A Vote-Based Computer System for Stand Management Planning

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ABSTRACT

A vote-based computer system for decision support was developed in Finland for finding the most acceptable timber harvesting alternatives during the planning of thinning operations in forests under joint-ownership. The alternatives are combinations of a harvesting method, a harvesting system, and the time of each harvest. A lot of information is needed during the planning process. The system was found to be a useful tool for managing information flows and order and organization of the mathematical and analytical methods that are embedded to system's modules. An advantage of this system is that it uses a module containing multi-criteria problem-solving methods. This makes the system's contribution to sustainable forest management effective.

Keywords: *timber harvesting system, harvesting scheduling, local contractors, logging damage, environmental conservation, recreation, multi-criteria decision support.*

INTRODUCTION

Modern stand management for timber production is meeting the increasing demands for sustainability, which means that the needs of ecological, economic, social, and environmental sustainability must be satisfied. Forest owners have many objectives that sometimes conflict. The wood supply chain can thus no longer be managed simply to supply timber. This makes planning and decision-making more complex and creates a need for effective planning systems, which are able to take into account criteria that have been ignored by conventional systems [13].

The choice of harvesting technology and timing in traditional timber harvesting systems for stand management is often based on linear programming or methods related to it [11]. The primary objective is generally to either minimise costs or maximise profits. Using goal programming or parametric optimisation, multiple objectives or criteria may exist, along with a demand for linearity and the necessity for cardinal and numerical evaluation models. This kind of data is not always available for some criteria, for example, biodiversity and aesthetic landscape values. Situations also occur where the scale of information regarding preference and evaluation is imperfect and of low quality. More effective planning systems that are able to deal with non-cardinal information are needed.

Group decision occurs during harvest planning for stand management when dealing with a forest holding owned by several people. In Finland, this kind of ownership is increasing, since forest holdings are increasingly being owned by groups of heirs and other consortia. This new situation requires new systems to support planning involving group decisions. These systems should be easy to understand and simple to use [8].

Many multi-criteria decision support methods are applicable for group decision support [8]. Also methods based on voting theory have been suggested [4], [9]. Most voting systems are considered as being single criterion tools since the individuals compare alternatives directly, but Fraser and Hauge [5] have developed a system called multi-criteria approval (MA), specifically for multiple criteria situations. So far, vote-based computer systems have not been introduced for planning using the Nordic cut-to-length timber harvesting method.

The aim of this study is to develop vote-based computerized timber harvesting systems with an illustrative stand management example. This example is part of a larger example used with a manual planning approach [9]. The system to be tested uses Multi-criteria Approval Voting (MAV), new way to organize information flows and new order of the mathematical and analytical methods. The usefulness of the computerized system is tested during the planning process, which precedes any timber trade negotiations. This example system chooses the best timber harvesting alternatives for jointly-owned forest.

PLANNING SYSTEM

The data flows and the basic structure of the planning system are shown as a flow diagram (Fig. 1). The system contains modules integrated to form the main program. The main program also provides the tools for automatic data handling, which in this context means data treatment of the information flows at the sequential planning stages. To describe the nature of the system, the information flows are labelled at each stage (Figure 1). A forest database is

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made using programs commonly used in forest management planning, e.g., Monsu. Planning data includes trees diameters (cm), lengths (m), volume (m^3/ha) and other characteristics of stands [14]. In this case, the forest management database does not contain information accurate enough for stand-level management planning. Additional information is requested, analysed, and saved by a person acting as the planning coordinator to create the stand information for selection of the timber harvesting alternatives. In this stage email is used. Additional information includes preferences of the owners of the forest by which a set of all alternatives is made. The planning coordinator in this case was a forest engineering expert.

The coordinator also arranges meetings of the decision makers, one before the Internet-based questionnaires are completed and another after the planning system has been applied and given a result. Information database is used in meetings and next stages. The first meeting is arranged in order to present the different timber harvesting alternatives to the owners of the forest. They then have an opportunity to familiarize themselves with the alternatives. The coordinator also introduces the MAV method.

the criteria and make evaluations of the alternatives with respect to some criteria that it is possible to qualitatively characterize. Evaluations of alternatives are made subjectively using an ordinal scale; in other words, alternatives may be ranked from best to worst by the decision-makers. The Borda count-module can be used to create a participants' composite order of importance for the alternatives.

The criteria are also ranked in importance by each individual decision-maker using the Borda-count voting module [1], [2]. The criterion ranked first receives n points, the second-ranked criterion receives n-1 points and so on to the lowest-ranked, which receives 1 point (where n is the number of criteria). The votes for each criterion for all members of the decision-making group are totalled and a composite order of criteria formed from these scores.

In basic voting, voters have equal importance. Additionally, in approval voting, voters can vote for as many candidates as they wish. Each approved candidate receives one vote and ideally the candidate with the most votes wins. The approval voting procedure was described and suggested independently by several researchers in the l970s, such as Brams and Fishburn [3].

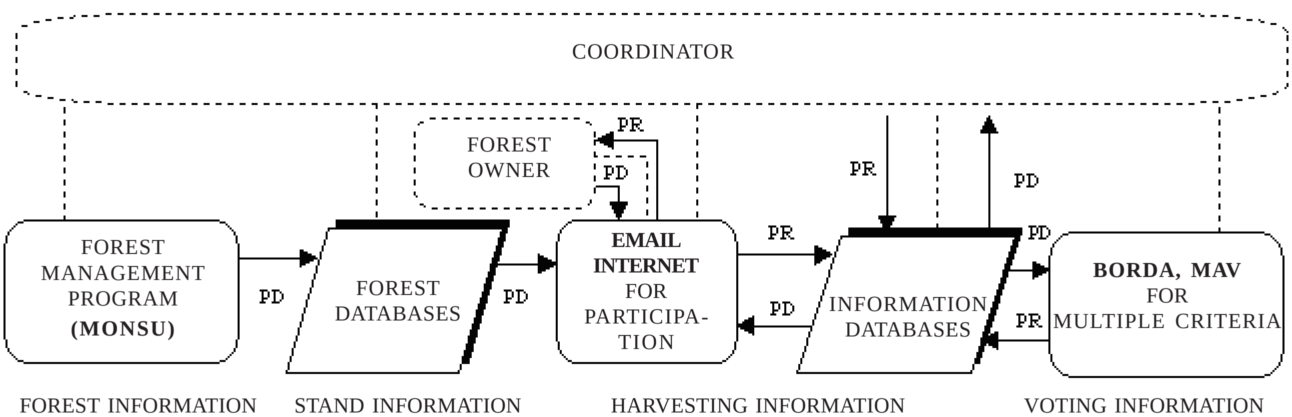

Figure 1. Basic structure of the planning system and its information flow: PD = planning data, PR = planning result.

Use of the planning system begins with the definition of the timber harvesting alternatives and the criteria by which the alternatives are compared. The coordinator defines the alternatives in co-operation with the owners of the forest using the system module that contains email and an Internet-based questionnaire template. This provides one means for the forest owners to participate in the planning.

The questionnaires that the MA method requires are also arranged using an Internet-based inquiry form. Forest owners or experts specify the order of importance for

After the criteria have been ranked, the limit between approval and disapproval for each criterion is defined with the MAV -module [5]. The limit between approval and disapproval for each criterion can be the midpoint of the range of variation or median of the criterion values for all alternatives.

The direction of preference (min/max) also needs to be defined. If more is preferred, an alternative will be approved for the criterion, if its value is higher than the median value. If less is preferred, an alternative will be approved for the criterion, if its value is below the median value.

The determination of the voting result is made automatically by computer. This procedure of the MAV -module begins with the selection of how many alternatives are *ordinally dominant*. The selection process uses an algorithm based on an ordinally deductive selection system [10]. According to the following formula an alternative *k* is classified as *ordinally dominant* if

$$f\left(n^*\right)_{ki} \geq 0 \ \ \forall n^*, \ \ 1 \leq n^* \leq n, \ \ \forall i \neq k \tag{1}$$

where $f\left(n^*\right)_{ki} = \sum_{j=1}^{n^*} g_{ijk}$

and

$$g_{ijk} = \begin{cases} 1, \text{ if } c_j(a_k) \in P' \wedge c_j(a_i) \notin P' \\ 0, \text{ if } c_j(a_k) \in P' \wedge c_j(a_i) \in P' \\ 0, \text{ if } c_j(a_k) \notin P' \wedge c_j(a_i) \notin P' \\ -1, \text{ if } c_j(a_k) \notin P' \wedge c_j(a_i) \in P' \end{cases}$$

where the value of criterion c_j in alternative a_k is $c_j(a_k)$, the value of criterion c_j in alternative a_i is $c_j(a_i)$, and the approved set of alternatives is *P'*.

Fraser and Hauge [5] describe the principle of the formula as: "Alternative *k* is classified as *ordinally dominant* if for every possible value of n^*, and all other alternatives $i \neq k$, $f(n^*)_{ki}$ remains greater than or equal to zero. If at any time, for any $i \neq k$ it becomes negative, alternative *k* is labelled as *indeterminate*."

According to Fraser and Hauge [5], there are five possible voting result classes in multi-criteria approval: *unanimous*, *majority*, *ordinally dominant*, *deadlocked*, and *indeterminate*. The *unanimous* class is a subclass of *majority* and both are subclasses of *ordinally dominant*. Based on pair-wise comparisons, each alternative is defined as either *ordinally dominant* or *indeterminate*.

The *unanimous* voting result means that only one alternative has been approved with respect to all criteria. When the result is a *majority*, only one alternative has been approved with respect to the majority of the criteria that have been defined as the most important. The result *ordinally dominant* occurs if one alternative is defined as superior on the grounds of the order of importance of the criteria and dichotomous preferences. When there is only one *ordinally dominant* alternative, the next step is to determine whether it belongs to one of the *ordinally dominant* subclasses: i.e. *unanimous* or *majority*.

A voting result is *deadlocked* if two or more alternatives are defined as being *ordinally dominant*; in other words, two or more alternatives are approved or disapproved with respect to the same criteria. If one approved alternative cannot be defined as being better than the others on the basis of the order of importance of the criteria, the voting result is *indeterminate*.

The results the system produces can be presented to the forests group of owners at the final meeting of the planning process and/or by email.

EXAMPLE

Three joint-owners of a forest area were involved in the process of planning the management of a stand from the area. Each had an equal share of the forest holding. This consortium-owned forest is comprised of about 30 hectares that are sub-divided into 13 compartments or stands. It is situated in North-eastern Finland. The area of the stand under consideration for planning is 3.8 hectares. It is pine-dominated and contains some spruce and birch. The structure of the stand is atypical for Finland, having two age-classes, with a dominant layer of trees averaging 17 metres in height and another tree storey with an average of 10 metres in height. A stand like this could be harvested using many different thinning plans.

The planning was for the selection of the best harvesting alternatives to be implemented as a single thinning during the next harvesting period. First, the timber harvesting alternatives were outlined and given to the planning system. Three different harvesting methods suitable for the stand were suggested: 1) thinning from below 2) thinning uniformly, and 3) thinning from above. Inquiries showed that three timber harvesting systems were available in the area: 1) chainsaw felling, with forest hauling by a forwarder 2) harvester felling, with forest hauling by a forwarder 3) felling and hauling by a machine (COMBI) that is a combination harvester and forwarder. In addition, two possible harvest times were considered: 1) summer and 2) winter, when the ground is frozen. Combining all the harvesting methods, harvesting systems, and times resulted in 18 possible timber harvesting alternatives for the stand that were to be used in the planning system (Table 1).

Table 1. Timber harvesting alternatives for thinning the stand area.

Alternative	Treatment method	Timber harvesting system	Time of harvesting
A1	thinning from below	chainsaw - forwarder	summer
A2	thinning from below	chainsaw - forwarder	winter
A3	thinning from below	harvester - forwarder	summer
A4	thinning from below	harvester - forwarder	winter
A5	thinning from below	COMBI machine	summer
A6	thinning from below	COMBI machine	winter
A7	thinning uniformly	chainsaw - forwarder	summer
A8	thinning uniformly	chainsaw - forwarder	winter
A9	thinning uniformly	harvester - forwarder	summer
A10	thinning uniformly	harvester - forwarder	winter
A11	thinning uniformly	COMBI machine	summer
A12	thinning uniformly	COMBI machine	winter
A13	thinning from above	chainsaw - forwarder	summer
A14	thinning from above	chainsaw - forwarder	winter
A15	thinning from above	harvester - forwarder	summer
A16	thinning from above	harvester - forwarder	winter
A17	thinning from above	COMBI machine	summer
A18	thinning from above	COMBI machine	winter

The net income from each timber harvesting alternative was calculated by means of the forest planning software Monsu [14]. The measure of this criterion was *United States Dollars* (USD). The prices for wood assortments' delivered to the roadside were used in the software. The net income was calculated by subtracting the harvesting system costs from the total of the prices of the wood assortments from the stand using a specific harvesting method.

The differences in the net income were obtained using the variations in the harvesting costs. First, harvesting costs per cubic meter were calculated using the productivity rates and hourly working costs [6], [7], [15], [16], [17]. Differences in the productivity of each timber harvesting system (m^3/h) resulted mainly from the average volume of the stems removed. Differences in harvesting costs for the stand resulted mainly from the total volume (m^3) of stems removed. For every harvesting alternative the total volume of stems removed was divided by the respective productivity, and the resulting number of working hours required was multiplied by the respective hourly working costs.

Logging damage to the trees remaining after the harvest was initially modelled based on assumptions, because no harvesting damage studies had been done for uneven-aged forests in Finland. The expert opinion is that in a stand with a structure having two age-classes, an overstorey of trees averaging 17 metres in height and understorey with an average height of 10 metres, using the harvesting systems suggested for the work would cause more logging damage than for an even-age stand. The estimates for the expected logging damage were based on results from earlier studies done in Russia [12]. Differences in logging damage between the chainsaw-forwarder system and the harvester-forwarder system was defined by Harstela [6]. Differences between the other systems and the COMBI system were based purely on expert opinion, since no reliable models had been developed for the system. The measure of this criterion was *damaged stems per total area of the stand*.

The forest's owners favoured the use of local contractors, since they were interested in providing job opportunities for people living near the forest holding. The measure of this social criterion was the distance between the stand and the home of each contractor, which was specified in kilometres (*km*) using a road map.

An ordinal scale was used for qualitative evaluation of two criteria. These were the effects of harvesting on the forest stand's recreational values and environmental conservation values. The measure of each of these criteria was a *rank*. Alternatives were ranked from best to worst for each criterion. Affecting both the recreational and environmental conservation values of the stand was the fact that the area was quite wet in summer, penetration resistance tests of the soil (kPa) were lower then than in winter. If a similar stand were harvested in winter the soil frost and the snow cover would therefore decrease any damage to the soil when compared to harvesting when the soil was wet and not frozen. The effects of harvesting on the forest/stand's environmental conservation values were assessed independently by two experts with consistent results. The owners of the forest determined the effects on its recreational pleasure.

The limit between approval and disapproval for each criterion was determined by the planning coordinator (Table 2). The limit was set as the median value for each of the criterion values for all of the alternatives.

The owners ranked the criteria by their importance. Each owner was asked to organise the criteria in his or her own personal order of importance (Table 3). The Borda count – module was used to create a composite of all of the owner's individual orders of importance for the criteria (Table 3). The resulting composite order was: 1) net income, 2) effects on recreational values, 3) favouring local entrepreneurs, 4) expectation of logging damage, and 5) effects on environmental conservation values.

Table 2. Criterion values for the stand's timber harvesting alternatives, the limit between approval and disapproval for each criterion, and the orientation of preference.

Timber harvesting alternative	**Favouring local contractors km**	**Logging damage damaged stems/stand**	**Nature Conservation a rank**	**Net Income US dollars**	**Recreation a rank**
A1	15	59	16	1810	10
A2	15	57	7	1157	1
A3	26	65	18	3635	12
A4	26	63	9	3635	4
A5	39	62	17	2620	11
A6	39	60	8	2620	3
A7	15	64	13	3979	13
A8	15	62	4	3547	2
A9	26	70	14	5384	15
A10	26	68	6	5384	6
A11	39	67	15	4581	14
A12	39	65	5	4581	5
A13	15	78	10	6347	16
A14	15	76	1	5876	7
A15	26	86	12	7423	18
A16	26	84	3	7423	9
A17	39	82	11	6888	17
A18	39	80	2	6888	8
median	26	65, 67	9, 10	4581	9, 10
preference	min	min	min	max	min

Table 3. Orders of importance for the criteria for each individual owner of the forest and the composite importance order.

	Owner 1		**Owner 2**		**Owner 3**		**Total votes**	**Composite order**
	rank	votes	rank	votes	rank	votes		
Local contractors	3	3	2	4	3	3	10	3
Logging damage	2	4	4	2	5	1	7	4
Nature conservation	5	1	5	1	4	2	4	5
Net income	1	5	3	3	1	5	13	1
Recreation	4	2	1	5	2	4	11	2

RESULTS

The planning system automatically computed the choice of the best timber harvesting alternatives once the limits of approval and the composite order of importance for the criteria were given. For the sake of testing the validity of the system, the results were also calculated manually by the researchers. The system's computer based calculations and the researchers' manual calculations gave the same results.

Table 4 shows which of the alternatives were approved (+) and which disapproved (-) with respect to each criterion when the median values were used as approval limits. When each alternative was compared with all the other alternatives in accordance with the aforementioned formula (1), the result was that alternatives 10, 14, and 16 were ranked as being better than the other alternatives. They were found to be acceptable for all criteria except logging damage. Because these alternatives were approved and disapproved on exactly the same criteria in relation to each other, it was impossible to determine one as being a superior thinning alternative for the stand. The voting result was therefore *deadlocked.*

DISCUSSION

In this study, a vote-based computer system for decision support was developed using an illustrative example. The system was applied to the selection of thinning alternatives for stand management. The system was found to be a useful tool for this type of support for group decision-making, because it can take easily into consideration criteria that had not been considered in previous planning systems for the Nordic cut-to-length timber harvesting method.

In the validity test, the computerised calculations of the system gave the same results as the manual calculations. This validation process supports two points of precision for the study: 1) the computer programmer did his or her job adequately, and 2) no error was made during the manual calculation. The result shows that the computerised system is a precise planning tool and suitable for further reliability testing in other real-world planning situations for timber harvesting.

An advantage of the system is that the planning stages are quick to complete. This results from the way the infor-

Table 4. Choice of the timber harvesting alternatives. Approvals (+) and disapprovals (-) of the alternatives for each criterion using the median criterion values as approval limits.

Harvesting alternative	Net income	Recreation	Favoring local contractors	Logging damage	Nature conservation
A1	-	-	+	+	-
A2	-	+	+	+	+
A3	-	-	+	+	-
A4	-	+	+	+	+
A5	-	-	-	+	-
A6	-	+	-	+	+
A7	-	-	+	+	-
A8	-	+	+	+	+
A9	+	-	+	-	-
A10	**+**	**+**	**+**	**-**	**+**
A11	+	-	-	-	-
A12	+	+	-	+	+
A13	+	-	+	-	-
A14	**+**	**+**	**+**	**-**	**+**
A15	+	-	+	-	-
A16	**+**	**+**	**+**	**-**	**+**
A17	+	-	-	-	-
A18	+	+	-	-	+

mation flows and order and organization of the mathematical and analytical methods. The system is also advantageous in situations where information that other planning systems demand is difficult or expensive to obtain or only available in a low quality. A further advantage is that the inquiries could be carried out via email and the Internet. Because of these advantages this vote-based planning system could be developed and would be suitable for consideration as support for many group decision-making situations in wood procurement organisations.

The system identified three equally top-ranked timber harvesting alternatives, 10, 14, and 16. This result is defined as a *deadlock* of the system's selection process. A *deadlocked* result is desirable as long as there are only a few deadlocked alternatives. From the point of view of the forest owners it is good to have a few alternatives for flexibility in timber trade and harvesting contractor negotiations. The final decision between the system's top alternatives; 10, 14, or 16; will be made based on the actual proposed contract costs and prices of the timber buyers and logging contractors. Before the actual timber sale, offers from buyers and contractors will be sought. The actual options for net profit from the timber sale could then be calculated based on the proposed cost of the harvesting alternatives.

A drawback of the system is that evaluating and estimating the priorities of the alternatives with respect to the criteria requires either expert knowledge or evaluation models produced by empirical research. In this study, available expertise was relied on, since no reliable models have been developed, and because the valuation and evaluation tends to be a task that varies from case to case.

As a whole, this kind of multi-criteria approach to forest management creates a good basis for sustainable timber production and sustainable wood supply-chain management. As the previous studies [8], [9], which used a conventional planning approach, this study demonstrates that planning for timber harvesting demands integration of the various aspects of ecological, economic, social, and environmental sustainability. Economic targets were important for the owners of the forest, but they also showed that they wanted to take some responsibility for the ecological and social issues related to stand management.

The results of this experimental study show the benefits of the computerized system. Although we did not assessed the extent to which it has a positive effect on management planning in actual practice, we demonstrated the potential to improve the way the information flows and the order and organization of the mathematical and analytical methods that are embedded in the system's models. When this approach is implemented, the planning data is updated automatically using the system to help decide how to achieve the top-ranked timber harvesting alternatives. The conventional approach to planning by the decision makers in the actual process uses no computer support, and although this approach has had a traditional place within the structure of stand management, its disadvantages are many. Based on the results of the present study, we believe that planning by decision makers should be supported by means of computer system because the information flows permitted by this approach improved, especially as a result of the automatic data handling during the stages of timber harvesting planning.

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