, thereby helping to overcome the deficiencies in strategic planning in forest management already mentioned (no alternatives, no consequences, no justification).

The activities undertaken in this study arose from the research questions and from the methodology adopted to realize the objectives of this study. The four parts of this methodology were:
1. Analysis of the decision situation in strategic planning in forest management.
2. Search for forest management models suitable for solving the decision problems described in part 1.
3. Development of mathematical models to support decisions in strategic planning in forest management.
4. Validation and implementation of these models.

Chapter two addresses important aspects of forest management. In this chapter forest management has been defined as the set of human actions aiming at the mutual adjustment of the forest ecosystem and society required to achieve a sustainable fulfilment of society's needs. The object of forest management is the relationship between society and the forest ecosystem. It is made clear that forest management is a complex decision making-process. The complexity is caused by the basic concepts of forest management (sustainability and multiple use) and other characteristics related to the object of forest management, namely:

- many of the goods and services a forest produces are difficult to quantify;
- goods and services are often nonmarketable, which makes their valuation difficult;
- natural processes play an important role in forests;
- the production period is long;
- trees are simultaneously product, stock and productionfactor;
- the planning problem has a certain scale.

In decision making in forest management a large amount of information is needed and all kinds of relationships between decisions have to be dealt with. Decisions in forest management cannot therefore be taken ad hoc, but have to be incorporated into a planning system, i.e. an organized set of planning processes. A planning process can be seen as an interrelated set of activities (including lines of thought) in which insight is gained, decisions are made and actions are undertaken.

In chapter three, strategic planning in forest management is described as the top layer of a hierarchical, multilayer, decision problem consisting of strategic planning, tactical planning and operational planning. Strategic planning means deciding on objectives and the strategies to realize them. Tactical planning focuses on deciding on the methods and related means required to realize the objectives decided on in the strategic planning. Operational planning deals with the management of the execution of activities decided on in the tactical planning. Strategic planning in forest management is related to land use planning and is a complex planning process in which the following decision problems have to be solved:

- zoning;
- the desired future forest;
- transition management.

The zoning problem consists of dividing the forest into zones and simultaneously assigning these zones to land use objectives. In zoning only the land use objectives are decided on and not the way in which they have to be realized. The realization of the land use objectives is planned when deciding on the desired future forest and the transition management. The desired future forest problem consists of assigning land within a zone to land utilization types in such a way that the land use objectives for that zone are realized. It usually takes decades for the desired future forest to be achieved. This forest should be seen as a beacon, which shows the direction in which to sail. Because of the long term effects of interventions in the forest ecosystem, the beacon has to be sited far ahead. The consequence of this, however, is that the beacon itself will never be reached, but will be relocated from time to time, in respons to changes in society. However, without such a beacon the continuity needed in management will not occur. The transition management problem consists of assigning land to transition management strategies in such a way that the current forest is transformed into the desired future forest. A transition management strategy is a description of the way in which the current forest will be transformed into the desired forest.

Chapter 4 provides a critical review of the models described in literature. As regards the zoning problem, the conclusion drawn from this chapter is that none of these models sufficiently address the division of the forest into zones. The spatial interactions are an important aspect in the decisions about zoning. The allocation of land to a land use objective has consequences for the allocation of other land to land use objectives. These consequences are related not only to the amount of land allocated, but also to the location of the land allocated. None of the models found in the literature addresses this problem of spatial interaction.

The models found in the literature contain elements useful for the desired future forest decision problem. These models mainly focus on identifying an optimal steady state structure from the point of view of timber production, but they can be enlarged into models which identify an optimal steady state structure from the point of view of multiple use. There are also some useful models for the transition management decision problem. Many of them focus on the scheduling of activities. Only a few of them address the problem of managing the forest in such a way that a desired future forest is realized.

During the literature study it also became clear that the desired future forest decision problem cannot be seen separately from the transition management decision problem: both decision problems have to be solved simultaneously to identify optimal decisions. The consequences of choosing a particular future forest in terms of the investments needed to realize it, become clear in the transition management decision problem. None of the models in the literature deal completely with this problem.

The literature was also reviewed for ways in which the basic concepts of forest management and other characteristics related to the object of forest management described in chapter two can be dealt with in quantitative models. This lead to the identification of two basic types of model: model I and model II. It is shown that whether a model I or a model II approach is chosen and the way in which multiple use is dealt with (combined, constrained or Goal Programming) is crucial to the features of the resulting model. It is also shown that the model I approach in combination with the constrained approach is most advisable in the Dutch context.

Chapter 5 gives an overview of STAGES. The aim of STAGES is to support decision making by giving insight into which objectives can be realized and their implications. It is based on two interrelated optimization models: a zoning model and a management model. The zoning model deals with zoning. The management model deals with the desired future forest and the transition management.

In the zoning model the zoning problem is formulated as a quadratic assignment problem. The basis of the model is that grid cells of a grid have to be assigned to uses in such a way that the total value derived from zoning is optimal. The total value of zoning is based on suitability ratings of grid cells for uses, preference scores for uses and the resulting spatial location of uses with respect to each other and with respect to the environs of the forest.

In the management model the desired future forest decision problem and the transition management decision problem are combined and are formulated as a linear programming problem. In the management model the forest is represented by zones and stands within these zones. In each zone the land use objectives are translated into constraints affecting the consequences of management and into a valuation of these consequences. The model has to assign available areas (in ha) in the stands to management options in such a way that the resulting value is optimal. The management options are derived from a description of a possible future forest in combination whit a transition management strategy to transform the current forest into the desired future forest.

STAGES is only one of the instruments needed in strategic planning in forest management. Its application yields some promising alternatives and their consequences. The next step is to mutually compare these alternatives by means of a multi-criteria evaluation method, so that the most preferred alternative can be determined and elaborated into a strategic plan. However, this was beyond the scope of the present study.

In the zoning model, land of a particular suitability and location is assigned to land use objectives in such a way that the greatest value is derived from zoning. However, the financial, social and economic consequences of zoning decisions are assessed in the management model. Hence, zoning decisions are based on only part of the information needed to make zoning decisions. The best way to redress this is to combine the zoning decision problem, the desired future forest decision problem and the transition management decision problem into one all-encompassing model. There is, however, no known algorithm that will solve this decision problem within an acceptable amount of time. A practical option is to relate the zoning model and the management model to each other in such a way that each of them takes the output of the other in consideration in making decisions. This option is elaborated in this study and is mathematically described in appendix B. The basis of the link between the zoning model and the management model is that in the zoning model assumptions are made about the implications of zoning decisions for management, and these assumptions play a role in making zoning decisions. After the zoning model has been run, the management model is run and yields the "real" consequences. If the "real" consequences of management match the assumed consequences of management, the algorithm terminates; if not, the assumptions made in the zoning model are updated with the "real" consequences and the zoning model is run again.

Chapter 6 mathematically describes the zoning model. The zoning problem is formulated as a quadratic assignment problem. The principle of this model is that grid cells from a raster have to be assigned land use objectives in such way that the resulting valuation of the zoning is optimal. Decision variables are binary (zero or one). This means that a particular grid is assigned to a particular use (decision variable is 1) or not (decision variable is zero). The assignment of land to land use objectives is based on the suitability rating of this land for the land use objectives and the preference score for land use objectives on one hand (linear part of the object function), and on the resulting location of land use objectives with respect to each other and the forest environs on the other (quadratic part of the objectfunction). The socio-economic and natural environment of the forest is included in the model as an extra layer of grids cell. Constraints about the minimum and maximum number of grid cells may be assigned to a certain land use objective can be incorporated into the model. The quadratic part of the object function gives more opportunities dealing with spatial considerations than the common LP formulations do.

The quadratic assignment problem is solved with a heuristic technique called simulated annealing. This technique starts from a known solution and searches for a better solution. It is an "iterative improvement" method. Using a heuristic technique does not guarantee that the solution found is always the optimal solution. Therefore, the algorithm was tested for optimality. From this test it is concluded that there is no guarantee that the simulated annealing algorithm will find the optimal solution in all cases, but that it is likely to give acceptable solutions for problems so large that mathematical programming methods which guarantee identification of the optimal solution can no longer be applied because of hardware restrictions. In addition it can be concluded that simulated annealing is a stable solution technique.

Chapter 7 mathematically describes the management model. It is a linear programming model that addresses both the desired future forest problem and the transition management problem. The forest is represented by zones and by stands per zone. The planning horizon is divided into planning periods. The decision variable in the management model is the amount (in ha) of a certain stand from a certain zone assigned to a certain management option. A management option is a description of a forest land utilization type and its consequences plus a transition management strategy and its consequences. For the transition management strategy, the land use objectives decided on in the zoning model are elaborated per zone into a set of constraints concerning the characteristics of the desired future forest. As well, constraints concerning the transition of the current forest into the future desired forest are formulated (restrictions on input or output during transition and restrictions on fluctuations in forest characteristics between successive periods during transition). The management model also provides opportunities for formulating constraints at forest level (for example, labour restrictions). Land within a zone is assigned to management options in such a way that all the constraints mentioned above are satisfied. The object function of the management model consists of a part that values the characteristics of the future desired forest, a part that values the characteristics during transition from the current forest to the desired future forest and a part that penalizes fluctuations in inputs and outputs during transition. The management model is flexible. Omitting the constraints pertaining to the transition management changes the management model into a model of the desired future forest. Omitting the constraints pertaining to the desired future forest changes the model into a transition management model.

Chapter 8 presents the results of a case study in which the zoning model and the management model were applied. This case study was carried out with data from the management plan of the "Waterbloem" national forest, which is in the southern part of the Netherlands.

In the application of the zoning model, seven alternatives were identified. It is shown that the quadratic part of the objective function can take spatial effects into consideration. The simulated annealing algorithm is shown to be capable of solving the problem described and provide acceptable solutions. The algorithm can handle much larger problems efficiently.

One of the zoning alternatives identified in the application of the zoning model was taken as input for the management model. In the application of the management model, five alternatives and their consequences were identified. The management model is shown to be capable of handling complex problems (2306 management options) and their consequences efficiently. The use of the management model provided insight into this complex decision problem.

In this case study the feedback relationships between the management model and the zoning model were not elaborated, because the algorithm needed to provide this link has not yet been completely implemented (see appendix B).

In chapter 9 the methodology proposed in chapter one to realize the objectives is discussed. The conclusion is that this methodology yields models that support strategic planning. These models are based not only on a consistent conception of strategic planning, but also allow some serious shortcomings in current planning practices arising from the lack of such models to be overcome. In addition, the methodology chosen in this research means that the concept of strategic planning adopted in this study covers a broad range of categories of forest ownership, and therefore so do the models developed to support strategic planning which are based on this concept. A disadvantage is that the models have to be refined and fine tuned per ownership category if they are to be implemented.

Further it can be concluded that the models are sound, but that in the current practice of forest management planning, not all the information needed to run them is available. On the other hand, the models only require information that is also needed in a strategic planning process which does not use quantitative models. If a land evaluation procedure forms part of the strategic planning process, then most of the information needed to run the models can be obtained from the results of that land evaluation procedure.

Chapter 10 describes the general conclusions and gives recommendations for further research.
The first conclusions relate to the objective to analyse strategic planning in forest management. It is concluded that the position and tasks of strategic planning in forest management have been described and that the decision problems to be solved in strategic planning have been analysed. As regards the second research objective (to develop a system to generate strategic alternatives for decision support in strategic planning in forest management), it is concluded that STAGES is based on a consistent conception of strategic planning in forest management, adresses all the decision problems of strategic planning and has been shown to be capable of generating alternatives and their consequences.

The recommendations for further research discussed are divided into improvements to existing "technical" aspects of the current models of STAGES, research on the further development and implementation of STAGES in forest management planning practice and research on the applicability of STAGES in other (non forest management) planning practices. The most important recommendation is to apply STAGES in case studies, because this will reveal what further research is needed to make STAGES suitable for practice.

SAMENVATTING

In het bosbeheer is strategische planning nodig. Het doel van dit onderzoek is het ontwikkelen van beslissingsmodellen voor de strategische planning in het bosbeheer.

In hoofdstuk 1 staan de veranderingen in het bosbeheer genoemd die dit onderzoek nodig maken. Vanwege de toename van het aantal mogelijke doelen en een toename van de beheersmogelijkheden dient bosbeheersplanning niet alleen een middelen-allocerend karakter te bezitten, maar ook een doelzoekend karakter. Wanneer het bosbeheer toegerust wil zijn voor deze taak, moeten bosbeheersplanners zich niet alleen bewust zijn van deze verandering in hun taak, maar moeten ze ook beschikken over instrumenten om hieraan gestalte te geven. Deze instrumenten ontbreken nagenoeg. Als gevolg hiervan kunnen we concluderen dat:

- er zelden alternatieven worden opgesteld;
- er onvoldoende aandacht wordt gegeven aan de lange-termijnconsequenties van beslissingen;
- beslissingen die genomen worden in de strategische planning moeilijk gerechtvaardigd kunnen worden.

Het identificeren van alternatieven en hun consequenties is een belangrijk deel van een planningsproces. De motivering van het kiezen voor een alternatief is de rechtvaardiging van de beslissing. Deze motivering wordt gebaseerd op een vergelijking van de consequenties van de alternatieven met beslissingscriteria, intenties, doelen of voorkeuren. De identificatie van alternatieven is zonder twijfel een cruciaal onderdeel van een planningsproces. Daarom is het ontbreken van instrumenten waarmee alternatieven (met hun consequenties) kunnen worden gegenereerd, een serieuze tekortkoming in de bosbeheersplanning.

Het hoofddoel van deze studie is het ontwikkelen van een STrategisch Alternatieven GEnererend Systeem (van nu af aan aangeduid met STAGES) ter ondersteuning van de strategische planning in het bosbeheer. STAGES dient bruikbaar te zijn voor een brede groep categorieën van boseigenaren. Het hoofddoel van STAGES is het genereren van alternatieven en hun financiële, economische, sociale en milieuconsequenties. Op deze manier draagt STAGES bij aan het oplossen van de genoemde problemen in de strategische planning (geen alternatieven: geen consequenties: geen rechtvaardiging).

De onderdelen van deze studie komen voort uit de onderzoeksvragen en de methodologie die is gebruikt om de gestelde vragen te beantwoorden. Deze methodologie bestond uit vier fasen:

1. Analyse van de besluitvormingssituatie in de strategische planning in het bosbeheer;
2. Studie naar kwantitatieve algoritmen en modellen die gebruikt zouden kunnen worden bij het oplossen van in fase 1 gesignaleerde beslissingsproblemen;
3. Ontwikkeling van wiskundige modellen ter ondersteuning van beslissingen in de strategische planning in het bosbeheer;
4. Validatie en implementatie van de ontwikkelde modellen.

In hoofdstuk 2 worden belangrijke aspecten van bosbeheer beschreven. Bosbeheer wordt gedefinieerd als de verzameling van menselijke acties gericht op het op elkaar afstemmen van het bosecosysteem en de samenleving om een duurzame vervulling van behoeften in de samenleving mogelijk te maken. Het object van bosbeheer is dus de relatie tussen bosecosysteem en samenleving. In dit hoofdstuk komt naar voren dat bosbeheer een complex besluitvormingsproces is. Deze complexiteit wordt veroorzaakt door de basisconcepties in het bosbeheer (duurzaamheid en meervoudig gebruik) en door andere aan het object van bosbeheer gerelateerde eigenschappen, namelijk:
- veel van de door het bos geproduceerde goederen en diensten zijn moeilijk te kwantificeren;
- goederen en diensten zijn vaak niet-marktbaar, hetgeen waardering moeilijk maakt;
- natuurlijke processen spelen een belangrijke rol in bossen;
- de lengte van de produktieperiode;
- bomen zijn produkt, voorraad en produktiefactor;
- de omvang van het planningsprobleem;
- risico en onzekerheid.

Bij het nemen van beslissingen in het bosbeheer is veel informatie nodig en moet rekening worden gehouden met allerlei relaties tussen beslissingen. Beslissingen in het bosbeheer kunnen daarom niet ad hoc worden genomen, maar moeten worden opgenomen in een planningsysteem. Een planningsysteem is een georganiseerde verzameling van planningsprocessen. Een planningsproces kan worden gezien als een set van aan elkaar gerelateerde (denk)activiteiten waarin inzichten worden verworven, beslissingen worden genomen en acties worden ondernomen.

In hoofdstuk 3 wordt strategische planning in het bosbeheer beschreven als het hoogste niveau in een hiërarchisch gelaagd beslissingsprobleem. De lagen zijn strategische planning, tactische planning en operationele planning. Strategische planning richt zich op het nemen van beslissingen over doelen. Tactische planning richt zich op het nemen van beslissingen over methoden en daarvoor benodigde middelen om de doelen waartoe besloten is in de strategische planning te realiseren. Operationele planning richt zich op de uitvoering van de beheersactiviteiten waartoe besloten is in de tactische planning. Strategische planning in het bosbeheer is gerelateerd aan landgebruiksplanning en is een complex planningsproces. Daarin moeten de volgende beslissingsproblemen worden opgelost:
- zonering;
- doelbos;

- omvormingsbeheer.

Het beslissingsprobleem ten aanzien van zonering (zoneringsprobleem) bestaat uit het indelen van het bos in zones en het gelijktijdig toewijzen van landgebruiksdoelen aan deze zones. Bij de zonering wordt alleen besloten welke landgebruiksdoelen worden nagestreefd en niet op welke wijze en tegen welke financiële en capacitaire inspanningen ze gerealiseerd dienen te worden. De realisatie van de landgebruiksdoelen wordt gepland in de beslissingsproblemen doelbos en omvormingsbeheer.
Het beslissingsprobleem ten aanzien van het doelbos (doelbosprobleem) bestaat uit het toewijzen van land binnen een zone aan landgebruikstypen op een dusdanige wijze dat de landgebruiksdoelen voor die zone worden gerealiseerd. De realisatie van het doelbos kost normaliter decennia. Het doelbos moet daarom worden gezien als een baken dat aangeeft in welke richting er gevaren moet worden. Vanwege de lange-termijneffecten van ingrepen in het bosecosysteem moet dit baken ver vooruit worden gezet. De consequentie hiervan is echter dat het baken zelf nooit bereikt wordt, maar van tijd tot tijd verzet wordt vanwege veranderingen in de samenleving. Echter, zonder een dergelijk baken zal de in het beheer benodigde continuïteit niet kunnen worden gerealiseerd.
Het beslissingsprobleem ten aanzien van het omvormingsbeheer (omvormingsprobleem) bestaat uit het toewijzen van land aan omvormingsstrategieën op een dusdanige wijze dat het huidige bos wordt omgevormd tot het doelbos. Een omvormingsstrategie is een kwalitatieve en kwantitatieve beschrijving van de manier waarop het huidige bos wordt omgevormd tot het gewenste bos.

Hoofdstuk 4 geeft een kritische beschouwing van bestaande modellen die zijn beschreven in de literatuur.
Voor het zoneringsprobleem wordt in dit hoofdstuk geconcludeerd dat de in de literatuur gevonden modellen onvoldoende ondersteuning bieden bij beslissingen over verdeling van het bos in zones. Een belangrijk aspect in het zoneringsprobleem is de ruimtelijke interactie tussen beslissingen. Het toewijzen van land aan een landgebruiksdoel heeft consequenties voor het toewijzen van ander land aan landgebruiksdoelen. Deze consequenties zijn niet alleen gerelateerd aan de hoeveelheid land die wordt toegewezen, maar ook aan de locatie van het land dat wordt toegewezen. Geen van de in de literatuur gevonden modellen gaat in op dit probleem.
De in de literatuur gevonden modellen bevatten bruikbare elementen voor het doelbosprobleem. De gevonden modellen richten zich voornamelijk op het vinden van een optimale steady state van het bos voor de houtproduktie, maar zouden uitgebreid kunnen worden tot modellen waarin de optimale steady state van het bos wordt bepaald vanuit een meervoudig gebruiksstandpunt.
Voor het omvormingsprobleem zijn er enkele bruikbare modellen gevonden in de literatuur. Een aanzienlijk aantal modellen richt zich op het plannen in de tijd van activiteiten. Slechts een enkel model richt zich op het probleem van het zodanig beheren van een bos dat het doelbos wordt gerealiseerd.
In de literatuurstudie is duidelijk geworden dat het doelbosprobleem niet los gezien kan worden van het omvormingsprobleem: om optimale beslissingen te kunnen nemen dienen

beide problemen samen opgelost te worden. De consequenties van het kiezen voor een doelbos in termen van investeringen die daarvoor moeten worden gedaan, worden immers pas duidelijk in het omvormingsprobleem. In de literatuur zijn geen modellen gevonden die zich op beide problemen richten.
Er is onderzocht hoe de basisconcepties en complicerende factoren van bosbeheer (zie hoofdstuk 2) in wiskundige modellen opgenomen kunnen worden. In dit verband zijn twee modellen beschreven: model I en II. Er is aangetoond dat de keuze voor model I of II in combinatie met de keuze voor hoe er in het model wordt omgegaan met meervoudig gebruik (combined, constrained of Goal Programming) cruciaal is voor de eigenschappen van het model dat daarop wordt gebaseerd. Verder is aangetoond dat in de Nederlandse context de model I-benadering in combinatie met de randvoorwaardenbenadering de voorkeur verdient.

Hoofdstuk 5 geeft een overzicht van STAGES. STAGES heeft als doel het ondersteunen van de strategische planning door het geven van inzicht in welke doelen kunnen worden gerealiseerd en wat de consequenties daarvan zijn. STAGES is gebaseerd op twee aan elkaar gerelateerde optimaliseringsmodellen: het zoneringsmodel en het managementmodel. Het zoneringsmodel richt zich op het zoneringsprobleem en het managementmodel richt zich op het doelbosprobleem en het daarbij behorende omvormingsprobleem.
In het zoneringsmodel is het zoneringsprobleem geformuleerd als een kwadratisch toewijzingsprobleem (QAP: Quadratic Assignment Problem). De basis van het model is dat grids in een gridraster worden toegewezen aan landgebruiksdoelen op een dusdanige wijze dat de totale waarde die wordt ontleend aan deze toewijzing optimaal is. De totale waarde van een zonering wordt bepaald door de geschiktheid van de grids voor de landgebruiksdoelen, voorkeuren van de beslisser voor landgebruiksdoelen en de resulterende ruimtelijke verdeling van landgebruiksdoelen ten opzichte van elkaar en ten opzichte van de omgeving van het bos.
In het managementmodel zijn het doelbosprobleem en het omvormingsprobleem gecombineerd in één probleem en dit probleem is geformuleerd als een lineair programmeringsprobleem (LP). In het managementmodel wordt het bos weergegeven door middel van zones en opstanden daarbinnen. Per zone zijn de landgebruiksdoelen vertaald naar randvoorwaarden aan de consequenties van het beheer (bijvoorbeeld kenmerken van het bos). Daarnaast zijn de landgebruiksdoelen ook vertaald naar een waardering van de consequenties van het beheer. De basis van het model is dat de beschikbare oppervlakte per opstand toegewezen wordt aan management-opties op zodanige wijze dat de resulterende waardering optimaal is. Een management-optie bestaat uit een combinatie van een landgebruikstype met een omvormingsstrategie, om uitgaande van de huidige opstand dat landgebruikstype te realiseren.

STAGES is slechts één van de instrumenten die nodig zijn in strategische plannng in het bosbeheer. Het toepassen van STAGES resulteert in een aantal alternatieven en hun consequenties. Deze alternatieven dienen met elkaar te worden vergeleken door middel van een multi-criteria evaluatiemethode, zodat het beste alternatief geïdentificeerd kan worden en kan worden uitgewerkt tot een strategisch plan. Dit voert echter buiten de kaders van deze studie. STAGES beperkt zich tot het genereren van alternatieven en hun consequenties.

In het zoneringsmodel wordt land toegewezen aan gebruiksdoelen op een zodanige wijze dat de daaruit ontstane zonering als hoogste gewaardeerd wordt. De financiële, economische, sociale en milieuconsequenties van zoneringsbeslissingen worden echter bepaald in het managementmodel. Dit betekent dat zoneringsbeslissingen gebaseerd zijn op slechts een deel van de informatie die nodig is om zoneringsbeslissingen te nemen. De beste manier om dit te voorkomen is het combineren van het zoneringsprobleem, het doelbosprobleem en het omvormingsprobleem in een allessociaal- reomvattend model. Er is echter geen algoritme bekend dat het dan ontstane beslissingsprobleem binnen een acceptabele tijd kan oplossen. Een praktische oplossing is het zoneringsmodel en het managementmodel op een zodanige wijze met elkaar te verbinden dat in elk van de modellen bij het nemen van beslissingen rekening wordt gehouden met de output van het andere model. Deze oplossing is uitgewerkt in deze studie en wiskundig beschreven in appendix B. De basis van de relatie tussen het zoneringsmodel en het managementmodel is dat in het zoneringsmodel aannames worden gedaan over de beheersconsequenties van het nemen van zoneringsbeslissingen. Deze aannames spelen mee in het nemen van zoneringsbeslissingen. Nadat het zoneringsmodel is 'gerund', wordt het managementmodel 'gerund'. De output van het managementmodel beschrijft de 'werkelijke beheersconsequenties'. Als deze 'werkelijke beheersconsequenties' overeenstemmen met de in het zoneringsmodel gedane aannames over deze consequenties dan stopt het algoritme. Als de 'werkelijke consequenties' afwijken van de gedane aannames, dan worden de aannames aangepast op grond van de 'werkelijke consequenties' en start een volgende iteratie met het runnen van het zoneringsmodel.

In hoofdstuk 6 wordt het zoneringsmodel wiskundig beschreven. Het zoneringsprebleem is geformuleerd als een QAP. De basis van het model is dat grids worden toegewezen aan landgebruiksdoelen op een zodanige wijze dat de resulterende waardering voor de zonering optimaal is. De beslissingsvariabelen zijn binair (of 0 of 1). Dit betekent dat een grid in zijn geheel aan een bepaald landgebruiksdoel wordt toegewezen (beslissingsvariabele is 1) of niet wordt toegewezen (beslissingsvariabele is 0). De toewijzing van grids aan landgebruiksdoelen is gebaseerd op de geschiktheidscijfers van een grid voor een bepaald landgebruiksdoel in combinatie met voorkeurscijfers voor landgebruiksdoelen aan de ene kant (lineair deel van de doelfunctie) en de resulterende locatie van landgebruiksdoelen ten opzichte van elkaar en de omgeving (kwadratisch deel van de doelfunctie). De sociaal-economische en natuurlijke omgeving van het bos is in het model opgenomen als een extra rand met grids. In het model kunnen restricties worden gesteld aan het minimum of maximum aantal grids toe te wijzen aan een bepaald gebruiksdoel. Het kwadratische deel van de doelfunctie geeft meer mogelijkheden om om te gaan met de ruimtelijke interacties tussen beslissingen dan Lineaire-Programmeringsmodellen geven.

Het kwadratisch toewijzingsprobleem wordt opgelost met een heuristiek genaamd Simulated Annealing. Deze heuristiek begint met een bekende oplossing en zoekt van daaruit naar betere oplossingen. Heuristieken garanderen niet dat altijd het globaal optimum wordt gevonden. Het algoritme is daarom getoetst op optimaliteit van de gevonden oplossingen. Op grond van deze test is geconcludeerd dat er geen garantie kan worden gegeven dat het Simulated Annealing algoritme in alle gevallen het optimum vindt, maar dat het zeer aannemelijk is dat het acceptabele oplossingen geeft voor problemen van een omvang waar wiskundige programmeringstechnieken, die het vinden van het optimum garanderen, niet toegepast kunnen worden vanwege beperkingen in de hardware. Daarnaast kan worden geconcludeerd dat Simulated Annealing een stabiele oplossingstechniek is.

In hoofdstuk 7 wordt het managementmodel wiskundig beschreven. Het managementmodel is een lineair-programmeringsmodel dat zowel het doelbosprobleem als het omvormingsprobleem omvat. Het bos wordt weergegeven door middel van zones en opstanden binnen zones. De planninghorizon is verdeeld in planningperioden. De beslissingsvariabelen zijn het aantal ha van een bepaalde opstand van een bepaalde zone die worden toegewezen aan een bepaalde management-optie. Een management-optie is een beschrijving van een landgebruikstype met daarmee samenhangende consequenties en een omvormingsstrategie om het huidige bos om te vormen tot het gewenste bos met daarmee samenhangende consequenties. Per zone zijn de landgebruiksdoelen uitgewerkt tot randvoorwaarden voor de eigenschappen van het doelbos. Daarnaast zijn er randvoorwaarden geformuleerd voor de omvorming van het huidige bos in het doelbos. Dit betreft randvoorwaarden aan inputs en outputs per periode en restricties aan het voorkomen van te grote schommelingen in inputs en outputs gedurende de planninghorizon. Het managementmodel geeft ook mogelijkheden tot het formuleren van randvoorwaarden op bosniveau (bijvoorbeeld beperkingen aan beschikbare arbeid). De beschikbare oppervlakte binnen een zone wordt zodanig toegewezen aan management-opties dat aan bovenstaande randvoorwaarden wordt voldaan. De doelfunctie van het model bestaat uit een deel waarin eigenschappen van het doelbos worden gewaardeerd, een deel waarin consequenties van het omvormingsbeheer worden gewaardeerd en een deel waarin te grote schommelingen in inputs en outputs gedurende het omvormingsbeheer worden beboet. Het managementmodel is flexibel. Het weglaten van randvoorwaarden voor het omvormingsbeheer verandert het model in een doelbosmodel. Het weglaten van randvoorwaarden voor het doelbos verandert het model in een omvormingsmodel.

In hoofdstuk 8 worden de resultaten beschreven van een case studie waarin het zoneringsmodel en het managementmodel zijn toegepast. De case studie is uitgevoerd met data van het beheersplan van 'Waterbloem'. Waterbloem is een bosbeheerseenheid van Staatsbosbeheer in het zuiden van Nederland.
In de toepassing van het zoneringsmodel zijn zeven alternatieven gegenereerd. Er is aangetoond dat het kwadratische deel van de doelfunctie een geschikt instrument is om ruimtelijke effecten te kwantificeren. Er is aangetoond dat het Simulated Annealing

algoritme in staat is het beschreven probleem op te lossen en acceptabele oplossingen te genereren. Het algoritme is in staat om nog veel grotere problemen op te lossen. Een van de gegenereerde zoneringsalternatieven is gebruikt als input voor het managementmodel. *In de toepassing van het managementmodel zijn vijf alternatieven gegenereerd.* Er is aangetoond dat het managementmodel in staat is op een efficiënte wijze grote complexe problemen op te lossen en hun consequenties aan te geven (Het huidige probleem omvatte 2306 management-opties). Het gebruik van het managementmodel verschaft inzicht in het complexe beslissingsprobleem.
In deze case studie is niet ingegaan op de terugkoppeling van de 'werkelijke beheersconsequenties' naar het zoneringsmodel, omdat het daarvoor benodigde algoritme nog niet volledig is geïmplementeerd (zie appendix B).

In hoofdstuk 9 wordt de in deze studie gebruikte methodologie bediscussieerd.
De conclusie is dat de gebruikte methodologie heeft geleid tot modellen die de strategische planning ondersteunen. Deze modellen zijn niet alleen gefundeerd op een consistente conceptie over de te nemen beslissingen in de strategische planning, maar geven ook mogelijkheden om enkele tekortkomingen in de huidige planning, die zijn ontstaan als gevolg van het ontbreken van dergelijke modellen, te verhelpen. Daarnaast maakt de gevolgde methodologie mogelijk dat het gehanteerde concept over strategische planning en de daarop gebaseerde modellen gebruikt kan worden door een brede groep categorieën van boseigenaren. Een nadeel is dat de modellen, voordat ze kunnen worden ingezet in het bosbeheer, afgestemd dienen te worden op de specifieke situatie van de betreffende eigendomscategorie.
Verder kan worden geconcludeerd dat de modellen gezond zijn, maar dat niet alle informatie die nodig is om de modellen te runnen op dit moment gegenereerd wordt in de huidige bosbeheersplanningpraktijk. Aan de andere kant gebruiken de modellen geen extra informatie ten opzichte van een situatie waarin geen kwantitatieve modellen worden gebruikt. Wanneer een landevaluatieprocedure onderdeel is van de strategische planning in het bosbeheer, dan kan het merendeel van de benodigde informatie ontleend worden aan de resultaten van die landevaluatieprocedure.

In hoofdstuk 10 worden conclusies getrokken en worden aanbevelingen voor verder onderzoek gedaan.
Het eerste doel van dit onderzoek is een analyse van de strategische planning in het bosbeheer. De positie en de taken van strategische planning in het bosbeheer zijn beschreven en de beslissingsproblemen die in de strategische planning moeten worden opgelost zijn geanalyseerd. Het tweede doel is het ontwikkelen van een strategisch alternatieven-genererend systeem ter ondersteuning van beslissingen in het bosbeheer. STAGES is gebaseerd op een consistente conceptie van strategische planning in het bosbeheer en richt zich op alle geïdentificeerde beslissingsproblemen binnen de strategische planning. Er is aangetoond dat met behulp van STAGES alternatieven en hun consequenties kunnen worden gegenereerd.

Bij de aanbevelingen voor verder onderzoek is het onderzoek gesplitst in onderzoek gericht op het verbeteren van bestaande 'technische' aspecten van de huidige modellen binnen STAGES en onderzoek gericht op de verdere ontwikkeling en implementatie in de bosbeheersplanningspraktijk van STAGES en het verkennen van de toepassingsmogelijkheden van STAGES in andere (niet bosbeheerbetreffende) planningsprocessen. De belangrijkste aanbeveling is STAGES toe te passen in case studies. Op deze manier wordt duidelijk welk nader onderzoek nodig is om STAGES geschikt te maken voor de praktijk.

REFERENCES

Alston, R.M., and Iverson, D.C. (1987). The Road from TimberRAM to FORPLAN: How far have we traveled? *Journal of Forestry* **85**(6), 43-49.

Andel, S. van, Bol, M., Goor, C.P. van, Laban, P. (ed.), Lammerts van Bueren, E.M. and Maaren, A. van (1981). Land Utilization Types for Forestry. In: Laban, P. (ed.) *Proceedings of the workshop on land evaluation for forestry International workshop of the IUFRO/ISSS Wageningen, The Netherlands November 10-14, 1980*, Wageningen, The Netherlands , ILRI publication no. 28. 355 pp.

Ansoff, H.I. (1965). *Corporate strategy an analytical approach to business policy for growth and expansion.* McGraw-Hill. 241 pp.

Ansoff, H.I. and Hayes, R.L. (1976). Introduction. In: Ansoff, H.I., Derck, R.O. and Hayes, R.L. (ed.) *From strategic planning to strategic management*, London, Wiley. 257 pp.

Anthony, R.N. (1965). *Planning and control systems. A framework for analysis* Division of Research. Graduate School of Business Administration Harvard University. 180 pp.

Armson, K.A. (1990). Towards new forest management strategies: two paths to one conclusion. *Journal of Forestry* **88**(6), 37-39.

Arp, P.A., and Lavigne, D.P. (1982). Planning with Goal Programming: A case study for multiple-use of forested land. *The Forestry Chronicle* **58**, 225-232.

Bare, B.B. and Field, R.C. (1987). An evaluation of FORPLAN from an operations research perspective. In: Hoekstra, T.W., Dyer, A.A. and Le Master, D.C. (technical editors). *FORPLAN: an evaluation of a forest planning tool. Proceedings of a symposium November 4-6, 1986, Denver, Colorado* USDA Forest Service General Technical Report RM-140 pp. 133-144.

Behan, R.W. (1990). Multiresource forest management: A paradigmatic challenge to professional forestry. *Journal of Forestry* **88**(4), 12-22.

Berg, van den A. and Coeterier, J.F. (1980). De waarneming en waardering van bossen. *Nederlands Bosbouwtijdschrift* **52**, 263-273.

Bergstrom, J.C. and Cordell, H.K. (1991). An Analysis of the demand for and value of outdoor recreation in the United States. *Journal of Leisure Research* **23**(1), 67-86.

BLB (1990). *Concept visie Landschap.* Utrecht, Directie Bos- en Landschapsbouw.

Blox, J.T.H.M., Enden, C. van der and Hart, H.W.C. van der (1989). *Bedrijfseconomie. Economisch handelen in bedrijfskundig perspectief.* Amsterdam, Elsevier. 444 pp.

Bos, J. (1993). Zoning in forest management: a quadratic assignment problem solved by simulated annealing. *Journal of Environmental Management* **37**, 127-145.

Bos, J., Bax, R.A. and Dijk, H. Van (1994). *Toepassing van een LP model t.b.v. de strategische planning in het bosbeheer, casestudy Waterbloem.* Wageningen, DLO Institute for Forestry and Nature Research (in preperation).

Bos, J. and Hekhuis, H.J. (1991). *Beheersplanning bos met meervoudige functievervul ling: doeloperationalisering en technische produktiefuncties. Managing multiple-use forests: operationalisation of objectives and technical production functions.* Wageningen, DLO Institute for Forestry and Nature Research rapport no. 671. 73 pp. (in Dutch with English summary).

Bos, J. and Hekhuis, H.J. (1994). Sustainability in forest management planning. In: Lier, H.N. van, Jaarsma, C.F., Jurgens, C.R. and Buck, A.J. de *Sustainable land use planning. Proceedings of an international Workshop, 2-4 september 1992, Wageningen, The Netherlands.* pp. 179-189.

Bos, J. van den (1969). Inzichten bij de inrichting van bosgebieden in verband met de openluchtrecreatie. *Nederlands Bosbouwtijdschrift* **41**(6), 168-170

Bosschap (1984). *Bosbouw en planologie. Beleidsnotitie van het Bosschap over het wezen van de bosbouw, de functies van het bos in relatie tot de ruimtelijke ordening.* 16 pp.

Botter, C.H. (1981). *Industrie en organisatie: een overzicht en uitzicht.* 12e druk Deventer, KLUWER, NIVE-publicatie no. 655. 299 pp.

Bowes, M.D. and Krutilla, J.V. (1989). *Multiple-use management: the economics of public forestlands.* Washington D.C., Resources for the Future, 357 pp.

Braat, L.C. (1992). *Sustainable multiple use of forest ecosystems: an economic-ecological analysis for forest management in the Netherlands.* Amsterdam, Vrije Universiteit, Proefschrift. 195 pp.

Brabänder, H.D. (1991). Möglichkeiten und Grenzen der Anwendung monetärer Steue-rungselemente bei der Sicherung landeskultureller Ansprüche an den Wald. *Forstarchiv* **61**, 242-247.

Brown, T. C. (1976). *Alternatives analysis for multiple use management: A case study.* USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins. Research Paper RM-176. 16 pp.

Brumelle, S.L., Carley, J.S., Vertinsky, I.B. and Wehrung, D.A. (1991). Evaluating the silvicultural investments: A review in the Canadian context. *Forestry Abstracts* **52**(9), 803-856.

Brundtland, G.H. (1987). *Our common future.* Oxford, World Commission on Environment and Development. 400 pp.

Buiten, H., Cosijn, R., Veen, H.E. van der and Werf, J.W. van der (1981). *Naar meer en beter bos in Nederland: een schets voor een visie op bosbouwbeleid en bosbeheer.* Stichting Wetenschappelijk Bureau D'66. 28 pp.

Buongiorno, J. and Gilles, J.K. (1987). *Forest management and economics a primer in quantitative methods.* New York, MacMillan. 285 pp.

Burkard, R. E. (1984). Quadratic Assignment Problems. *European Journal of Operatio nal Research* **15**, 283-289.

Burkard, R. E. and Rendl, F. (1984). A thermodynamically motivated simulation procedure for combinatorial optimization problems. *European Journal of Operational Research* **17**, 169-174.

Burrough, P.A. (1986). *Principles of geographical information systems for land resources assessment.* Oxford, Carlendon. 193 pp.

CBS (1985). *Centraal Bureau voor de Statistiek. De Nederlandse Bosstatistiek deel 1: de oppervlakte bos 1980-1983.* Den Haag, Staatsuitgeverij. CBS-publicaties 1985.

Chapelle, D.E., Mang, M. and Miley, R.C. (1976). Evaluation of TimberRAM as a forest management planning model. *Journal of Forestry* **74**(5), 288-293.

Clawson, M. (1974). Economic and social conflicts in land use planning. *Natural Resources Journal* **15**, 473-489.

Clawson, M. (1976). *Forests for Whom and for What.* 2nd print. Baltimore, Published for Resources for the Future inc. by the John Hopkins University Press. 175 pp.

Clawson, M. (1978). The concept of Multiple Use Forestry. *Environmental Law* **8**, 281-308.

Cleiren, L.H.J. (1992). Meer dunnen: beter bos. *Bosbouwvoorlichting* **31**(8), 85-88.

Cocklin, C. (1989) Mathematical programming and resources planning I: the limitations of traditional optimization. *Journal of Environmental management* **28**, 127-141.

Connolly, D. T. (1990). An improved annealing scheme for the QAP. *European Journal of Operational Research* **46**, 93-100.

Davis, L.S. and Johnson, K.N. (1987). *Forest management.* McGraw-Hill 90 pp.

Davis, G.B. and Olson, M.H. (1985). *Management information systems: conceptual foundations, structure, and development.* New York, McGraw-Hill. 693 pp.

Delft, A. van and Nijkamp, P. (1977). *Multi-criteria analysis and regional decision-making.* Leiden, Nijhoff. Studies in applied regional science vol. 8. 135 pp.

Dijkstra, D.P. (1984). *Mathematical programming for natural resource management.* New York, McGraw-Hill. 318 pp.

Doorn, J. van and Vught, F. van (1978). *Planning methoden en technieken voor beleidsondersteuning.* Amsterdam, Van Gorcum. 244 pp.

Dress, P.E. (1975). Forest land use planning an applications environment for goal pro gramming. pp. 46-47. In: Meadows, J., Bare, B.B., Ware, K. and Row, C. (eds.) *System analysis and forest resource management. Proceedings of a workshop. System analysis working group. Society of American Foresters.* Athens, University of Georgia. pp. 37-47.

Duerr, W.A., Teeguarden, D.E., Christiansen, N.B. and Guttenberg, S. (1979). *Forest resource management. Decision-making principles and cases.* Philadelphia, Saunders. 612 pp.

Eriksson, L.O. (1983). *Long range forestry planning A case study of a forest in a transition period.* Garpenberg, The Swedish University of Agricultural Sciences, Department of Operational Efficiency, Report no. 154. 78 pp.

Faludi, A. (1982). *The return of rationality.* Amsterdam, Planologisch en Demografisch Instituut.

Universiteit van Amsterdam. werkstuk 54. 34 pp.

Faludi, A. (ed.) (1973a). *A reader in planning theory.* Oxford, Pergamon. Urban and Regional Planning series. Volume 5. 399 pp.

Faludi, A. (1973b). *Planning theory.* Oxford, Pergamon. 306 pp.

FAO, (1984) *Land Evaluation for Forestry.* Rome, Food and Agriculture Organization of the United Nations. FAO Forestry paper 48. 123 pp.

Field, C., Dress, P.E., Turner, B.J., Willson, R.B. and Flowers, W.R. (1980). Determining the optimal sustained yield forest structure in USDA forest service planning In: Vodak, M.C., Leuschner, W.A. and Navon, D.I. (ed.) 1981. *Proceedings of the International Union of Forestry Research Organizations (IUFRO) Symposium on forest management planning: present practise and future decisions, August 18-20, 1980, Blacksburg, Virginia.* Blacksburg, The School of Forestry and Wildlife Resources. Publication FWS-1-81: 68-79.

Filius, A.M. (1983). Boom- en bossoortenkeuze vanuit sociaal-economisch gezichtspunt bezien. *Nederlands Bosbouwtijdschrift* **55**(4), 177-189.

Fresco, L., Huizing, H., Keulen, H. van (1990). *Land evaluation and farming systems analysis for land use planning: FAO guidelines: working document.* Rome, FAO. 207 pp. + 1 appendix.

Gadow, K. von (1980). The principle of Sustention in Forestry Planning. *South African Journal* **14**, 25-28.

Gale, R.P and Cordray, S.M. (1991). What should forests sustain? Eight answers. *Journal of Forestry* **89**(5), 31-36.

Garey, M.R. and Johnson, D.S. (1979). *Computers and intractability: a guide to the theory of NP-completeness.* San Francisco, Freeman. 338 pp.

Glück, P. (1982). Das Elend der Kielwassertheorie. *Internationaler Holzmarkt* **5**, 15-18.

Gong, P.(1993). *Optimal timber harvesting under uncertainty.* Garpenberg, Swedish university of agricultural sciences, department of forest economics. Report 102. 38 pp.

Gregory, G.R. (1972). *Forest resource economics.* New York, Ronald Press. 548 pp.

Gregory, G.R. (1987). *Resource economics for foresters.* New York, Wiley. 477 pp.

Gunn, E.A. (1991). Some aspects of hierarchical production planning in forest management. In: Buford, M.A. (ed.) *Proceedings of the 1991 Symposium on Systems Analysis in Forest Resources, March 3-6, 1991, Charleston, South Carolina.* Asheville, Southeastern Forest Experiment Station. General Technical Report SE-74 pp. 54-62.

Haas, G. E., Driver, B. L., Brown, P. J. and Lucas, R. G. (1987). Wilderness manage ment zoning. *Journal of Forestry* **85**(12), 17-21.

Hekhuis, H.J., de Molenaar, G.J. and Jonkers, D.A. (1994). *Het sturen van natuurwaarden door bosbedrijven: een evaluatie methode voor multifunctionele bossen.* Wageningen, DLO-Instituut voor Bos- en Natuuronderzoek. rapport 78. 146 pp.

Helliwel, D.R. (1987). Multiple-Use Forestry in the United Kingdom. *AMBIO* **16**(2-3), 129-133.

Hertog, B. den (1986). Inrichting en meervoudig terreingebruik. *Nederlands Bosbouwtijdschrift* **58**(1/2), 34-39.

Hessels, E.P.L. (1978). Uitgangspunten voor het beheer van het Nederlandse bos. *Nederlands Bosbouwtijdschrift* **50**(9), 257-261.

Hillier, F. S. and Liebermann, G. J. (1990). *Introduction to Operations Research.* 5th edition, Oakland, Holden-Day. 954 pp.

Hinssen, P.J.W. (1991). De betekenis van automatisering voor bosbeheersplanning. *Nederlands Bosbouwtijdschrift* **63**, 260-268.

Hof, J. (1993). *Coactive forest management*. SanDiego, California, Academic Press. 189 pp.

Irland, L.C. (1986). Strategic thinking - A critical gap in American forestry planning and management. *Renewable Resources Journal* 4(1), 14-18.

Jöbstl, H.A. (1973). *Ein modell des Forstbetriebes: neue Ansätze und Technieken für die lang- und mittelfristige Planung*. Veröffentlichungen des Institutes für forstliche Wirtschaftslehre an der Hochschule für Bodenkultur in Wien. Wien, Kommissionsverlag: Österreichischer Agrarverlag 1014. 208 pp.

Jöbstl, H.A. (1978). *Unternehmungsplanung in der Forstwirtschaft. Ein Beitrag zu den Grundlagen einer forstlichen Planungslehre mit Modellansätzen und computergestützten Berechnungsexperimenten für Nachhaltsregelung und Mittelfristplanung*. Veröffentlichungen des Institutes für forstliche Wirtschaftslehre an der Universität für Bodenkultur in Wien. Wien, Kommissionsverlag: Österreichischer Agrarverlag, 1014 Wien 212 pp.

Johnson, K.N. and Scheurmann, H.L. (1977). Techniques for prescribing optimal timber harvest and investments under different objectives- discussion and synthesis. *Forest Science Monograph* 18. 31 pp.

Johnson, K. N. and Stuart, T. W. (1987). *FORPLAN version 2: Mathematical Programmer's Guide*. Washington D.C., Land Management Planning Systems Section, USDA Forest Service.

Johnson, K.N, Stuart, T.W. and Crim, S.A. (1986). *FORPLAN version 2: An Overview*. Washington D.C., USDA Forest Service. Land Management Planning Systems Section.

Johnston, D.R., Grayson, A.J. and Bradley, R.T. (1967). *Forest Planning*. London, Faber and Faber. 541 pp.

Jonge, D. de (1969). Het bos als recreatiegebied: uitkomsten van gedragsstudies. *Nederlands Bosbouwtijdschrift* 41(6), 162-167.

Kampfraath Committee (1975). *Rapport van de Commissie Onderzoek Beheer Terreinen Staatsbosbeheer*. Den Haag Staatsuitgeverij. 106 pp.

Kanowski, P.J., Savill, P.S. *et al.* (1992). Plantation forestry. In: Sharma, N.P. (ed.) *Managing the World's forests looking for balance between conservation and development*. Dubuque, Kendal-Hunt. 605 pp.

Katteler, H.A. and Kropman, J.A. (1975). *De recreatieve funktie van het bos: gebruik en beleving van het bos door de rekreant*. Nijmegen, Instituut voor toegepaste sociologie. 58 pp.

Kennedy, J.J. (1985). Conceiving forest management as providing for current and future social value. *Forest Ecology and Management* **13**, 121-132.

Kent, B., Bare, B.B., Field, R.C. and Bradley, G.A. (1991). Natural resource land management planning using large-scale linear programs: the USDA Forest Service experience with FORPLAN. *Operations Research* **39**(1), 13-27.

Keuning, D. and Eppink, D.J. (1987). *Management en organisatie*. Leiden, Stenfert Kroese. 517 pp.

Kirkpatrick, S., Gelatt, C.D.jr., Vecchi, M.P. (1983). Optimization by simulated annealing. *Science* **220**, 671-680.

Kleefmann, F. (1984). *Planning als zoekinstrument: Ruimtelijke planning als instrument bij het richtingzoeken.* Deel 5 uit de serie 'Planologische verkenningen.' Den Haag, VUGA. 132 pp.

Kloet, W.G. Van der (1963). Wat is de recreatieve betekenis van het bos en welke eisen stelt de recreatie aan het bos. *Nederlands Bosbouwtijdschrift* 35(4), 121-127.

Laban, P. (ed.) (1981). *Proceedings of the workshop in land evaluation for forestry: International Workshop of the IUFRO/ISSS.* Wageningen, The Netherlands, November 10 - 14, 1980. Wageningen, ILRI. publication 28. 355 pp.

Lammerts van Bueren, E.M. (1983). Een landevaluatiebenadering toegepast op bossen. *Nederlands Bosbouwtijdschrift* 55(1), 14-22.

Lee, H.J. van der, Moëd, J. and Dierckxsens, M.J.B.L. (1987). *Strategisch management een leerboek.* Alphen aan de Rijn, SAMSON. 173 pp.

Leuschner, W.A. (1990). *Forest regulation, harvest scheduling, and planning techniques.* New York, Wiley. 281 pp.

LNV (1990a). *Uitvoeringsprogramma meerjarenplan bosbouw 1990 - 1994.* Den Haag, SDU.

LNV (1990b). *Natuurbeleidsplan: regeringsbeslissing.* Den Haag, SDU. 272 pp.

LNV (1992). *Evaluatie meerjarenplan bosbouw 1986-1991. Ministerie van Landbouw, Natuurbeheer en Visserij.* Den Haag, SDU. 147 pp.

Lohmander, P. (1987). *The economics of forest management under risk.* Garpenberg, Swedish university of agricultural sciences, department of forest economics. Report 79. 316 pp.

L&V (1986). *Meerjarenplan bosbouw.* Den Haag, SDU. 162 pp.

Maaren, A. van (1988). Door de vierde nota het bos niet meer zien? In: *Commentaren op de Vierde nota over de ruimtelijke ordening.* Wageningen, Permanente Contactgroep Ruimtelijke Organisatie - PCRO. Wageningse ruimtelijke studies. **1**, 77-92.

Maaren, A. van (1991). Planning in het wetenschapsveld bosbouw. In: *Ruimtelijke planning in Wageningen, opvattingen in kaart gebracht.* Wageningen, Permanente Contactgroep Ruimtelijke Organisatie - PCRO. Wageningse ruimtelijke studies **8**, 44-56.

Maaren, A. van (1993) Functiebeloning: een afwijkende mening *Nederlands Bosbouwtijdschrift* 65(3), 169-174.

Maessen, P.P.Th.M. (1985). Onderzoek naar de bosbouwkundige planning voor het beoordelen van het beheer van bosbedrijven. *Nederlands Bosbouwtijdschrift* 57(7/8), 196-201.

Mclaughlin, M. P. (1989). Simulated annealing. *Dr. Dobb's Journal: Software tools for the professional programmer.* **155**, 26-93

Mendoza, G.A., Bare, B.B. and Zhou, Z. (1993). A fuzzy programming approach to forest planning under uncertainty. *Agricultural Systems* **41**, 257-274.

Mesarovic, M.D., Macko, D. and Takahara, Y. (1970). *Theory of hierarchical, multilevel, systems.* New York, Academic Press. 294 pp.

Mintzberg, H. (1979). *The structuring of organizations A synthesis of research.* Englewood

Cliffs, Prentice-Hall. 512 pp.

Mitchell T.R., Anderson, D. and Mealy, S.P. (1987). A multistage approach to forest planning. In: Dress, P.E. and Field, R.C. (eds.) *The 1985 symposium on system analysis in forest resources, Athens, Georgia, December 9-11, 1985.* Athens, Georgia, Center for Continuing Education. pp. 43-54.

Nautiyal, J.C. and Pearse, P.H. (1967). Optimizing the conversion to sustained yield - a programming solution *Forest Science* 13(2), 131-139.

Navon, D.I. (1986). Evaluation of FORPLAN from an operations research perspective: Discussion paper. In: Hoekstra, T.W., Dyer, A.A. and Le Master, D.C. (eds.) 1986. *An evaluation of a forest planning tool. Proceedings of a symposium, nov. 4-6, 1986, Denver, Colorado.* Denver, Colorado, USDA Forest Service. General Technical Report RM-140.

Nil, de A. (1974). Factoren tot het bepalen van de recreatieve waarde van bosgebieden. *Groene Band* 14.

Nip, J. (1984). Landschapsbouwkundige aspecten van bos. *Groen* **40**, 486-491.

NRLO (1989a). *Op toepassing gericht ecologisch onderzoek.* Den Haag, Nationale Raad voor Landbouwkundig Onderzoek. NRLO-rapport nr. 89/18. 98 pp.

NRLO (1989b). *Prioritaire vragen voor het bosbouwkundig onderzoek.* Rapport van de Taakgroep/Programma AdviesCommissie Bossen. Den Haag, Nationale Raad voor Landbouwkundige Onderzoek. NRLO-rapport 89/22. 43 pp.

NRLO (1990a). *Meerjarenvisie Landbouwkundig Onderzoek 1991 - 1994.* Den Haag. Nationale Raad voor Landbouwkundig Onderzoek. 191 pp.

NRLO (1990b). *Uitwerking van prioritaire vragen voor het bosbouwkundig onderzoek* rapport van de Taakgroep/Programma-AdviesCommissie Bossen. Den Haag, Nationale Raad voor Landbouwkundig Onderzoek. NRLO rapport nr 90/6. 58 pp.

OECD (1986). *The public management of forestry projects.* Paris, Organization for Economic Cooperation and Development. 99 pp.

PCRO (1990). *Ruimtelijke planning in Wageningen: Opvattingen in kaart gebracht.* Wageningen, Permanente Contactgroep Ruimtelijke Organisatie. Landbouwuniversiteit Wageningen. Wageningse Ruimtelijke studies 8. 142 pp.

Pearce, D.W. and Turner, R.K. (1990). *Economics of natural resources and the environment.* New York, Harvester Wheatsheaf. 378 pp.

RINM (1984). *Evaluation of forest land Kali Konto upper watershed, East Java. Volume 1. Summary, conclusions and recommendations.* Research Institute for Nature Management, the Netherlands. 58 pp.

Rustagi, K.P. (1976). *Forest management planning for timber production: A goal programming approach.* New Haven, CF, Yale School of Forestry and Environmental Studies. Bul. 89. 80 pp.

SBB (1984). *Planning met behulp van bosdoeltypen. (Bosdoeltypen uit: Meerjarenplan Bosbouw)* Staatsbosbeheer. 61 pp. + appendices.

SBB (1990). *Beheersplan "De Waterbloem",* Periode 1990-2000. Staatsbosbeheer. 100 pp. + appendices.

Sekot, W. (1991). *Stand und Entwicklungsmöglichkeiten der Forsteinrichtung als Führungsinstrument im Forstbetrieb.* Habilitationsschrift. Wien, Eigenverlag des

Instituts für forstliche Betriebswirtschaft und Forstwirtschaftspolitiek. Schriftenreihe des Instituts für forstliche Betriebswirtschaft und Forstwirtschaftspolitiek Band 12. 545 pp. + appendices.

Sissingh, G. (1978). Mogelijkheden en beperkingen van het Nederlandse bos ten aanzien van het realiseren van de doelstellingen. *Nederlands Bosbouwtijdschrift* **50**(3), 39-51.

Soest, J.P van, Kasteren, J. van, Janse, F., Groen, A. et al. (1988). *De werkelijkheid van het model.* Amsterdam, Aramith. 79 pp.

Speidel, G. (1984). *Forstliche Betriebswirtschaftslehre*, 2. Aufl. Berlin, Parey. 226 pp.

Speidel, G. (1972). *Planung im Forstbetrieb Grundlagen und Methoden der Forsteinrichting.* Berlin, Parey. 267 pp.

Spencer, R.D. (1984). Comprehensive strategic land-use planning in Victoria. *Australian Forestry* **47**(1), 45-57.

Verkoren, J. (1978). De maatschappelijke betekenis van het bos ten aanzien van het realiseren van de doelstellingen. *Nederlands Bosbouwtijdschrift* **50**(3), 34-38.

Vught, F.A. van (1982). *Experimentele beleidsplanning. Bestuurskundige expedities in de jungle van het planningsdenken.* Den Haag, Vuga. Beleidsverkenningen Deel 1. 381 pp.

Walther, P. (1986). The meaning of zoning on the management of natural resource lands. *Journal of Environmental Management* **22**, 331-343.

Wedershoven, W.J.M. (1982). *Een lineair beheersmodel op basis van de kap- en verjongingsbeslissing.* Wageningen, Landbouwuniversiteit. Vakgroep Boshuishoudkunde. 88 pp. + appendices.

Weintraub, A. and Cholaky, A. (1991). A hierarchical approach to forest planning. *Forest Science* **37**(2), 439-460.

Winston, W.L. (1991). *Operations Research applications and algorithms.* Second edition. Boston, PWS-Kent. 1262 pp.

Wit, A.P.W. de and Gerritse, A.J. (1986). *Integrated modeling of renewable natural resources part: Forest ecosystem Management Final report EC Fast II programme, sub programme SYRENA.* Wageningen, Rijksinstituut voor onderzoek in de Bos en Landschapsbouw "De Dorschkamp". Rapport nr. 466.

Zonneveld, I.S. (1977). Classificeren en evalueren van bos mede met behulp van de spontane vegetatie. *Nederlands Bosbouwtijdschrift* **49**(2), 44-65.

Zuurbier, P.J.P., Bots, J.M. and Edwards, A.R. (1991). *Besturen van organisaties. Een inleiding tot de bedrijfskunde.* Eerste druk. Culemborg, Educaboek. 382 pp.

GLOSSARY

area:	In this study an area is a unique geographic, contiguous, heterogeneous piece of land. In decision models in forestry it is assumed that an area will or will not be assigned to a chosen purpose (discrete decision variables).
desired future forest:	A description of a forest in terms of forest land utilization types which achieves the land use objectives decided on in the zoning problem.
desired future forest decision problem:	A mathematical description of the problem of choosing which hectares from land units within a zone are assigned to land utilization types in such a way that the land use objectives decided on in the zoning problem are achieved for that specific zone.
even-aged management:	Kind of forest management in which a stand is regenerated by cutting all the trees at once and replanting the entire clearcut area within one year. As a result, trees within a stand are all even-aged.
forest:	A set of plots of land which has or could have tree vegetation and is managed as a whole to achieve tree-related owner objectives (Davis & Johnson, 1987, p. 29).
forest management:	Forest management is defined as the set of human actions aiming at the adjustment of the forest ecosystem and society to each other in order to achieve a sustainable fulfilment of society's needs.
forest function:	A relationship between society and forest in which society's needs are fulfilled.

land evaluation:	The process of assessment of land performance when used for specified purposes, involving the execution and interpretation of surveys and studies of landforms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation (FAO, 1984, p. 116).
land use:	A term employed in a general sense to refer to any form of use of land, in contexts which do not necessarily carry the technical connotation of land utilization type (FAO, 1984, p. 118).
land use planning:	Land use planning aims at identifying the "best" use of land, in view of accepted objectives, and of environmental and societal opportunities and constraints (Fresco *et al.*, 1990).
LUR land use requirement:	The conditions of land necessary or desirable for the successful and sustained practices of a given land utilization type (FAO, 1984).
LUT land utilization type:	A land utilization type is a formal description or definition of the way in which the land is used. The description of a land utilization type consists of a set of technical specifications within a given physical, economic and social setting. The degree of detail in which a land utilization type is described varies with the purpose and intensity of the evaluation: at the minimum a summary description, but in intensive studies giving technical specifications in substantial detail (FAO, 1984, p. 13).
LMU land mapping unit:	An area of land possessing specified land qualities and land characteristics, which can be demarcated on a map and which is employed as a basis in land evaluation. Land mapping units may have various degrees of homogeneity, according to the scale of survey (FAO, 1984, p. 116).

LQ

land quality: A complex attribute of land which acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specified kind of use (FAO, 1984, p. 116).

land suitability: The fitness of a given type of land for a specified kind of land use (FAO, 1984, p. 116).

land use objective: A land use objective is an allocation choice in the zoning model and is specified by the needs of society that will be fulfilled (in terms of forest functions), a description of forest structure and composition needed to achieve a forest which is suitable to fulfil this functions and a set of forest land utilization types which are feasible in the context of this land use objective.

matching: The process of comparing the land use requirements of land utilization types with the land qualities of land units (FAO, 1984, p.119).

management option: A management option is an allocation choice in the management model. It consists of a transition management strategy that converts the current forest into a desired future forest, a description of the consequences of this transition management strategy (forest characteristics and financial, social and economic consequences), a description of management in the desired future forest and a description of the consequences of the desired future forest management to maintain the desired future forest (characteristics of the forest and the financial and economic consequences).

model I and model II: The terms Model I and Model II refer to the two basic model structures into which most of the models made for decision support in strategic planning in forest management can be divided. The main difference between them is that in model I the initial division into land units is retained throughout the entire planning horizon, whereas in model II a division into land units is only retained during the lifetime of the stand it bears.

multiple use forestry: Any practice of forestry which fulfils two or more objects of management, whether products, services of other benefits. (FAO, 1984, p. 119).

model:	A model is an abstract representation of the real world and is useful for purposes of thinking, forecasting and decision making.
operational planning:	A decision-making process in which the actual execution of management activities is decided on.
planning system:	A planning system is an organized set of planning processes.
STAGES:	STAGES is a STrategic Alternatives GEnerating System for decision support in strategic planning in forest management. It consists of two interrelated optimization models: a zoning model and a management model
steady state:	The situation in which the structure of the forest does not change, when examined at the level of the forest. The forest does change locally, but as a whole it is in an equilibrium.
strategic planning:	Strategic planning is the process of searching for objectives and deciding on them. It is not restricted to deciding on the objectives of an organization, but also concerns deciding on strategies (ways and means) with which the objectives will be realized (Keuning & Eppink, 1987)
stratum:	A stratum is a category of land that responds the same way to management actions, relative to the yield of interest, wherever the land occurs.
stand type:	All forest land that has the same defined combination and attribute range of the physical, vegetation, and development characteristics chosen to classify the forest into homogeneous types (synonyms: land type, site type, condition class, forest type, analysis area) (Davis & Johnson, 1987, p. 32/33).
stand:	A homogeneous, geographically contiguous plot of land, of the same stand type and larger than some defined minimum size (synonyms: homogeneous land unit, capability unit, ecological land unit, logging unit) (Davis & Johnson, 1987, p. 32/33).
tactical planning:	Tactical planning is the process in which the management activities and related means needed to realize the objectives are decided on.

transition management strategy: A description of how the current forest will be transformed into the desired future forest.

transition management decision problem: A process of choosing in which the land of stands within a zone is assigned to transition management strategies in such a way that the desired future forest is achieved.

uneven-aged management: Kind of forest management in which a stand is regenerated by means of cutting a selection of single trees or groups of trees and not the whole stand. As a result, trees within a stand are uneven-aged.

use: A use is a description of land use objectives in terms of functions to be fulfilled.

zone: A zone is an area of the forest and is homogeneous with respect to land use objectives. In model terms, a zone can be defined as a cluster of grid cells all assigned to the same use. Each zone consists of one or more stands.

zoning decision problem: The process of choosing, in which the forest is divided into zones and land use objectives are simultaneously assigned to these zones.

APPENDICES

APPENDIX A. A numerical example of decisions on zoning, desired future forest and transition management

In this appendix the decisions in strategic planning in forest management (zoning, desired future forest and transition management) are illustrated by means of a very simple numerical example. The stands to be managed are represented as grid cells in a grid (see figure A.1), to illustrate for a very simple situation the decisions that have to be made in strategic planning.

1	2	3
4	5	6
7	8	9

Figure A.1 The stands to be managed

A new strategic plan has to be made for this forest. The following land use objectives are considered to be important:
- timber production (T);
- nature conservation (N);
- recreation (R).

The suitability of the stands for these land use objectives has already been assessed in a land evaluation procedure. It is expressed in a suitability rating (0-9). The outcome of the assessment is given in figure A.2.

suitability for timber production

9	6	5
5	7	5
6	8	5

suitability for nature conservation

1	5	7
9	4	2
8	1	1

suitability for recreation

5	5	5
5	8	9
9	7	9

Figure A.2 Suitability rates

The heart of zoning decisions is to divide the forest into zones and to assign land use objectives to each zone. Let us assume that the best zoning decision is to assign each stand to that land use objective for which it has the highest suitability rating. The resulting zoning map, obtained by solving a linear assignment problem, is presented in figure A.3

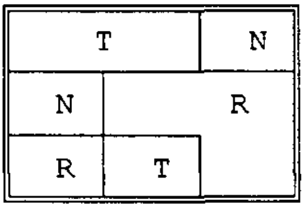


Figure A.3 Zoning map

key: T = Timber
N = Nature Conservation
R = Recreation

The zoning map presented in figure A.3. is not the only possible outcome of the zoning process. Better alternatives may exist. In the zoning decision problem the alternatives and their consequences have to be identified and the best alternative has to be chosen.

The alternative described does not pay attention to the spatial interrelationships in forest use. If nature conservation and recreation conflict, the zoning would be improved if the zones assigned to nature conservation and the zones assigned to recreation were located apart. Figure A.4 shows an alternative that takes account of the spatial interrelationships between uses.

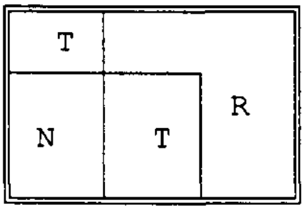


Figure A.4 Alternative zoning map

key: T = Timber
N = Nature conservation
R = Recreation

Zoning maps not only show the boundaries of the zones, but also the land use objectives per zone. This information is crucial for the decisions about the desired future forest. The first step towards solving the desired future forest decision problem is to elaborate the land use objectives per zone into statements about the forest characteristics desired. The results of this first step are given in table A.1 The second step is to assign forest land within a zone to land utilization types. The following land utilization types have been identified:

Pseudotsuga menziesii	even-aged management with a rotation of 100 years
Pinus sylvestris:	even-aged management with a rotation of 100 years
Alnus Glutinosa and *Fagus sylvatica*:	even-aged management with a rotation of 100 years
Quercus robur:	even-aged management with a rotation of 120 years
Fagus sylvatica:	even-aged management with a rotation of 125 years
Quercus robur, Betula pendula and *Pinus sylvestris*:	uneven-aged management with a "rotation" (of oldest trees) of 190 years.

Table A.1 Management constraints per use

TIMBER:	If a zone is assigned to timber the following constraint has to be satisfied: - not less than 8 m^3 harvest per ha per year.
NATURE:	If a zone is assigned to nature conservation the following constraints have to be satisfied: - mean rotation not less than 120 years, - number of tree species not less than 2 (average), - no more than 4 m^3 harvest per ha per year.
RECREATION:	If a zone is assigned to recreation the following constraints have to be satisfied: - mean rotation not less than 100 years, - number of tree species not less than 3.

For each of the forest land utilization types, the consequences in terms of the characteristics listed in table A.1 are assessed. Based on these consequences, the stands in our example are assigned to one or more of these forest land utilization types (based on the zoning map of figure A.3.). The outcome of this assignment process is given in table A.2.

The desired future forest presented is not the only possible solution to the desired future forest decision problem. There are alternatives. During the decision making these alternatives and their consequences have to be identified and the best alternative has to be chosen. No alternatives will be presented in this example.

The last decision problem to solve is the transition management decision problem. In table A.2. the desired forest has been described. Comparing this forest with the current forest (table A.3.) clearly reveals that transition management is badly needed. Transition management is the strategy required to transform current forest and management into the forest and management desired. Per stand it has to be decided how the current forest will be managed and in due time will be transformed into the desired future forest.

Table A.2 Desired future forest

Stand	Number of hectares	Forest land utilization type
1	1	pm(100)
2	1	ps(100)
3	0.5	qr(100)
3	0.5	qr(40), bp(30), ps(30)
4	1	qr(40), bp(30), ps(30)
5	1	ag(40), fs(60)
6	0.25	ag(40), fs(60)
6	0.25	pm(100)
6	0.25	ps(100)
6	0.25	fs(100)
7	1	ag(40), fs(60)
8	1	pm(100)
9	0.5	pm(100)
9	0.5	ps(100)

Explanation: ag(40), fs(60) means 40% of total basal area consists of *Alnus glutinosa* and 60% of total basal area consists of *Fagus sylvatica*

Key:

ag: *Alnus glutinosa* (L.) Gaertner.

bp: *Betula pendula* Roth.

fs: *Fagus sylvatica* L.

pm: *Pseudotsuga menziesii* (Mirb.) Franco.

ps: *Pinus sylvestris* L.

qr: *Quercus robur* L.

The planning horizon is 50 years. At the end of this time the current forest has to be transformed into the desired future forest. The planning horizon is divided into 5 10-year periods. Per period the forest is described in the following tables. In this example the desired future forest is described solely by means of a distribution of the desired tree species.

In stand 2 the distribution of hectares among tree species already corresponds with the distribution aimed at in the desired future forest. At the beginning of the first period this stand is therefore considered to have already been transformed (see table A.3).

Table A.3 Forest at beginning of first period (t=0)

Stand	Ha transformed	Distribution tree species
1	0	ll(100)
2	1	ps(100)
3	0	ps(100)
4	0	ll(100)
5	0	ps(100)
6	0	ps(100)
7	0	qr(100)
8	0	pn(100)
9	0	qr(100)

Explanation: the standnumbers which are represented bold are to be transformed in this period.

ll: *Larix leptolepis* (Sieb. & Zucc.)

pn: *Pinus nigra subsp. laricio* (Poir.) Palibin.

In the first period, stands 1 and 3 are transformed into the desired future forest. The results are given in table A.4.

Table A.4 Forest at beginning of second period (t=1)

Stand	Ha transformed	Distribution tree species
1	1	pm(100)
2	1	ps(100)
3	1	qr(70), bp(15), ps(15)
4	0	ll(100)
5	0	ps(100)
6	0	ps(100)
7	0	qr(100)
8	0	pn(100)
9	0	qr(100)

In the second period, stands 4 and 5 are transformed into the desired future forest. The results are given in table A.5.

Table A.5 Forest at beginning of third period (t=2)

Stand	Ha transformed	Distribution tree species
1	1	pm(100)
2	1	ps(100)
3	1	qr(70), bp(15), ps(15)
4	1	qr(40), bp(30), ps(30)
5	1	qr(40), fs(60)
6	0	ps(100)
7	0	qr(100)
8	0	pn(100)
9	0	qr(100)

In the third period, stand 7 and part of stand 6 are transformed into the desired future forest. The results are given in table A.6.

Table A.6 Forest at beginning of fourth period (t=3)

Stand	Ha transformed	Distribution tree species
1	1	pm(100)
2	1	ps(100)
3	1	qr(70), bp(15), ps(15)
4	1	qr(40), bp(30), ps(30)
5	1	qr(40), fs(60)
6	0.75	ps(50), ag(10), fs(40)
7	1	ag(40), fs(60)
8	0	pn(100)
9	0	qr(100)

In the fourth period, stands 7 and 8 and the remainder of stand 6 are transformed into the desired future forest. The results are given in table A.7.

Table A.7 Forest at beginning of fifth period (t=4)

Stand	Ha transformed	Distribution tree species
1	1	pm(100)
2	1	ps(100)
3	1	qr(70), bp(15), ps(15)
4	1	qr(40), bp(30), ps(30)
5	1	ag(40), fs(60)
6	1	pm(25), ps(25), ag(10), fs(40)
7	1	ag(40), fs(60)
8	1	pm(100)
9	0	qr(100)

In the fifth period, stand 9 is transformed into the desired future forest. The forest at the end of the planning horizon is given in table A.8

Table A.8 Forest at end of planning horizon (t=5)

Stand	Ha transformed	Distribution tree species
1	1	pm(100)
2	1	ps(100)
3	1	qr(70), bp(15), ps(15)
4	1	qr(40), bp(30), ps(30)
5	1	ag(40), fs(60)
6	1	ag(10), fs(40), pm(25), ps(25)
7	1	ag(40), fs(60)
8	1	pm(100)
9	1	pm(50), fs(50)

The outcome of the transition management decision problem is not the only possible outcome. There are several alternatives and these should be identified. In the transition management decision problem these alternatives and their consequences have to be identified and the best alternative has to be chosen.

This completes the example illustrating the three decision problems. In the example the focus was on the outcome of the decisions and not on how the decisions have to be made. Furthermore, the financial, economic, social and environmental consequences of the decisions were not described. In chapter 8 a detailed description of a case study is given, and the consequences are discussed.

APPENDIX B. The algorithm that constitutes the basis of the link between the zoning model and the management model

B.1. The algorithm

Table B.1 gives a short and general outline of the algorithm.

Table B.1. Outline of an iterative procedure of linkage between models

1.	START (n := 0)
2.	n :=n+1
3.	UPDATE INPUT ZONING MODEL
4.	RUN ZONING MODEL
5.	COMPARE THE SOLUTION TO THE ZONING PROBLEM WITH THE SOLUTION TO THE ZONING MODEL IN ITERATION n-1. IF BOTH SOLUTIONS COINCIDE GO TO 8 (if n=1 this step is skipped)
6.	RUN MANAGEMENT MODEL
7.	GO TO 2
8.	END

At first glance it seems that the algorithm presented here differs from the algorithm described in chapter 5. In this chapter the criterion for stopping is that there is no difference between the expected consequences of management and the 'real' consequences of management. In the algorithm of table B.1 the stopping criterion is that the result of the zoning model is equal to the result produced by the zoning model in the previous iteration. In fact, these two stopping criteria do not differ, because if the zoning solutions are equal, the input (and therefore the output) of the management will be equal to the previous output of the management model. In this algorithm the equality of results to the zoning problem is chosen as stopping criterion because of reasons of efficiency. The equality of expected and 'real' consequences was chosen in chapter 5 because that is the real stopping criterion. In the remainder of this section the algorithm is elaborated. The symbols used in this elaboration are defined in table B.2.

Table B.2 Definitions

$SUIT^{n}_{gu}$	suitability rate of grid cell g for use u used in iteration n. $SUIT^{0}_{gu}$ is the suitability rate of grid cell g for use u assessed in a land evaluation procedure without taking into account financial and other consequences.
$NSUIT^{n}_{gu}$	update of suitability rate of grid cell g for use u in iteration n. This update is based on the real consequences of management.
ß	smoothing constant
$REAL^{n}_{gu}$	'real' consequences of management decisions for grid g and use u in iteration n. The starting value $REAL^{0}_{gu}$ is based on the assumption that per zone the available hectares are equally divided among the feasible management options for that zone.
TROF	parameter representing trade-off between suitability and consequences of management (1 point in suitability corresponds with TROF points in consequences)

1. **START**

   n := 0

   assess $SUIT^{0}_{gu}$ and $REAL^{0}_{gu}$

2. **n := n+1**

   The iteration counter n is set

3. **UPDATE INPUT ZONING MODEL**

   In this step the input of the zoning model is updated. In this update the effects of changes in the expected consequences of management are smoothed by a procedure based on simple exponential smoothing (Winston, 1991, p. 1167).

```
DO FOR g=1 to G
BEGIN
      DO FOR u=1 to U
      BEGIN
```

$$NSUIT^{n}_{gu} = SUIT^{0}_{gu} + (REAL^{n-1}_{gu} / TROF)$$

$$SUIT^{n}_{gu} = ß\ NSUIT^{n}_{gu} + (1-ß)\ SUIT^{n-1}_{gu}$$

```
      END (FOR u)
END (FOR g)
```

β is a smoothing constant that satisfies $0 < \beta < 1$. For larger values of β, more weight is given to the most recent updates, for smaller values of β more weight is given to more previous updates. This smoothing constant is introduced to speed up the algorithm. See section B.3 for the results of testing the effect of β.

4. RUN THE ZONING MODEL

The zoning model is computed for the $SUIT_{gu}^{n}$ determined in step 3.

5. COMPARE THE SOLUTION TO THE ZONING PROBLEM WITH THE SOLUTION IN ITERATION n-1. IF BOTH SOLUTIONS COINCIDE GO TO 8

If $n=1$ then this step is skipped. If $n>1$ then the solution to the zoning problem is compared with the solution to the zoning problem in the previous run. If they are equal, then the management model will yield the same results as in iteration n-1. This means that the zoning decisions are made on basis of a correct assumption about the consequences of management, so the algorithm terminates. If the solution to the zoning problem in iteration n does not equal the solution to the zoning problem in iteration n-1, then the algorithm proceeds.

6. RUN THE MANAGEMENT MODEL

The input of the management model (constraints and coefficients for the object function) is based on the output of the zoning model. See the numerical example of appendix A.

The management model is computed for the input determined.

Based on the output of the management model $REAL_{gu}^{n}$ is determined for the combinations of g and u which are marked optimal in the output of the zoning model. For all other combinations $REAL_{gu}^{n} = REAL_{gu}^{n-1}$

7. GO TO 2

8. END

B.2. A numerical example

The algorithm is illustrated by means of a numerical example, which is a continuation of the numerical example given in appendix A. In the numerical example constraints at forest level (see also chapter 7) are omitted, to simplify the explanation. The inclusion of constraints on forest level is discussed in section B.3.

The forest consists of nine stands (i.e. grid cells). Three land use objectives are important: timber production, nature conservation and recreation. The suitability of a grid cell for a certain land use objective is given in table B.3. If a grid cell has been assigned to a certain land use objective, the management has to meet certain criteria related to that land use. These criteria (i.e. constraints) are given in table B.4. In the management model, land per grid cell has to be assigned to management options in such a way that these constraints are satisfied. Table B.5. indicates the consequences of assigning land to management options.

Table B.3 $SUIT^{0}_{gu}$

Grid cells	Score for timber	Score for nature	Score for recreation
1	9	1	5
2	6	5	5
3	5	7	5
4	5	9	5
5	7	4	8
6	5	2	9
7	6	8	9
8	8	1	7
9	5	1	9

Table B.4 Management constraints per use

TIMBER:	If a zone is assigned to timber the following constraint has to be satisfied: - not less than 8 m^3 harvest per ha per year.
NATURE:	If a zone is assigned to nature conservation the following constraints have to be satisfied: - mean rotation not less than 120 years, - number of tree species not less than 2 (average), - no more than 4 m^3 harvest per ha per year.
RECREATION:	If a zone is assigned to recreation the following constraints have to be satisfied: - mean rotation not less than 100 years, - number of tree species not less than 3.

Table B.5 Forest land utilization types and their consequences

LUT	ROT	NUM	HAR	GEV
Pseudotsuga menziesii	60	1	10	100
Pinus sylvestris	80	1	6	25
Agnus glutinosa and *Fagus sylvatica*	100	2	7	-25
Quercus robur	100	1	5	50
Fagus sylvatica	150	1	5	-50
Quercus robur, Betula pendula and *Pinus sylvestris*	190	3	2	-100

ROT: rotation in years; NUM number of tree species; HAR: harvest in m^3 per ha per year; GEV: ground expectation value

Now all the information needed is available and the algorithm can start. TROF is set at 50 and ß at 0.5.

1. **START**

$n := 0$

$SUIT^0_{gu}$ is given in table B.3.

The only management consequence considered is the ground expectation value. The expected consequences of management are based on the assumption that all the available hectares per stand will be divided equally among the feasible management options. The mean ground expectation value is (100 +25-25+50-50-100)/6 = 0.0 This means that $REAL^0_{gu} = 0.0$ for every combination of g and u

2. **$n := 0 + 1$**

3. **UPDATE INPUT ZONING MODEL**

$$NSUIT^1_{gu} = SUIT^0_{gu} + (REAL^0_{gu} / TROF) = SUIT^0_{gu}$$

$$SUIT^1_{gu} = \beta\ NSUIT^1_{gu} + (1-\beta)\ SUIT^0_{gu} = SUIT^0_{gu}$$

4. **RUN THE ZONING MODEL**

The zoning model is computed and the output in iteration 1 is given below.

T	T	N
N	R	R
R	T	R

Output in iteration 1

Key: T = Timber
N = Nature conservation
R = Recreation

5. **COMPARE THE OUTPUT OF THE ZONING MODEL WITH THE OUTPUT OF THE ZONING MODEL IN ITERATION n-1. IF BOTH SOLUTIONS COINCIDE GO TO 8**

The output of the first iteration cannot be compared with a previous map, because n=1

6. **RUN THE MANAGEMENT MODEL**

The management model is constructed on the basis of the zoning map in iteration 1 and the rules of table B.4.

The management model is computed for the input determined

The real consequences of assigning grid cell g to use u can only be determined for the grid cell use combinations decided on in step 4. The outcome is given below.

$REAL^{1}_{gu}$ first part filled with output management model

Grids	Timber	Nature	Recreation
1	100		
2	100		
3		-20	
4		-20	
5			-100
6			-100
7			-100
8	100		
9			-100

The remainder of table 4 is filled in with data from the previous assumptions ($REAL^{0}_{gu}$). The outcome is given below.

$REAL^1_{gu}$ remainder filled in with previous assumptions

Grids	Timber	Nature	Recreation
1	100	0	0
2	100	0	0
3	0	-20	0
4	0	-20	0
5	0	0	-100
6	0	0	-100
7	0	0	-100
8	100	0	0
9	1	0	-100

7. GO TO 2

2. n := 1 + 1

3. UPDATE INPUT ZONING MODEL

$NSUIT^2_{gu} = SUIT^0_{gu} + (REAL^1_{gu} / TROF)$

The outcome is given below.

$NSUIT^2_{gu}$

Grid cells	Score for timber	Score for nature	Score for recreation
1	11	1	5
2	8	5	5
3	5	6,6	5
4	5	8,6	5
5	7	4	8
6	5	2	7
7	6	8	7
8	10	1	7
9	5	1	7

$$SUIT^2_{gu} = ß\ NSUIT^2_{gu} + (1-ß)\ SUIT^1_{gu}$$

The outcome is given below

$SUIT^2_{gu}$

Grid cells	Score for timber	Score for nature	Score for recreation
1	10	1	5
2	7	5	5
3	5	6,8	5
4	5	8,8	5
5	7	4	8
6	5	2	8
7	6	8	8
8	9	1	7
9	5	1	8

4. RUN THE ZONING MODEL

The zoning model is computed and the output is given below.

T	T	T
N	R	R
R/N	T	R

Output in iteration 2

Key: T = Timber
N = Nature conservation
R = Recreation

R/N: R is optimal and N is also optimal. If R is chosen, then the output is identical with the output in iteration 1 and the algorithm terminates. The worst case scenario is chosen and therefore we choose N.

5. **COMPARE THE OUTPUT OF THE ZONING MODEL WITH THE OUTPUT OF THE ZONING MODEL IN ITERATION n-1. IF BOTH SOLUTIONS COINCIDE GO TO 8**

The outputs are not equal (see above)

6. **RUN THE MANAGEMENT MODEL**

The management model is constructed on basis of the zoning map in iteration 1 and the rules of table B.4.

The management model is computed

The real consequences of assigning grid cell g to use u can only be determined for the grid cell use combinations decided on in step 4. The outcome is given below.

$REAL^2_{gu}$ first part filled in with output from management model

Grid cells	Score for timber	Score for nature	Score for recreation
1	100		
2	100		
3		-20	
4		-20	
5			-100
6			-100
7		-20	
8	100		
9			-100

The remainder of table 4 is filled in with data from the previous assumptions ($REAL^1_{gu}$). The outcome is given below.

$REAL^{2}_{gu}$ remainder filled in with previous assumptions

Grid cells	Score for timber	Score for nature	Score for recreation
1	100	0	0
2	100	0	0
3	0	-20	0
4	0	-20	0
5	0	0	-100
6	0	0	-100
7	0	-20	-100
8	100	0	0
9	0	0	-100

7. GO TO 2

2. n := 2 + 1

3. UPDATE INPUT ZONING MODEL

$NSUIT^{3}_{gu} = SUIT^{0}_{gu} + (REAL^{2}_{gu} / TROF)$

The outcome is given below.

$NSUIT^{3}_{gu}$

Grid cells	Score for timber	Score for nature	Score for recreation
1	10	1	5
2	7	5	5
3	5	6,6	5
4	5	8,6	5
5	7	4	8
6	5	2	8
7	6	7,6	8
8	9	1	7
9	5	1	8

$$SUIT^3_{gu} = \beta\, NSUIT^3_{gu} + (1-\beta)\, SUIT^2_{gu}$$

The outcome is given below

$SUIT^3_{gu}$

Grid cells	Score for timber	Score for nature	Score for recreation
1	10	1	5
2	7	5	5
3	5	6,7	5
4	5	8,7	5
5	7	4	8
6	5	2	8
7	6	7,8	8
8	9	1	7
9	5	1	8

4. RUN THE ZONING MODEL

The zoning model is computed and the output is given below.

T	T	N
N	R	R
R	T	R

Output in iteration 3

Key: T = Timber
N = Nature conservation
R = Recreation

5. **COMPARE THE OUTPUT OF THE ZONING MODEL WITH THE OUTPUT OF THE ZONING MODEL IN ITERATION n-1. IF BOTH SOLUTIONS COINCIDE GO TO 8**

The outputs are not equal, the algorithm continues

6. **RUN THE MANAGEMENT MODEL**

The management model is constructed on basis of the zoning map in iteration 1 and the rules of table B.4.

The management model is computed

The real consequences of assigning grid cell g to use u can only be determined for the grid cell use combinations decided on in step 4. The outcome is given below

$REAL^3_{gu}$ first part filled in with output from management model

Grid cells	Score for timber	Score for nature	Score for recreation
1	100		
2	100		
3		-20	
4		-20	
5			-100
6			-100
7			-100
8	100		
9			-100

The remainder of table 4 is filled in with data from the previous assumptions ($REAL^2_{gu}$). The outcome is given below.

$REAL_{gu}^{3}$ remainder filled in with previous assumptions

Grid cells	Score for timber	Score for nature	Score for recreation
1	100	0	0
2	100	-20	0
3	0	-20	0
4	0	0	0
5	0	0	-100
6	0	-20	-100
7	100	0	-100
8	0	0	0
9	0	0	-100

7. GO TO 2

2. n := 3 + 1

3. UPDATE INPUT ZONING MODEL

$NSUIT_{gu}^{4} = SUIT_{gu}^{0} + (REAL_{gu}^{3} / TROF)$

The outcome is given in table below.

$NSUIT_{gu}^{4}$

Grid cells	Score for timber	Score for nature	Score for recreation
1	10	1	5
2	7	5	5
3	5	6,6	5
4	5	8,6	5
5	7	4	8
6	5	2	8
7	6	7,6	8
8	9	1	7
9	5	1	8

$$SUIT^{4}_{gu} = \beta\, NSUIT^{4}_{gu} + (1-\beta)\, SUIT^{3}_{gu}$$

The outcome is given below

$SUIT^{4}_{gu}$

Grid cells	Score for timber	Score for nature	Score for recreation
1	10	1	5
2	7	5	5
3	5	6,65	5
4	5	8,65	5
5	7	4	8
6	5	2	8
7	6	7,7	8
8	9	1	7
9	5	1	8

4. RUN THE ZONING MODEL

The zoning model is computed and the output is given below.

T	T	N
N	R	R
R	T	R

Output in iteration 4

Key: T = Timber
N = Nature conservation
R = Recreation

5. **COMPARE THE OUTPUT OF THE ZONING MODEL WITH THE OUTPUT OF THE ZONING MODEL IN ITERATION n-1. IF BOTH SOLUTIONS COINCIDE GO TO 8**

The output of iteration 4 coincides with the output of iteration 3, therefore the algorithm terminates in iteration 4.

8. **END**

B.3 Restrictions to the algorithm

Optimality

In the example described TROF was set at 50 and ß at 0.5 The algorithm was also tested for other values of TROF and ß. In all cases the algorithm terminated in a finite number of steps (see table B.6).

Table B.6 Number of iterations needed until convergence at a certain combination of TROF and ß

ß	TROF			
	50	25	10	1
0	2	2	2	2
0.5	4	3	3	4*
1.0	4	4	4	4*

* yielded optimal solution

Although the algorithm converged in all combinations considered, it did not always yield the optimal solution. Because of the simplicity of the example, the optimum per TROF could be determined visually. It appeared that the optimum[2] was identified only twice (see table B.6). The algorithm can be improved at this point by choosing better starting values for $REAL^{0}_{gu}$.

[2]In the example of this appendix the optimum is reached when the sum (TROF x value of the object function of the zoning model) plus (value of the object function of the management model) is maximal.

The effect of choosing better starting values can be illustrated by means of the following example. Considered a forest consisting of one stand i.e. a grid cell. This grid cell has to be assigned to Timber production or to Recreation. The suitability rating is 7 for Timber production and 8 for Recreation. If the management consequences for both are equal, then the optimal decision is to assign the grid to recreation. However, the management consequences are not equal. The management consequences of assigning the grid to Timber production are +100 and the management consequences of assigning the grid to Recreation are -100. If the trade-off parameter TROF is set at 50, it is clear that assigning the grid cell to Timber production will yield the optimal combined solutions of the zoning model and the management model. The one point decrease in zoning score is compensated by an increase of 200 in management consequences (from -100 to +100).

If $REAL^{0}_{gu}$ is set 0 for Timber production and 0 for Recreation, then the algorithm will converge to assigning the grid cell to Recreation (if β is 0.5). If $REAL^{0}_{gu}$ is set at 100 for Timber production and is set at -100 for Recreation, then the algorithm will converge to assigning the grid cell to Timber production, which is the optimal solution. Thus, by choosing good starting values for $REAL^{0}_{gu}$ the performance of the model in identifying the optimal solution can be improved. The conclusion from this is that in every situation several runs with different starting values have to be carried out and the best solution has to be adopted.

How to deal with infeasibility

In certain situations an optimal solution in the zoning model can result in an infeasible problem in the management model. If only constraints are formulated per zone, the infeasibility can easily be found; it is related to an incorrect operationalization of land use objectives into constraints. If constraints are formulated at forest level as well as per zone, then the feasibility cannot easiliy be found and is related to a lack of information in the zoning model. This is illustrated by the following example.

Consider a forest consisting of 9 stands i.e. grid cells. Timber production and Recreation are the only two land use objectives considered. If a grid cell is assigned to Timber production, then the management consequences are +100. If a grid cell is assigned to Recreation, then the management consequences are -100. If in the management model a constraint has been formulated at forest level which states that the sum of the management consequences in the forest must be more than 600, then each zoning solution in which more than one grid cell is assigned to recreation will lead to an infeasible management problem (one grid cell assigned to Recreation and 8 grid cells to Timber production results in a total sum of -100 + 800 = 700, if 2 grid cells are assigned to Recreation and 7 grid cells to Timber production the result is -200 + 700 = 500 which is not allowed).

Infeasibility of the management problem can be avoided by adding constraints to the zoning model in such a way that the solutions to the zoning problem which would lead to an infeasible management problem are excluded. For example, in this case adding a constraint to the zoning model that states that the total number of grid cells assigned to recreation must be less than two will avoid infeasible problems in the management model. In a real world application, the management problem will be so complex that it is not easy to anticipate infeasibilities in the management model, therefore the inclusion of constraints in the zoning model is in general not a good way to deal with possible infeasibilities in the management model. A better way to avoid infeasibility in the management model, is to replace certain constraints at forest level by "soft constraints". This means replacing the constraint

output of total forest $\geq$ 600

by

min { P^- }

output of total forest = 600 + P^+ - P^-

P^- is penalized in the object function by means of a big negative object coefficient. In this way the model will try to minimize P^-. If the outcome of the management model is P^- = 0.0 then the original constraint has been satisfied. If the outcome of the management model is $P^- > 0.0$ then the original constraint would have led to an infeasible problem in the management model. All other things being equal, the same approach holds for other constraints. Thus, by replacing constraints at forest level by "soft constraints", possible feasible problems will be dealt with in the same way as with the original constraints at forest level and for infeasible problems P^- indicates how strongly the original constraints at forest level would have been violated in the original model.
This approach was applied to the numerical example described in this appendix with one forest level constraint, namely that the sum of the management consequences on the forest must be more than 600. The results of this test are described in table B.7.

Table B.7 Value of the state variable P^* at the point of convergence for certain combinations of TROF and ß

ß	TROF			
	50	25	10	1
0	740	740	740	740
0.5	740	460	60	0
1.0	740	60	0	0

From table B.7 it can be concluded that replacing the original constraint on forest level by a "soft constraint" at forest level averted infeasibility on most occasions.

B.4 Conclusions and recommendations for further research

In this appendix an algorithm that constitutes the basis of the link between the zoning model and the management model was described and discussed. The algorithm was tested for situations in which only constraints per zone are formulated. From these tests it can be concluded that the algorithm converges in all the cases considered. However, the algorithm did not always identify the optimal combination of solutions to the zoning model and the management model. Its performance can be improved on this point. The starting values for $REAL^0_{gu}$ seem to be an important factor in the performance of the algorithm. Further research is needed at this point. For example, the following idea should be elaborated and the effects of it should be tested. Assign all grid cells to use 1 and determine the management consequences per grid cell. The resulting management consequences form the starting point for $REAL^0_{g1}$. Do this for all uses identified.

If constraints at forest level are included in the management model, the output of the zoning model can result in an infeasible problem in the management model. This infeasibility can be detected by replacing the original constraints at forest level by "soft constraints". If the management problem is feasible, this approach will yield the same solution as the original problem; if the management problem is infeasible, this approach will make visible to what extent constraints are violated.

The final conclusion is that although theoretical, the basis for a link between the zoning model and the management model has been found. However, further research is needed before the algorithm that performs this link can be implemented on a computer.

In addition, further research has to be done on how to identify cycling of the algorithm and how to deal with it. Cycling means that the algorithm is trapped in an infinite loop in which the same sequence of solutions is generated time after time. In the numerical example cycling did not occur, but it cannot be guaranteed that it will not occur if other data are used.

APPENDIX C. The assessment of attraction coefficients

Consider the following situation. From the point of view of use u (recreation) it is no problem that use f (nature conservation) is located nearby. From the point of view of nature conservation it is a problem if recreation is located nearby. Thus from one point of view the two uses do attract each other and from another point of view they conflict.

In this appendix an example is given of how to deal with different relationships between two uses. Let REL_{uf} be the measure of the attractiveness between use u and use f seen from the point of view of use u. In the case of the relationship between recreation (use u) and nature conservation (use f) REL_{uf} will be positive and REL_{fu} will be negative. ATT_{uf} can be calculated as the weighted mean of these two values:

$$ATT_{uf} = \frac{WGT_u \, REL_{uf} + WGT_f \, REL_{fu}}{WGT_u + WGT_f}$$

Say $REL_{uf} = 1$ and $REL_{fu} = -1$, $WGT_u = 2$ and $WGT_f = 1$

$$ATT_{uf} = \frac{2x1 + -1x1}{2 + 1} = 1/3$$

In this case the attraction coefficient is positive, but if the weights for use u and f were equal, the attraction coefficient would be zero and if the weight for use f were higher than the weight for use u, the attraction coefficient can attain negative values.

APPENDIX D. Information needed to run the models

D.1 The zoning model

The zoning model needs the following information:
- location of grid cells in a grid;
- suitability rating per combination of grid cell and use;
- preference scores;
- attraction coefficients;
- weighting parameter.

As already stated in chapter 3, strategic planning in forest management has to be preceded by a land evaluation process. The outcome of the land evaluation process provides most of the information needed in the zoning model. If the information assessed in the land evaluation process is stored in a geographic information system based on a grid, then the location of grid cells is already available. For a description of how a land evaluation process has to be carried out see Laban (1981) and FAO (1984).

In the land evaluation process each land use objective has been translated into a set of forest land utilization types that are feasible within the context of the particular land use objective. The land evaluation process yields suitability ratings per grid cell per forest land utilization type. The suitability rate of a grid cell for a land use objective has to be based on an aggregation of the suitability ratings of the grid cell for the forest land utilization types that belong to the set of feasible forest land utilization types within the context of the land use objective. How the aggregation of suitability ratings per land utilization types to suitability rate for land use objectives has to be carried out is beyond the scope of this study.

The preference scores for uses (land use objectives) are determined by the decision maker and have to be considered as exogeneous decisions. The effect of the preference scores depends on the setting of parameters in the model. In this study the assessment of the value of assigning a certain grid cell to a certain use is kept simple to keep the explanation of the model clear (multiplication of suitability rating and preference score). For the model it makes no difference how the value of assigning a certain grid cell to a certain use is assessed. The fact that a preference score has to be given differs from current practice. In current practice preferences are also given to uses, but the preference does not have to be expressed quantitatively.

Attraction coefficients are a means to ensure that certain uses are located far from each other and other uses are located near each other. Here we come to one of the criticisms of the zoning model. The attraction coefficients play a role in the quadratic term of the object function of the model. This quadratic term, however, is not based on relationships found in reality. The effect of a certain value for the attraction coefficients depends on other parameters in the models. The assessment of attraction coefficients is therefore based not only on a judgment of the user of the zoning model, but also on the outcome of calibration runs with the model.

The effect of the weighting parameter depends on the setting of the other parameters in the model. Therefore, the value of the weighting parameter also has to be based on judgments of the user of the model concerning the outcome of a set of calibration runs.

In conclusion it can be stated that the information needed for the zoning model is available if a land evaluation procedure has been carried out or it can be based on the judgment of the model user. No additional assessments are needed in comparison to the situation in which a land evaluation procedure has been carried out.

D.2 The management model

The management model needs the following information:
- description of the forest (zones and stands per zone);
- description of feasible management options per stand;
- description of consequences of allocating one hectare of a certain stand to a certain management option;
- valuations of the resulting consequences of decisions for the desired future forest situation and transition management situation, and the requirements of these consequences.

The division of the forest into zones can be obtained from the output of the zoning model. The division of the forest in stands within the zones is based on additional information, which can be obtained from the land evaluation process (in the land evaluation process land is divided into land units on basis of the characteristics of the land).

The description of feasible management options and assessment of consequences of them is an intrinsic part of daily forest management and is also needed in a strategic planning process in which quantitative models are absent.

More research is needed to be done on the translation of land use objectives into valuations of the resulting consequences of decisions for the desired future forest situation and transition management situation and the requirements of these consequences. Few quantitative relationships between the forest characteristics and the realization of land use objectives are available. At the IBN-DLO a research programme which aims at the operationalization of land use objectives into objectives concerning the realization of forest characteristics is currently under way. The first results have already been published (Bos & Hekhuis, 1991; Bos & Hekhuis, 1994; Hekhuis, De Molenaar and

Jonkers, 1994). This research also contributes to improving the assessment of suitability ratings in the land evaluation process. For the time being, the translation of land use objectives into valuations of the resulting consequences of decisions for the desired future forest situation and transition management situation and the requirements of these consequences has to be based on the judgments of the model's user.

D.3 Conclusions

On one hand it can be concluded that not all the information needed to run the models is available. On the other hand the models do not require any information that is not also needed in a strategic planning process in which no quantitative models are applied. If a land evaluation procedure is part of the strategic planning process, then most of the information needed to run the models can be obtained from the results of the land evaluation procedure.

Curriculum Vitae

Jan Bos was born 10 March 1963 in Emmercompascuum and completed his secondary education in 1981. He followed a propaedeutic year at the Evangelische Hoogeschool in Amersfoort and in 1982 began studying Forest Management at Wageningen Agricultural University. He graduated in 1987 with Forest Engineering and Operations Research as his main subjects. A few months before his graduation he started his PhD study at the Department of Forest Management of Wageningen Agricultural University. In 1990 he accepted a part-time job at the DLO Instituut voor Bosbouw en Groenbeheer "De Dorschkamp" (IBG-DLO) in Wageningen. In 1991 he left the university and became fully employed at IBG-DLO, which in 1991 merged with the Rijksinstituut voor Natuurbeheer (RIN-DLO) to form the Institute for Forestry and Nature Research (IBN-DLO). In 1992 and the early 1993 he was secretary to two taskforces, one coordinating the development of the research program and the other coordinating the development of the organizational structure of IBN-DLO. During that time he also did research on the operationalization of abstract objectives about the functioning of the forest into concrete objectives about the characteristics of the forest. He has published several articles on this topic with H.J. Hekhuis. Part of the research done for this PhD has already been published in an article in the Journal of Environmental Management. Since 1994 he has been directie-secretaris (secretary to the executive board) at IBN-DLO.