AN INTEGRATED MCDA SOFTWARE APPLICATION FOR FOREST PLANNING: A CASE STUDY IN SOUTHWESTERN SWEDEN

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Abstract. Forest planning in Sweden today translates not only into planning of timber production, but also for the provision of other functions and services. Multi-criteria decision analysis (MCDA) methods provide a way to take also non-monetary values into account in planning. The purpose of this study was to gain experience on how to use a forest decision support system combined with an MCDA tool in practical forestry. We used a new forest planning tool, PlanWise, which includes an integrated MCDA module, PlanEval. Using the software, the decision maker can compare different forest plans and evaluate them against his/her objectives in a structured and analytical manner. The analysis thus provides a ranking of the alternatives based on the individual preferences of the decision maker. PlanEval and the MCDA planning process are described in a case study, where the manager of a forest estate in southwestern Sweden used the program to compare different forest plans made for the estate. In the paper, we analyze possibilities and challenges of this approach and identify problems such as the adherence to formal requirements of MCDA techniques and the difficulty of comparing maps. Possibilities to expedite an MCDA planning process further are also discussed. The findings confirm that integration of an MCDA tool with a forest decision support system is valuable, but requires expert assistance to be successful.

Keywords: AHP, case study, forest decision support system, Heureka, multi-criteria decision analysis

1 Introduction

The planning of Swedish forests has until recently predominantly meant the planning of timber production. However, as interest is increasingly directed also toward non-timber forest values, new approaches for planning are needed. Instead of considering only economic objectives, other goals such as conserving pleasant scenery or increasing the possibilities for recreation may be relevant to include in the forest plan. Attention has been paid to multi-resource management by non-industrial private forest owners in Sweden (Ingemarsson et al. 2006). The largest Swedish forest owner, Sveaskog, has also stressed the importance of marketing other values of the forest besides timber (Sveaskog 2010).

Inclusion of several incommensurable interests implies that one needs to strike a delicate balance between different objectives in the forest plan. Multi-criteria decision analysis (MCDA) is one method for bringing more than one objective into the planning process and analyzing the relative importance of different objectives. An

MCDA process generally starts by structuring the problem into objectives and criteria; continues by generating alternatives and then assessing the importance and weight of the objectives and alternatives involved; and results in an overall ranking of the alternatives according to the preferences of the decision maker (e.g. Belton and Stewart 2001, Kangas and Kangas 2005). In addition to choosing a preferred course of action, a principal benefit of MCDA is that it facilitates the decision maker's learning about different values and objectives. One common classification of MCDA approaches makes a distinction between Multi Attribute Decision Making (MADM) and Multi Objective Decision Making (MODM) (Mendoza and Martins 2006). The main difference between these two approaches is that, whereas MADM methods are concerned with ranking a finite number of alternatives, MODM approaches are concerned with finding solutions to optimizing problems with several objective functions and a set of constraints. Examples of MADM methods are direct point allocation, the Analytical Hierarchical Process (AHP), and outranking methods. One of the

Figure 1: Starting view in PlanEval.

most well-known MODM methods is goal programming. (For an introduction of methods in a forestry setting, see Kangas et al. 2008.)

Forest planners have used computers since the 1960s to assist in planning (Martell et. al. 1998). Computers have been especially useful for solving optimization problems in long-range planning at the forest level where the planning horizon tends to extend over one or more forest rotations. As operations research methodologies have found use in forest decision support systems (DSSs) (Gunn 2007) and there are a number of well-established MCDA methods available in forestry, one would expect that MCDA tools would be a common feature in forest DSSs. However, this does not seem to be the case. Of a total of 56 unique forest DSSs documented by FORSYS (2010) and NCS (2010), there are many systems that present data on a variety of forest products and services, but only five with built-in MCDA techniques (Monsu, MONTE, DSD, EMDS and Heureka). The Finnish system Monsu, and its Spanish counterpart MONTE, are long-term forest planning systems that may be used to solve MODM problems interactively (Pukkala 2004). Monsu and MONTE are also the only systems with land-

scape visualization capabilities, although these functions are not integrated with the MCDA interface. EMDS provides decision support for landscape-level analyses (Reynolds et al 2008; EMDS 2010; FORSYS 2010). It implements the AHP and Simple Multi-Attribute Rating Technique (SMART) to support the prioritizing of management activities on the basis of an objective hierarchy defined by the user. EMDS is static and cannot make long-term projections. DSD (Decision Support Dobrova) v1.1 is specifically concerned with the long-term analysis of species mixtures of stands under different scenarios and stand treatment schedules (Lexer et al. 2005). The user sets weights for three given top-level objectives –timber production, nature conservation, biodiversity– employing the AHP method while the weights for the lower-level objectives of the hierarchy are fixed.

Heureka is a new forest planning package consisting of several applications (Wikström et. al. 2011). In this paper, we used two of the applications, PlanWise and PlanEval. PlanWise is a tool for long-term forest planning and analysis. PlanEval is an MCDA application for evaluation of plans generated with PlanWise,
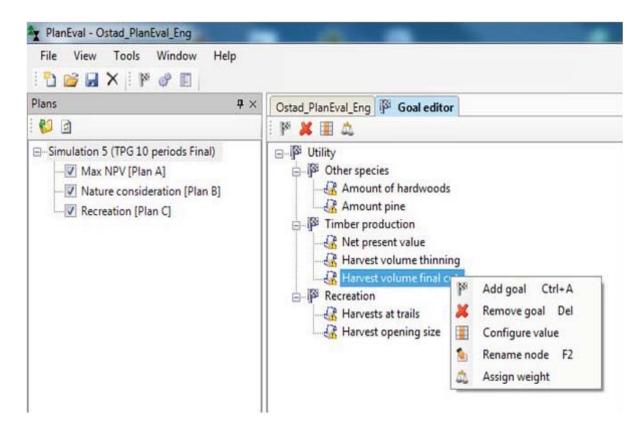
Figure 2: Objective hierarchy of the case study.

and is directly linked to PlanWise. This integration of the MCDA methodology to the forest planning system into PlanWise has features that are not fully replicated in any of the mentioned forest DSSs; it is designed for MADM problems (contrary to Monsu/MONTE), offers greater flexibility than DSD as regards attributes and their representation, and works with an extended planning horizon, which provides an additional dimension compared with the static analysis of EMDS.

An alternative to integrating the tool for MCDA with the forest DSS is to use separate MCDA software such as Mesta (Hiltunen et.al. 2009), HiView, V.I.S.A., Expert Choice, or Web-HIPRE (see French and Xu 2005 for a comparison of different software). However, the user must then prepare separately the data needed for the analysis. This is something that takes time, could induce errors, and limits the possibility of switching attributes during the choice process.

The objective of this study is to gain experience in how to use a forest decision support system combined with an MCDA tool in practical forestry. This was done by applying PlanWise and PlanEval to the planning process of developing a long-term plan for a forest estate in Southwestern Sweden. In the next chapter, PlanWise and PlanEval are described briefly. Thereafter, the different phases of the case study are explained, and a dis-

cussion and conclusions presented on the basis of the case study.

2   MCDA IN PLANWISE

PlanWise consists of two main components: a growth-and-yield simulator and an optimizer. The growth-and-yield simulator computes alternative treatment programs for each treatment unit, normally a stand, in a given forest area. PlanWise has extensive functionality for specifying different kinds of management systems (even-aged or uneven-aged) and silvicultural activities. The optimization tool is basically a graphical user interface with the Zimpl optimization modeling language (Koch 2009), which is used to formulate linear programming and mixed-integer programming problems. The treatment programs form the variables of a Model I type of harvest scheduling model (Johnson and Scheurman 1977). Once the user has created a set of alternative plans PlanEval supports the user in comparing the plans.
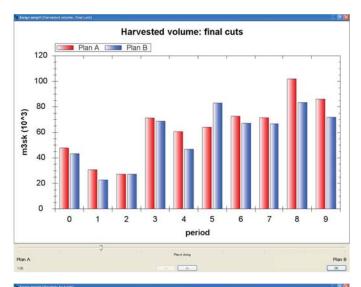
When beginning the multi-criteria analysis with PlanEval, the user first chooses which plans to compare from the PlanWise database (Figure 1). The next step is to choose the preferred weighting method. At present, supported methods are the AHP (Saaty 1990) and direct point allocation. In these methods, the objectives

of the decision maker are first arranged in a hierarchical structure (Figure 2). The alternative plans are then evaluated with respect to each objective, and the objectives compared to find their relative weights. In direct point allocation, the user distributes a total of 100 points in each comparison of alternatives and objectives. In the AHP, pairwise comparisons of alternatives and objectives are made on a preference scale of 1 to 9. According to this scale, a score of 1 means equal preference over the choices and 9 means an extremely strong preference of one choice over another. Finally, a ranking of the plans to their order of preference is acquired. It is possible to use the AHP and direct point allocation in the same analysis, for example by using the AHP to compare the objective weights and direct point allocation to compare the plan alternatives.
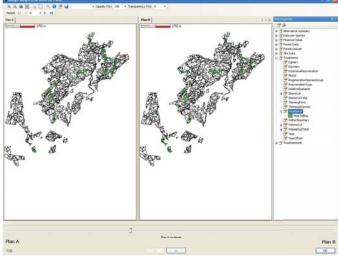
PlanEval is directly connected to PlanWise during the analysis, and the user is thus free to choose the most representative variable for each objective among the hundreds of data items calculated in PlanWise (Figure 2). This is done via the "configure value" function in the program. Here, it is also possible to choose the desired planning periods and to set values for objectives through the keyboard. There are a number of ways to visualize the data; different variables may be assessed as scalars, graphs or maps (Figure 3). Bar graphs show the temporal pattern of the variable over the chosen periods. In the map view, the user may create simple thematic maps of the variables, as well as zoom in on and out of the map as desired. Temporal changes can be assessed by switching between different planning periods. The choice of the variable or its representation method is not fixed; the user may, for instance, first analyze the objective with respective to one representation, then select another representation, and only thereafter state his/her preference.

The results of the analysis are presented in a results table (Figure 4). The overall scores for the alternatives are given on the uppermost row, and the subtotals of the evaluated weights in the matrix below. The result table gives the user-given values in blue and method-calculated sums in red. This should help the user understand the effects of single comparisons on the overall analysis. If desired, the user can then return to the comparison and adjust single weights. There is currently no support for sensitivity analysis or the computation of consistency ratios in PlanEval.

3   CASE STUDY

3.1   Planning area and planning process The multi-criteria analysis was performed on a forest estate in southwestern Sweden (Figure 5). The objective of the analysis was to produce alternative multiple-use for-
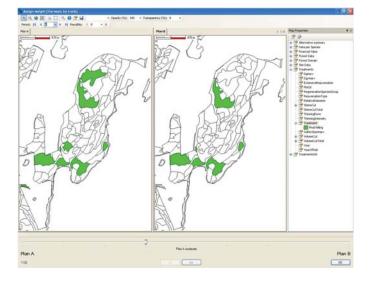

Figure 3:   Different data representation methods in PlanEval, from top down: chart; map; zoomed-in map.

Figure 4: Results table.

est management plans and select the one that best fulfils the estate's forestry objectives. This plan was to be a strategic forest management plan for a 50-year horizon and covering both timber production and other uses of the forest. The total planning area was 2930 ha divided into 1634 stands. The majority of the stands are spruce-dominated production forest, but there are also a considerable number of pine, birch, oak, and beech stands. About 15% of the forest, including many of the hardwood stands, is classified into areas of increased nature consideration, where only light or no operation is allowed. In addition to timber production, parts of the forests are used as recreation areas and biodiversity protection sites including some stands reserved for the Natura 2000 conservation program.

The planning process followed the Intelligence – De-

sign – Choice- model described by Simon (1960). The main phases of the study are presented in Figure 6. The objectives considered in the planning process, as well as the final forest management plan, were chosen by the manager with the support of his forestry consultant. They discussed the alternative actions during the process, but the manager was the actual decision maker (DM). The process started with data acquisition in May 2009 and ended with a one-day meeting with the DM at the end of August the same year, when the DM used the MCDA module PlanEval to compare the plan alternatives.

3.2 Intelligence phase– formulating the planning problem In the intelligence phase of planning, the problem is defined. In this study, this meant analyzing
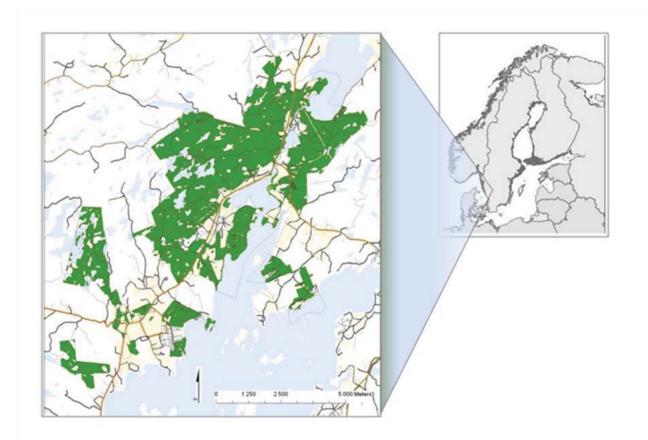
Figure 5: Forest estate of the case study in southwestern Sweden.

the state of the forests and identifying objectives and sub-objectives for the strategic planning. As a first step of the study, the forest data of the estate were entered into the Heureka planning system. We also received a brief description of the current planning situation from the DM by e-mail. The forest data together with the current state description were then used to produce (i) a set of thematic maps showing standing volume, land use, pathways, cultural heritage sites, protected areas and areas with a high proportion of hardwoods; and (ii) a summary table of objectives and other management concerns.

During a one-day visit to the estate, the DM's objectives were discussed using the maps and summary table as reference material. All place-specific objectives were marked on the maps, and the summary table was updated. In addition, a field trip was carried out to gain a better understanding of the objectives and forest management traditions involved in the estate's forest planning. After a renewed round of mail contact, a description of objectives and other management concerns was settled (Table 1). A number of other interests were also discussed with the DM during the "intelligence"

phase interviews. Among them were wind power, which would indirectly preclude adaptations to recreation in the vicinity; eco tourism, which would have similar requirements already accounted for through recreational aspects in the model; and a rock quarry. However, it was deduced that they would not have an effect on the forestry that could be modeled with a long-range, large-scale forest DSS such as PlanWise.

3.3   Design phase– alternative forest plans In the design phase, three different forest plan alternatives were developed with PlanWise. The different alternatives were based on the considerations identified in the intelligence phase (Table 1). The plan alternatives were developed in the following steps. First, the stands were allocated to different domains. A domain in PlanWise is a group of stands that are defined to have similar treatment rules. For instance, key biotopes, some of the Natura 2000 stands and the stands close to ospreys were set to undisturbed growth. Other stands meeting certain conditions were designated to be established with pine after the final cut, whereas the basic setting was to regenerate with the most profitable tree species (usually
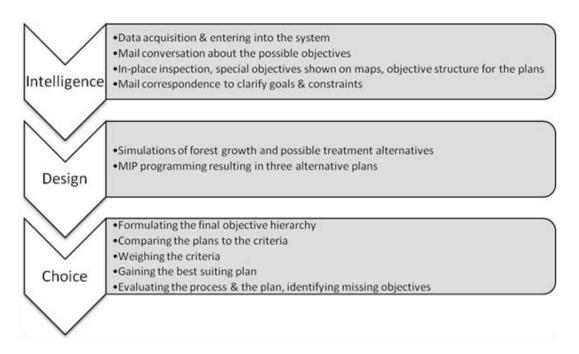
Figure 6: Phases of the case study.

spruce). Second, treatment schedules were simulated for each stand as input to the optimization model. Third, the objective function and constraints of the optimization model were set by us to create three plans. The net present value was maximized in all problems. The constraints differentiating the plans are presented in Table 2. We aimed to produce one plan more directed towards timber production (plan A), one towards nature conservation (plan B), and one towards recreation (plan C). Note that requirements stated as compulsory in Table 1 were observed in all plans.

The current price list (2009) for Södra skogsägarna with a premium for certification according to FSC and PEFC was used. Extra costs associated with, in particular, continuous-cover forestry were disregarded as they would be compensated by subsidies. A discount rate of 3% was used. The standard setting with respect to growth and yield functions, resource use in harvesting, and costs for regeneration was applied (Heureka 2009). Because of the spatially explicit requirements on opening size and the limitations of harvest on opposing sides of paths and streams, the problem was solved as a mixed integer problem. The model was formulated with the AIMMS$^{\textregistered}$ 3.9 optimization modeling system (Bisschop and Roelofs 1999), and solved from within AIMMS$^{\textregistered}$ with ILOG$^{\text{TM}}$ CPLEX 11.0. That AIMMS$^{\textregistered}$ was used instead of the built in user interface in PlanWise was only the result of the path and stream requirement and represented only a change of interfaces for formulating the problem; the treatment schedules were retrieved

from the same databases, the same solver was used and the solutions were stored in the same way as would have been the case if the PlanWise interface had been used.

3.4   Choice phase– evaluating plans and the objectives In the choice phase, the DM compared the three plans in an MCDA process using PlanEval, the PlanWise MCDA module. Prior to the case study, a simple cognitive walk-through was performed on a prototype of the module to identify possible and probable challenges in practical forest planning. The walk-through also highlighted which parts of the process needed to be conducted by the consultant and which could potentially be left to the DM.

The DM (neither the forest manager nor the forest consultant) was not previously familiar with MCDA methods. Thus, we first explained the concept of MCDA and the functions of PlanEval. The three plan alternatives and the processes leading to their design were introduced in an overall manner.

As the first step involving the MCDA software, a draft objective hierarchy was offered to the DM. This draft was based on the previous discussions and the objective structure used when preparing the plan alternatives. The objective hierarchy was discussed in detail, with emphasis given to the possibility to change it if needed. At the conclusion, the DM was satisfied with the proposed hierarchy, the only change being the addition of dividing the initial proposition of "Harvest volume" into volume from thinning and volume from final cuts (Figure 2).

Table 1: Objectives and other management concerns in the case study.

Timber production

- <u>Economic value</u>: The greater the net present value the better.

- <u>Harvests over time</u>: The more even the timber volume from harvests over time the better.

Nature conservation

- <u>Key biotopes</u>: Key biotopes, Natura 2000 areas, and other stands requiring additional care are set aside for undisturbed growth or continuous cover forestry.

- <u>Buffers</u>: 10 m around all lakes, streams and fields are set asides.

- <u>Tree retention</u>: 5%-15% of the standing volume is left at final harvest (including what is left in buffers).

- <u>Osprey</u> (*Pandion haliaetus*): All stands within a radius of 200 m of two nests are set aside.

- <u>Voluntary reserves</u>: Stands that have high nature values but are not already protected could optionally be set aside.

Recreation

- <u>Trekking and illuminated paths</u>: It would be desirable to avoid harvest on both sides of the same stretch of a path within a green-up period of 10 years.

- <u>Boating and fishing</u>: It would be desirable to avoid harvest on both sides of the same stretch of the major stream of the area (Valån) within a green-up period of 10 years.

- <u>Opening size</u>: The smaller the better.

Water

- <u>Water source</u>: For each of three catchment areas of about 600 ha, a maximum of 15% of the area can be felled during each five-year period.

Forestry tradition

- <u>Deciduous stands</u>: Stands that are deciduous today should be maintained as mainly deciduous.

- <u>Species diversity</u>: The more pine stands the better.

The DM was then given a computer having the Heureka system and the different plan alternatives. From this point on, the DM used the software, although the researchers provided close consultancy.

The plans were then compared with respect to the objectives, and the importance of each objective was weighted. The AHP was used for both evaluations. In the plan comparisons, the DM could choose the most suitable data to represent each objective freely from the PlanWise database. The different data available, as well as the representation methods, were discussed with the researchers during the process, and the DM was guided to navigate through the database. After choosing the data variables and representation method for each objective, the DM evaluated the plans pairwise against each objective. Thereafter, the different objectives were evaluated against each other in the same manner.

As a result of the AHP in the case study, plan A received the largest preference value. The results table (Figure 4) was examined in detail, and different objectives and their weights in the final result were discussed.

The MCDA analysis using the software, (i.e., the choice phase), took altogether four hours, with two hours spent explaining the method and program functions and two hours spent carrying out the actual multi-criteria analysis with PlanEval. Two of the authors were present

Table 2: Aspects differentiating plans A, B and C.

Aspect	Plan A	Plan B	Plan C
Voluntary reserves	No requirement	All optional set aside areas required to be reserves	Half the area of all optional set aside areas required to be reserves
Species diversity	No requirement	Pine established if conditions suitable	Pine established if conditions suitable
Opening size	Maximum 10 ha	Maximum 10 ha	Maximum 5 ha
Paths and streams	No requirement	No requirement	No final harvest on both sides of the same stretch[a]

[a]Concerns some designated paths and the Valån stream and with a green up period of 10 years.

during the session and offered consultancy in the use of the software.

4 Discussion

The case study helped identify both accomplishments and more demanding aspects in an MCDA process aiming at a long-term plan for a larger private forest holding. The MCDA process provided an opportunity for the DM to scrutinize the objectives and led to the choice of a most preferred plan. There are a number of issues that one needs to pay attention to in the process, some of which are discussed below.

In the intelligence phase, the problem and its dimensions were mapped thoroughly. Several discussions, both in person and via email, were conducted between the researchers and the DM to identify, describe, and clarify objectives and constraints in the estate's forest planning. Many aspects of the multiple uses of the forest were already taken into account in this phase, leaving not a lot of room for greatly diverging plans to be developed. In view of this observation, it is reasonable to question whether MCDA was motivated at all or would the same achievements have been reached using more conventional methods. However, despite careful investigation in the intelligence phase, some different valuations were expressed when evaluating the plan alternatives with the MCDA software in the choice phase. When comparing the plan alternatives, the economic objectives were emphasized more heavily and other objectives were given less importance than expressed initially. Although this creates a problem of mismatching alternatives, it also shows how the DM preferences could be clarified during the process. Further, some objectives such as quiet regions, were mentioned in the initial interview, but not explicitly taken into account in the plans as "there is an abundance of quietness here already." That is, the large forest area could allow a number of interests to co-exist even if the forest management plan does not prioritize it as such. This phenomenon is likely to be a matter of

scale; such objectives may be more difficult or sensitive on smaller estates.

In the design phase, the provided plan alternatives were based on the interpretation made by the researcher, translating the description into well-defined plan alternatives. Here, the decisions made in the plan alternative simulations were based on knowledge of what objective variables were possible to include in the PlanWise software. This raised some questions from the DM, as some objectives (e.g., wind power) could not be taken into account in the planning, but could play an important role in future decisions relating to the forest area. On the other hand, many of the non-timber production objectives were already included in the optimization model and taken into account in all plans. These were for example the key biotope areas, buffer zones around the water bodies, and the set-aside areas around the osprey nests.

In the choice phase, the possibility of retrieving data from the forest plans during the course of the analysis was found to be an important feature. In the analysis, it was easy to adjust the objective of total removal into removals from thinning and final cuts, as they were considered as more relevant variables. The DM could also choose relatively easily between the different data representation methods. All data views were utilized; net present value was presented as a scalar value, the quantity of broadleaved trees and pines, as well as the removal resulting from thinning and final cuts, were examined with diagrams, and fellings near recreational paths and size of harvesting openings were examined on maps. The chronological assessment of data by switching the view between different planning periods appeared easy to use and understand. The representation of data on maps was useful especially when assessing smaller areas with more specific objectives, such as a few hundred hectares containing a Natura 2000 area; when examining the whole study area the differences between alternatives were more difficult to detect and assess given the small scale and large amount of information. This observa-

tion adds to the list of challenges facing the adoption of spatial forest planning tools in practice (Bettinger and Sessions 2003). Another problem was the abundance of variables available; without prior knowledge of the data produced in PlanWise, navigation between different datasets was tedious and the required data were sometimes hard to find.

The AHP method used in the case study is one of the most widely used MCDA methods applied in forestry, and has been described as a relatively easy method to apply in forest planning situations (Ananda and Herath 2009). However, the method is still not self-evident. It has been noted in previous studies that time is needed to introduce and train the concepts before the process can be used in its intended way (e.g. Saaty 1990, Kangas et. al. 2001). This observation was evident also in our case study. The DM faced difficulties, especially in assessing only one objective at a time, and the DM repeatedly referred back to weights given for previous objectives. For example, the net present value, which was considered the most important objective, was mentioned also when comparing the distribution of timber removal over time: "We want to make as much money as possible so we need to prioritize alternative A." According to the method, the importance of the net present value is already taken into account when weighting it and should not affect the valuation of other variables. The names given to and presented with plans A, B, and C indicated their main focuses, which probably even further directed the attention of the DM from individual objectives. The fact that economic value was already pointed out as the main objective in the initial conversations and that plan A was named "Max NPV" may have tempted the decision maker to prefer plan A, whatever the characteristics of the other plans. This may also explain the observation that plan A was given a higher weight for the amount of hardwoods than plan B despite the latter plan having more of the desired property.

Another problem with the AHP is the large number of pairwise comparisons required even with a relatively small objective hierarchy; there were 31 pairs in this case study. This problem became especially evident in the assessment of maps; as the alternatives consisted of combinations of hundreds of treatment units, the comparison of each pair took considerable time. The slowness of the analysis led the DM to weighing less important alternatives very hastily, with almost no attention paid to the data. This creates a risk of missing clear differences between the alternatives that could affect the weight given to each alternative.

Construction of the objective hierarchy, navigation within the PlanWise database, and understanding the MCDA method required continuous co-operation between the consultant and the DM. As stated by the DM,

the method became clearer only after seeing the results of the evaluation, despite the introduction and examples of the process provided beforehand. A small test analysis prior to the actual MCDA analysis, where the DM would have been able to use the program, could have helped in understanding the process better, although more time would have been needed to carry out the analysis. As such, the program needs to be driven with help from an experienced decision analyst.

5   Conclusions

Research is needed to further demonstrate in what planning situations this MCDA software is particularly suitable. In cases like the one described in this paper, where the planning problem appears fairly well defined and there is limited leeway for different plans, sensitivity analysis around one base alternative might have worked as well, maybe even better. One may also draw the conclusion that a meticulous intelligence phase could save time by narrowing the search in later phases. It may pay off to engage the DM more actively in the design phase when specifying the plan alternatives, thus getting a better understanding of the capabilities of the DSS. In the current case, it turned out that the DM had questions on both what was missing and what was included in the plans when confronted with them in the choice phase. That the MCDA method presumes that the problem is approached by focusing on one objective at a time is obviously not self-evident. Proper time and good instructions are needed for the DM to fully appreciate the method. The possibility to evaluate plans using value functions could lessen the burden on the user to make comparisons of plans. More time would then be available for inspecting the most preferred plan or plans. This may also circumvent some of the conceptual problems in the use of the MCDA techniques by separating plans from objective values.

The integration of the MCDA module with the rest of the system seems valuable as this makes it easy to select and change objectives in real time in the choice phase. It also appears vital to be able to choose in what way the objectives should be represented, whether as scalars, charts or maps. When it comes to maps, the scale has to be considered; when the area is large and there is much detail, it can be difficult to distinguish between maps. A general conclusion is that the presented software is useful for assessing the details of different plan alternatives. However, the software is also quite complex to use and the resulting data are difficult to interpret without prior knowledge about the functions and the methods available. It is necessary to go through the terminology and the workflow to ensure that the user can appreciate the methodology. Thus, the entire process, with due consid-

eration to all phases, needs to be planned carefully.

Acknowledgements

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