# HERO heuristic optimization for forest planning

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## Abstract

HERO heuristic optimization method has been developed for purposes of forest planning at area or forest holding level, the area under planning consisting of plenty of forest stands each having several alternative treatment schedules to be chosen among. The idea is to find for each forest stand, or compartment, a treatment schedule that is optimal at the level of the whole area. HERO consists of two main phases: estimation of the utility model to be maximized (i.e. analysing and modelling objectives and preferences), and maximization of the utility model. The variables of the utility model can be selected from parameters that are associated with the whole forest area, such as drain, costs, income, or qualities of the growing stock. Using HERO, also nonlinear functional relationships between forestry parameters and utility can be dealt with. In the estimation of the utility model, techniques of the AHP and multi-attribute utility theory, as well as related methodologies, can be utilized. Applications of HERO include, among others, interactive forest planning, participatory forest planning, and incorporating biological diversity into numerical forest planning. In this presentation, a closer look is taken at the last-mentioned application. Experiences of the applications have been promising. For example, HERO has proved to be a flexible tool in objective setting, and easy to use and understand – also in interactive planning. Due to its area level approach HERO is worth developing further also for purposes of landscape ecological planning.

**Keywords:** biodiversity, decision support, forest management planning, heuristics, utility maximization

# 1 Principles of HERO

The HERO heuristic optimization method has been specially developed for tactical forest planning mainly at area or forest holding level. The idea is to seek – and to find – such a combination of stand-level treatment regimes for the area or the forest holding as will provide the best end result at the level of the whole area/holding, with respect to the objectives set for forest treatment and utilisation.

Prior to actual optimization, objectives have to be set for forest treatment and utilisation, and each stand has to be provided with a host of alternative treatment regimes for the duration of the planning period (typically 10 to 20 years). The outcomes of the alternative regimes are computed through simulation of forest development.

When applying HERO, selecting the best alternative may be divided into two stages: estimation of the utility model and maximization of this model. HERO uses an additive utility model, the variables of which are management objectives whose coefficients are the objectives' relative importance (weights), scaled to sum equal to one. The weights are estimated applying pairwise comparisons carried out by the decision maker. The relative importance of the objectives can be computed using the eigenvalue method of ratio scale estimation (Saaty 1977). In that, the objectives are compared pairwise using a graphical interface, instead of the verbal scale as proposed by Saaty (1980). The relative importance of two objectives at a time are defined by adjusting the lengths of the horizontal bars on the computer screen.

The relative worth of the planning alternatives with respect to the objectives are presented in the form of sub-priority functions. The sub-priority function depicts the change in the utility as a function of the objective variable (Fig. 1). The utility model consisting of objective variables and sub-priority functions is a tool enabling different objective parameters to be made commensurable.

The method enables the presentation of objective variables in a hierarchical manner. When this is done, the objective is described using a hierarchically inferior model, whose variables are the components describing the objective in more detail and whose coefficients are the components' relative importance. For instance, the net income from wood production can be divided into net

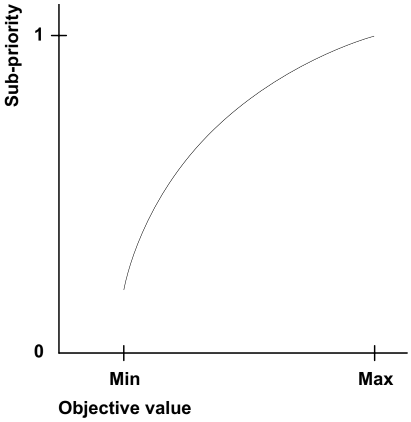

Figure 1. An example of non-linear sub-priority functions describing functional relationship between utility and the value of an objective variable.

incomes of different periods, and biodiversity can be operationalized by means of the components explaining it. This being the case, the sub-priority functions are defined to depict the impact of the components on the utility felt through the objective variables they explain.

When estimating the sub-priority function, first the maximum and minimum values that can be achieved for the objective parameter or component are computed. In addition, a few intermediate values are selected. The desirability of these values is then estimated, e.g., by means of pairwise comparisons and the values are then allocated relative priorities. These priority values define the sub-priority function. A sub-priority function can be non-linear, which is often the case, for example, when describing the relationships between biodiversity and environmental variables (see e.g. Williams & Gaston 1994). The sub-priority functions, with maximum value equalling one, is estimated separately for each component. Estimation can be based equally on expertise or subjective value information. Ratios of values of objectively measurable variables can also be used. Further advantages connected to this manner of estimation are that one operates in real case-wise production possibilities, and ease of operation.

At the “maximization of overall utility” stage, one uses the heuristic direct-search algorithm to search for the best treatment regime for the forest area. In the beginning of the optimization process, one treatment schedule is selected randomly for each compartment. The values and the sub-priorities of the objectives are computed, as well as the total utility. After that, one compartment at a time is examined to see whether another treatment regime would increase the utility. If this is the case, the current treatment regime is replaced by the one that increases utility. Once all the treatment regimes of all the compartments have been studied in this way, the process is repeated again, starting from the first compartment, until no more schedules increasing the utility are found. In order to ensure that the global optimum is found, the whole maximization stage is repeated several times, and the solution with the greatest utility value is taken as the optimal solution.

When applying HERO, the user has to adhere to objective variables that can be described within the planning system applied. The MONSU software (Pukkala 1998), making use of HERO, currently enables the examination of conventional forestry parameters depicting the growing stock (e.g. volumes by tree species) as well as parameters depicting the amount of decaying timber (standing and fallen), mushroom and berry crops, recreational and landscape values, and certain habitat indices for wild game as well as indices for biological diversity. The range of components is constantly growing as the planning software evolves.

For more details on techniques and qualities of HERO, readers are referred to Pukkala and Kangas (1993). So far, applications of HERO include interactive planning of private non-industrial forestry (Kangas et al. 1996a), public participation in forest management planning (Kangas et al. 1996b), taking risk and attitude towards risk into account in planning calculations (Pukkala & Kangas 1996), incorporating biodiversity into numerical forest planning (Kangas & Pukkala 1996), taking variation in forest characteristics at both stand and area level into account in calculations (Pukkala et al. 1997), and modelling ecological expertise to be used in optimization (Kangas et al. 1998). Next, one of these applications, namely that of incorporating biodiversity into planning calculations, is briefly presented.

## 2 An application of HERO: integrating biodiversity with forest management planning

In the case of tactical forest planning with plenty of stand-wise alternatives and, correspondingly, their area/holding level combinations to be chosen among, numerical methods for comparing decision alternatives are required. In the following, the use of HERO as a framework for the integration of biological diversity into calculations of tactical forest planning, and utilizing expert judgments in it, is briefly described. For more details, see Kangas and Pukkala (1996).

The operationalisation of biodiversity for planning calculations can be illustrated by means of a decision hierarchy. Biodiversity is presented as a decision objective in the hierarchy. The components of biodiversity are added into the hierarchy at the level immediately below the level of the objectives. In the same way as the weights of multiple objectives are determined using HERO, the importance of the chosen components of biodiversity are assessed.

A sub-priority function is estimated as presented above for each component. For example, if the volume of dead and decaying wood ($m^3$/ha) is taken as a component of biodiversity, a sub-priority function is estimated describing the functional relationship between the amount of dead and decaying wood and the related sub-priority.

If needed, more detailed components can be defined with neither theoretical nor methodological problems arising. In that case, the sub-priority functions are estimated for the more detailed components. In addition, the weights of the more detailed components, with respect to the more general component, should be assessed.

In the above manner, biodiversity can flexibly be operationalized for the calculations of tactical forest planning. The techniques used in the HERO optimization method allow case-wise choice of biodiversity components as well as their weighting and sub-priority functions. The result of operationalisation is a formula for calculating the biodiversity indices for forest plans on a ratio scale. The greater the index, the better the forest plan in regard to biodiversity considerations. The index can be used in planning calculations as any numerical parameter (Fig. 2). Because of the case-wise calculation procedure involved, biodiversity indices cannot be universally interpreted nor compared.

When operationalizing biodiversity for planning calculations, ecological expertise can be utilized. This being the case, the components of biodiversity are chosen, the weights of the components are assessed, and the sub-priority functions are derived on the basis of expert knowledge; i.e. experts on conservation forest biology make the pairwise comparisons needed in the operationalisation step. HERO serves as a framework where expert knowledge can be modelled and integrated into decision support.

A case study was carried out in eastern Finland covering about 1500 hectares of state-owned forest land and governed by the Finnish Forest and Park Service. Eleven experts were recruited for the planning process. Before making any comparisons, the experts examined the case study area and its potentials in regard to biodiversity management. In addition to the eigenvalue technique, analyses of pairwise comparisons were made also using the variance component modelling approach presented by Alho et al. (1996). The method of Alho et al. enables statistically sound and versatile analyses of the uncertainty involved in the expert predictions. In the case study, a method for combined use of HERO and Delphi techniques was developed, with all the comparisons being repeated three times in order to improve the coherence between the judgements of different experts (Kangas et al. 1998).

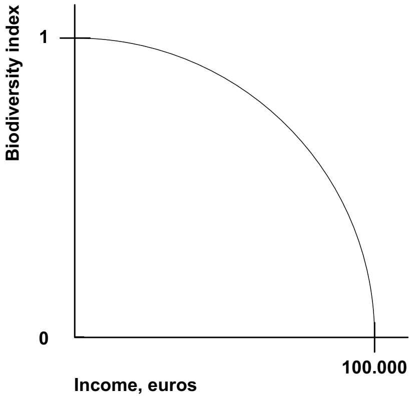

Figure 2. A figure in principle of a production-possibility boundary between a biodiversity index in the end of the planning period and income from cuttings during the planning period, within a forest area under planning.

The mean volume of broadleaved trees, the proportion of old trees, and volume of deadwood were chosen as the components of biodiversity in the case study. These components were regarded to be critical variables with respect to the occurrence of many rare, threatened, and endangered species in the boreal forests of Finland. The final model was constructed after the third Delphi round as a mean model of expert views. The sub-priority functions finally accepted in the case study were all non-linear.

## 3 Some experiences and conclusions

The initial empirical experiences gained of the applications of HERO in tactical forest management planning have been encouraging (e.g. Kivivuori 1995, Karvinen 1995).

Considering the prevailing planning practice, the experiments made have, however, included a lot of other things in addition to the pure optimization method, e.g. biodiversity assessments. Actually, the conceptual model of multi-objective planning as a whole has been the target of testing. Parties involved – the public, planners, foresters and forest owners – have mainly participated with enthusiasm in the procedural tests. People are putting a lot of trust in the improvement of the quality of planning.

Perhaps the greatest advantage of HERO, from the practical standpoint, is in its flexibility especially regarging setting of objectives and taking case-wise subjective preferences into account in planning. In that, HERO fits with the idea of value focused thinking. This is important both in customer-oriented planning of private forestry and in participatory planning. A futher advantage is that, due to the sub-priority estimation procedure, also case-wise expert knowledge is easy to utilize in HERO calculations. Because HERO does not put any demands for the form of sub-priority functions, it can cope with area-level spatial variables having non-linear utility effects more easily than mathematical programming, and other non-linearities.

Some of the methods that are being tested, and the planning system used to apply them, are still prototypes. More development and fine tuning is required before they are ready for application in routine planning work. As we gain more information on the various forest uses, objectives and values, and as planning systems evolve, the range of variables analytically assessable in conjunction with the formulation of plans will grow. This also means that the ways in which different decision criteria and objectives can be integrated will become more diverse and more specific.

A drawback of any heuristic approach is that the solution may not always be optimal, but only an approximation to it. According to the tests carried out, and experiences gained in applications, this kind of inefficiency does not seem to be a serious problem: most often the global (technical) optimum is found, and the solutions are always close to optimum.

The application of HERO, or any other optimization method, does not produce satisfactory solutions to all possible problems of tactical forest management planning. In addition to calculation executed by computers, the currently available software and the calculations they enable, intuitive input from the decision-makers, and the skills and knowlwdge of planners and experts are needed. Thus, the planning process as a whole is, in practice, more or less heuristic, no matter what kind of optimization algorithms are used.

Concerning the biodiversity application, the assessment of biodiversity also requires improvement: the approach described above should be seen primarily as a preliminary model and as the starting point for further development, and neither is its application entirely beyond all ecological criticism (see Pukkala et al. 1997). For example, the additive assumption as applied in the utility model, is perhaps too strong regarding the components of biodiversity. In principle, interactive terms could be added into the utility model. This would, however, make the estimation process much more complicated; too complicated for forestry practice.

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