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# Approaches for aggregating preferences in participatory forest planning: An experiment with university students

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**Abstract:** Traditionally, the main focus of forest management planning has been the production of timber. However, forests are today regarded as a source for a wide range of commodities and services, such as biodiversity and recreation to name a few. This results in planning situations that often involve several stakeholders or social groups where a multiplicity of criteria of very different natures must be considered. An approach that has been proposed for situations like these is the combination of multiple criteria decision analysis (MCDA) and participatory planning. This type of merger has been applied in an increasing number of cases related to forestry during recent years.

A crucial part of a participatory MCDA process is the aggregation of individual stakeholder preferences into a collective preference. Equitability and transparency are desirable properties of the aggregation mechanism, which will increase the participants' trust in the process. Furthermore, the way stakeholders interact within the process will be of import for the outcome of the process. Successful communication and conflict management can increase the mutual understanding of values and objectives among stakeholders and form a basis for sound relations and future collaboration.

This study aims to evaluate the outcome of different approaches for aggregation of stakeholders' preferences in a participatory MCDA process. The outcome of the process can be evaluated by the actual result of the aggregation, the effort and time spent on the process by the stakeholders and the analyst, and by the potential benefits for the stakeholders.

The study is based on data from a role playing case where university students have been acting as stakeholders in a participatory forest planning situation. A prepared objective hierarchy and five alternatives were presented to the students, who were asked to give their preferences on the criteria and the alternatives using "pairwise" comparisons. The students were asked to make the "pairwise" comparisons individually. After having given their individual preferences, the group together made "pairwise" comparisons to determine the relative importance of each stakeholder. The individual preferences were then aggregated into a collective preference by different approaches: Weighted arithmetic mean, geometric mean, and goal programming.

The results show a variation in the performance of the different approaches. Thus, the aggregation procedure must be chosen with consideration to the particularities of the planning situation in question.

***Keywords:*** *Analytic Hierarchy Process, goal programming, multiple criteria decision analysis, participatory planning, preference aggregation*

## 1. INTRODUCTION

Traditionally, the main focus of forest management planning has been the production of timber. However, forests are today regarded as a source for a wide range of commodities and services, such as biodiversity and recreation to name a few. This results in planning situations that often involve several stakeholders or social groups where a multiplicity of criteria of very different natures must be considered. An approach that has been proposed for situations like these is the combination of multiple criteria decision analysis (MCDA) and participatory planning. This type of merger has been applied in an increasing number of cases related to forestry during recent years (Diaz-Balteiro and Romero, 2008).

A crucial part of a participatory MCDA process is the aggregation of individual stakeholder preferences into a collective preference (Munda, 2004). Equitability and transparency are desirable properties of the aggregation mechanism, which will increase the participants' trust in the process. This study aims to evaluate the outcome of three different approaches for aggregation of stakeholders' preferences in a participatory MCDA process. The approaches tested in a role play with students in this study are: Extended Goal Programming (EGP), the weighted arithmetic mean method (WAMM) and the geometric mean method (GMM).

## 2. ANALYTICAL FRAMEWORK

In this section, the aggregation methods applied in this study – WAMM, GMM, and EGP – are presented briefly. These methods have the same starting point. First, a fundamental objective hierarchy, consisting of criteria and alternatives, is created (Keeney, 1992). The decision maker then states his or her preferences by "pairwise" comparisons of criteria and alternatives (Saaty, 1990), resulting in "pairwise" comparison matrices. Judgments are made using a nine-point ratio scale to determine the strength of preference for one criteria or alternative over another; the scale is denoted by both numerals and verbal statements (Saaty, 1977).

### 2.1. Weighted Arithmetic Mean Method and Geometric Mean Method

With GMM, the geometric mean of the judgments of all stakeholders for each element in the "pairwise" comparison matrices is calculated. This results in consensus matrices from which first weights and then rankings are determined. WAMM can be used in another way: Weights for criteria and alternatives are synthesized for each individual and then a consensus ranking is determined by calculating the weighted arithmetic mean for the overall weight of each alternative, using the weights of influence that are attached to the stakeholders in this last step. WAMM and GMM are the most common methods for aggregating preferences within the Analytic Hierarchy Process (AHP) (Dyer and Forman, 1992).

AHP is a method for decision analysis developed by Thomas L. Saaty (1990). In the case study of this paper the standard AHP method was used for obtaining criteria weights and weights for alternatives when using WAMM and GMM as aggregation methods; for a full description of the method see e.g., Belton and Stewart (2002), Saaty (1990). In AHP, weights for criteria are determined by using the eigenvalue technique; that is, to find the eigenvector corresponding to the largest eigenvalue for each "pairwise" comparison matrix. In the standard AHP approach, stakeholders make judgments in the form of "pairwise" comparisons not only on criteria but also on alternatives with respect to each criterion. An optional method for evaluating the alternatives is to define a value function for each criterion that assigns weights to the alternatives according to these functions. For a single decision maker, the overall priority for an alternative is calculated by multiplying the weight for the criteria with the weight for the alternative with respect to the criterion in question. This is done for all criteria; the resulting products are summed to produce the overall weight for the alternative. However, in a group decision-making situation the preferences of the different stakeholders have to be aggregated in order to produce a consensus ranking of alternatives.

### 2.2. Extended Goal Programming

Goal programming (GP) is a method for decision analysis that deals with problems where target levels can be assigned to the attributes and where the non-achievement of the corresponding goals is minimized. How this non-achievement is measured depends on the specific GP approach that is used. Two common GP approaches are Archimedean (or weighted) GP and MINMAX (or Chebyshev). Archimedean GP can be interpreted as the maximization of a separable and additive utility function, which means that the overall utility is maximized and that the solution obtained is the best from the point of view of the majority. MINMAX GP, on the other hand, implies the optimization of a utility function where the maximum deviation is minimized, which means that the solution obtained is the best from the point of view of the minority or the "worst-off individual" (Diaz-Balteiro and Romero, 2001).

A recently proposed method for aggregating preferences in the form of "pairwise" comparisons is the EGP approach, which is based upon the determination of cardinal compromise consensus (González-Pachón and Romero, 2007). The method combines the Archimedean and the MINMAX formulations and makes it possible to find compromise solutions between the two models. This is done by introducing a user-defined control parameter (λ, μ) which regulates the trade-off between the point of view of the majority (λ or μ =1) and the point of view of the minority or the worst off individual (λ or μ = 0). The method is adapted to the present study and covers the following three steps:

1. *Determination of criteria weights for each stakeholder*

Preferences in the form of "pairwise" comparisons of $i = 1,2,...,q$ criteria are made by $t = 1,2,...,k$ individual stakeholders in order to establish a ranking of $s = 1,2,...,r$ alternatives. The starting point is the "pairwise" comparison matrices of the individual stakeholders. Weights for the criteria are determined for each individual by solving the following EGP model:

***Model 1***

*Achievement function*

$$\text{Min } (1-\lambda)D + \lambda\left[\sum_{i=1}^{q}\sum_{\substack{j=1\\ j\neq i}}^{q}\left(n_{ij} + p_{ij}\right)\right]$$

*s.t.*

*Goals and constraints*

$$m_{ij}w_j - w_i + n_{ij} - p_{ij} = 0 \qquad i, j \in \{1,\ldots,q\}$$

$$\sum_{i=1}^{q}\sum_{\substack{j=1\\ j\neq i}}^{q}\left(n_{ij} + p_{ij}\right) - D \leq 0$$

$$\sum_{i=1}^{q} w_i = 1$$

$$n \geq 0 \quad p \geq 0$$

$$\lambda \in [0,1] \qquad \text{(user-defined control parameter)}$$

where $m_{ij}$ is the judgment made on criterion $i$ compared to criterion $j$ and $w_i$ is the weight of criterion $i$ for stakeholder $t$. D is the maximum deviation of any judgment from the criteria weights that are established. The negative and positive deviation variables are denoted by $n_{ij}$ and $p_{ij}$. The parameter λ is a user-defined control parameter that can be set to any value between 0 and 1; λ=1 gives an Archimedean GP model, while λ=0 gives a MINMAX GP model, and intermediate values yield compromise solutions between these two models. The parameter λ should correspond to the kind of consensus that is suitable for or desired in the participatory process.

2. *Aggregation of the individual criteria weights*

Next, the criteria weights for each individual stakeholder $t$ are to be aggregated into a set of criteria weights common to all stakeholders. This is done by applying the following model:

***Model 2***

*Achievement function*

$$\text{Min } (1-\mu)D + \mu\left[W^t\sum_{t=1}^{k}\sum_{i=1}^{q}\left(n_i^t + p_i^t\right)\right]$$

*s.t.*

*Goals and constraints*

$$w_i^c + n_i^t - p_i^t = w_i^t \qquad i \in \{1,\ldots,q\} \quad t \in \{1,\ldots,k\}$$

$$W^t \sum_{i=1}^{q} \sum_{t=1}^{k} \left(n_i^t + p_i^t\right) - D \leq 0$$

$$\sum_{i=1}^{q} w_i^c = 1$$

$$n \geq 0 \quad p \geq 0$$

$$\mu \in [0,1] \qquad \text{(user-defined control parameter)}$$

where $w_i^t$ is the weight of criterion *i* for stakeholder *t*, and $n_i^t$ and $p_i^t$ are the negative and positive deviation variables for criterion *i* and stakeholder *t*. The aggregated weight of criterion *i* is denoted by $w_i^c$ and the weight of influence for stakeholder t by $W^t$. The parameter μ is analogous to parameter λ in model 1.

*3. Determination of consensus rankings of alternatives*

To determine consensus rankings of alternatives, criteria weights need to be combined with the outcomes of the different alternatives. However, the outcomes are measured in different entities and have to be normalized to be comparable. The normalization is performed as follows:

$$\frac{O^{i*} - O_s^i}{O^{i*} - O_*^i}$$

where $O^{i*}$ and $O_*^i$ are the ideal and the anti-ideal values, respectively, for the *i*th criterion within the set of alternatives (*s*); $O_s^i$ is the outcome that corresponds to the *s*th alternative when it is evaluated according to the *i*th criterion. With this normalization procedure the normalized outcomes are expressed as distances from the ideal value and all outcomes are in the range between 0 (ideal/best value) and 1 (anti-ideal/worst value).

Consensus rankings of the alternatives can be obtained by two opposite approaches that employ different norms or definitions of distance. First, the best consensus ranking is determined by maximizing the weighted average of the outcomes. This is done by applying the following formula:

$$(A_s)_{p=1} = \sum_{i=1}^{q} w_i^c O_s^i$$

where $(A_s)_{p=1}$ is the overall priority for the *s*th alternative when the norm p=1 is used.

Second, the best consensus ranking from the point of view of minimizing the most displaced result is established. This is obtained by applying the following formula:

$$(A_s)_{p=\infty} = MAX_{\forall i}\left[w_i^c O_s^i\right]$$

where $(A_s)_{p=\infty}$ is the overall priority for the *s*th alternative plan when the norm p=∞ is used.

## 3. CASE STUDY

### 3.1. Background and role play

The present study was performed by simulating a group decision making process by role play with 6 students enrolled in a course in forest landscape multiple use management at the Swedish University of Agricultural Sciences. Beforehand, the students received basic information on role playing as a technique and a scenario with a description of the background situation, the decision problem and five different roles.

The students were presented with the following background scenario for the role play, modeled on a real case study in progress in the municipality of Lycksele in northern Sweden. The town of Lycksele is the regional centre in a forest landscape area where commercial forestry is an important industry for the local economy. However, the forest around the town holds other values and is important to the inhabitants of the town for other purposes than wood production; e.g., for preserving biodiversity and for providing forest suitable for recreation. Thus, the municipality has initiated a project with the goal to produce a multiple use forest management plan for an area of approximately 10 000 hectares. The planning process is to be a participatory process where the forest company and the municipality together with the representatives for three different interest groups will choose a multiple use forest management plan from five different alternatives.

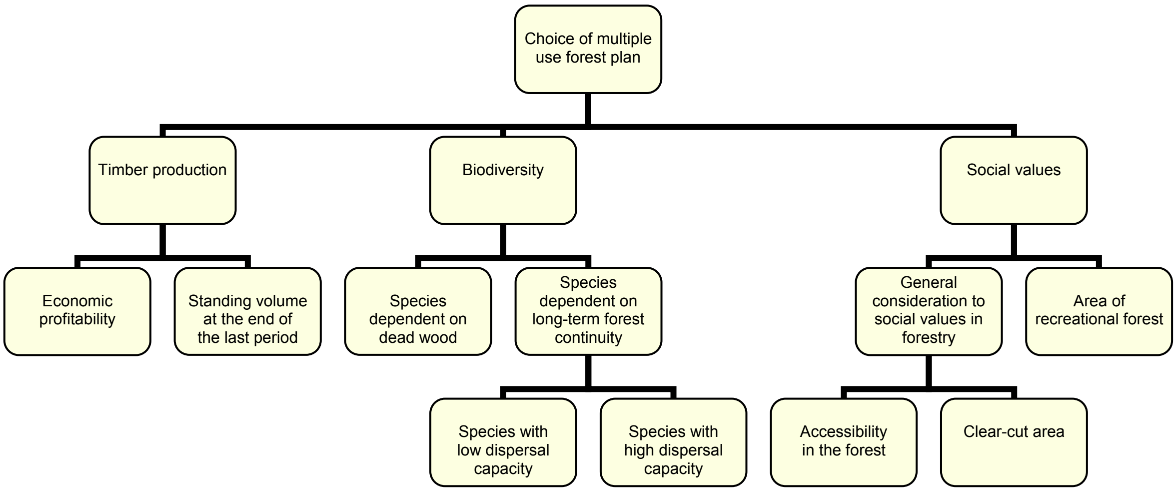


**Figure 1.** The objective hierarchy of the case study

An objective hierarchy (Figure 1) was constructed beforehand, prior to the role play session with the students. The hierarchy was based on the background information of the case and constructed with consideration to the desired properties of a fundamental objective hierarchy (Keeney, 1992). The performance of the alternatives in terms of the lowest-level criteria was to be evaluated in the following way:

- Economic profitability: Net present value (NPV), in millions of Swedish Crowns
- Standing volume at the end of the last period: Volume, in $m^3$
- Species dependent on dead wood: Combination of 1) volume left at harvesting, in percent, and 2) area of forest with no treatment or management for nature conservation, in hectares
- Species with low dispersal capacity: Area of forest with no treatment or management for nature conservation, in hectares
- Species with high dispersal capacity: Area of forest older than 100 years at the end of the last period, in hectares
- Accessibility in the forest: Combination of 1) volume left at harvesting, in percent, and 2) area of forest with management for social/recreational values, in hectares
- Clear-cut area: Average for all periods, in hectares
- Area of recreational forest: Area of forest with management for social/recreational values, in hectares

Five forest plan alternatives (called A, B, C, D, and E) were also prepared and presented in tables, diagrams, and maps. The forest plans had the following strategic alignments:

- Plan A: Timber production
- Plan B: Biodiversity
- Plan C: Recreation
- Plan D: Mixed 1 (Timber production, biodiversity and, to some extent, recreation)
- Plan E: Mixed 2 (Timber production, recreation and, to some extent, biodiversity)

The role persons were named The Municipality Ecologist, The Tourism Entrepreneur, The Forest Company Representative (two students were assigned this role together, since there were five roles but six students) The Nature Conservationist, and The Representative for Sport and Outdoor Life; and each was characterized by a brief description. The students were asked to make "pairwise" comparisons individually of both the criteria and the alternatives. An MS Excel worksheet was developed for eliciting preferences according to the

AHP method. The worksheet was also used for calculating approximate criteria and alternative weights for AHP (Anderson et al., 1994). The EGP models were formulated and solved with the software LINGO.

After having given their individual preferences, all participants together made "pairwise" comparisons to determine the relative importance of each stakeholder. From these "pairwise" comparisons made by the group, the AHP worksheet was used to obtain the following weights of influence for the different stakeholders: The Municipality Ecologist – 0.23, the Tourism Entrepreneur – 0.31, the Forest Company Representative – 0.09, the Nature Conservationist – 0.18, the Representative for Sport and Outdoor Life – 0.19.

In addition to letting the stakeholders make "pairwise" comparisons of alternatives, value functions were also used to rank the alternatives. We did this by defining linear value functions by which the "best" alternative receives the value 1, the "worst" alternative value 0, and the other alternatives are assigned intermediate values linearly.

The individual preferences were aggregated into a collective preference by using different approaches: WAMM, GMM, and EGP. The weights of influence for each stakeholder were used with WAMM and EGP. Figure 2 gives an overview of the inputs and outputs of the different methods.

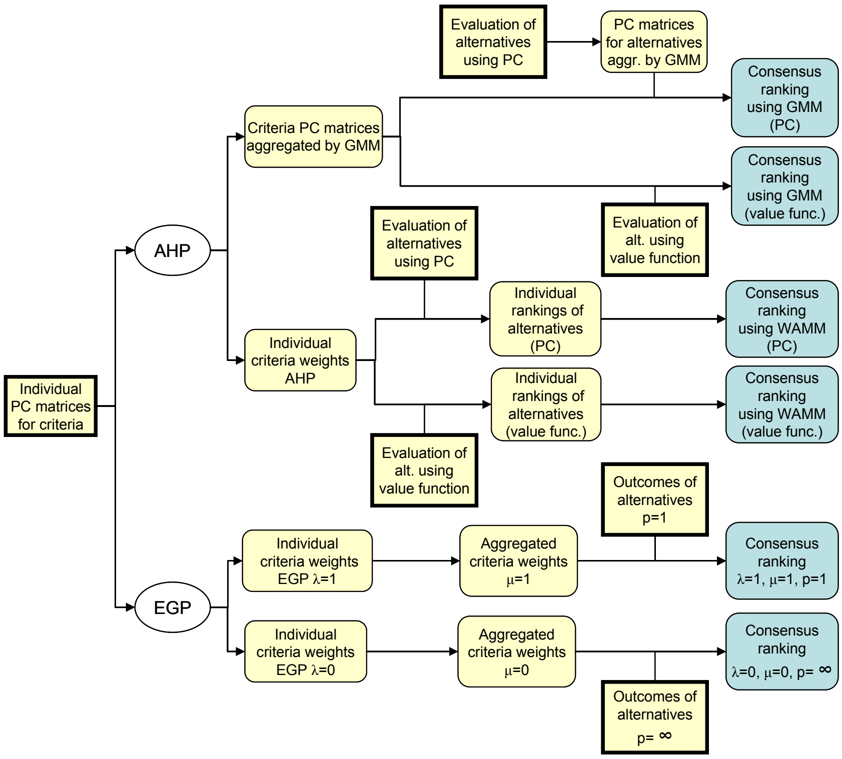


**Figure 2.** Overview of the inputs and outputs of the different aggregation methods. Square boxes with bold lining represent input of raw data, the rounded boxes represent data generated in the process, and the rounded boxes of darker shade represent the output (PC="pairwise" comparison)

### 3.2. Results

This subsection presents the results in the form of the consensus rankings of alternatives that were determined by the different approaches for aggregation.

**Table 1.** Consensus rankings of the alternatives A-E resulting from the different methods. The rankings range from 1 to 5 where 1 is the highest rank and 5 is the lowest rank. Values within parentheses are the weights for each alternative for AHP (the larger the value, the higher ranked is the alternative) and the distances from the ideal for EGP (the lower the value, the higher ranked is the alternative); the rankings are determined from the values in parentheses

| **Alternative** | | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|---|
| WAMM | "Pairwise" comparisons | 3 (0.18) | 5 (0.15) | 1 (0.30) | 2 (0.22) | 4 (0.16) |
| | Value functions | 3 (0.19) | 5 (0.12) | 1 (0.30) | 2 (0.20) | 3 (0.19) |
| GMM | "Pairwise" comparisons | 5 (0.12) | 2 (0.19) | 1 (0.34) | 3 (0.18) | 4 (0.17) |
| | Value functions | 5 (0.13) | 4 (0.14) | 1 (0.36) | 3 (0.16) | 2 (0.21) |
| EGP | $\lambda = 1, \mu = 1, p = 1$ | 2 (0.58) | 5 (0.81) | 1 (0.36) | 4 (0.60) | 2 (0.58) |
| | $\lambda = 0, \mu = 0, p = \infty$ | 2 (0.19) | 5 (0.38) | 4 (0.33) | 1 (0.13) | 3 (0.30) |

Both AHP and EGP produced individual criteria weights that were relatively similar. By inspection of the consensus rankings one can note that the two rankings obtained from using the WAMM are quite similar, while the two rankings obtained from using the GMM are somewhat different although C get the highest rank for both rankings. The two rankings obtained with EGP have different alternatives in the top of the rankings.

## 4. DISCUSSION AND CONCLUSIONS

In all but one of the consensus rankings, plan C get the highest rank. This is the "Recreation" alternative; and one explanation as to why this alternative is ranked highly is that the Tourism Entrepreneur and the Representative for Sport and Outdoor life, who both have recreation as their main interest, together have a large weight (0.31 and 0.19). When individual preferences are aggregated using WAMM or GMM, the result is the mean of the individual preferences. When EGP is used with $\lambda=1$, $\mu=1$ and $p=1$, the aggregated preference is the (weighted) median of the individual preferences. However, when EGP is used with $\lambda=0$, $\mu=0$ and $p=\infty$, the ranking changes and plan D, the "Mixed 1" alternative, is ranked as number 1. The role of parameters $\lambda=0$ and $\mu=0$, are to minimize the greatest deviation and thereby balance the solutions. For example, when model 2 is applied, $\mu=0$ will work to find aggregated criteria weights that are balanced in the sense that these aggregated criteria weights are, as far as possible, at the same distance from the criteria weights of each of the individual stakeholders. This is a solution to the advantage of the individual with most displaced preferences with respect to the majority. That plan D, the "Mixed 1" alternative, get the highest rank is probably a consequence of the balancing effect; plan D is in fact a compromise solution between timber production, biodiversity and, to some extent, recreation.

The value functions that are applied in this study seem to be a promising procedure, even though the functions are simplified to assume linearity. To use value functions saves the stakeholders' time and effort and, in the case of the individual preference approach, produce similar results as the "pairwise" comparison procedure. Non-linear value functions can be constructed either by working directly with stakeholders stating their preferences or by using expert evaluations, but this would naturally mean an increase in time and effort spent on the process.

The results of this study indicate that especially the EGP method is attractive, because of the possibility to obtain both majority consensus solutions and balanced solutions which minimize the distance of the worst-off individual from the consensus solution. For example, in politically sensitive situations EGP with $\lambda=0$, $\mu=0$ and $p=\infty$ could be a useful tool because of the possibility to find balanced consensus solutions that are not determined exclusively by the weight of influence assigned to each stakeholder.

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