Ecological Economics 68 (2009) 2535–2548

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Methods

# A critical review of multi-criteria decision making methods with special reference to forest management and planning

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ARTICLE INFO

*Article history:*
Received 29 May 2008
Received in revised form 20 May 2009
Accepted 21 May 2009
Available online 6 June 2009

*Keywords:*
Decision criteria
Weights
Forest options
Preference elicitation
Value/utility functions

*JEL classification:*
C65
D81
Q23
Q57

ABSTRACT

This paper provides a review of research contributions on forest management and planning using multi-criteria decision making (MCDM) based on an exhaustive literature survey. The review primarily focuses on the application aspects highlighting theoretical underpinnings and controversies. It also examines the nature of the problems addressed and incorporation of risk into forest management and planning decision making. The MCDM techniques covered in this review belong to several schools of thought. For each technique, a variety of empirical applications including recent studies has been reviewed. More than 60 individual studies were reviewed and classified by the method used, country of origin, number and type of criteria and options evaluated. The review serves as a guide to those interested in how to use a particular MCDM approach. Based on the review, some recent trends and future research directions are also highlighted.



## 1. Introduction

Forest resource use decisions are complex because of competing uses such as timber harvesting, recreation, water supply, biodiversity conservation and presence of heterogeneous stakeholders (Ananda and Herath, 2003a,b). Forest policy making involves ecological, socioeconomic, and political processes and values, and making difficult tradeoffs among these multiple objectives (Gregory and Keeney, 1994). There have been major conflicts between timber harvesting and conservation of biodiversity in old-growth forests in the Pacific Northwest region of the U.S. and tropical rain forests in the Amazon River Basin. Stakeholder involvement in the planning, management, and policy analysis can help to resolve conflicts, increase public commitment and reduce distrust between governmental agencies and stakeholders (Tanz and Howard, 1991).

As the complexity of decisions increases, it becomes more difficult for decision-makers to identify a management alternative that maximizes all decision criteria. Planning requires a multi-objective approach and analytical methods that examine tradeoffs, consider multiple political, economic, environmental, and social dimensions, reduce conflicts, in an optimizing framework.

Multi-criteria decision making (MCDM) is an approach for solving forest resource management problems over the last three decades. Quantifying the value of ecosystem services in a non-monetary manner is a key element in MCDM (Martinez-Alier et al., 1999; Carbone et al., 2000; Munda, 2000). MCDM models improve the information basis of strategic planning, communication, and understanding in natural resource management. MCDM can be used in interactive decision making and a decision support system for policy makers. This paper reviews empirical applications of MCDM in forest management, and policy analysis to assist readers in understanding the assumptions, strengths, and limitations of alternative approaches.

The specific objectives of this paper are to

(a) review selected MCDM models and their empirical applications in forestry,
(b) examine the potential of MCDM in decision making in forestry, and
(c) identify the problems in wider use of MCDM techniques in forestry.

Several authors have reviewed MCDM techniques previously. Herath (1982) and Hayashi (2000) reviewed MCDM applications in agricultural resource management. Romero and Rehman (1987)

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doi:10.1016/j.ecolecon.2009.05.010

reviewed the applications of MCDM in natural resource management. Smith and Theberge (1987) reviewed the basic theory of measurement and its application in assessing multiple criteria. Stewart (1992) made a theoretical review by identifying pitfalls in using various MCDM approaches. Dyer et al. (1992) presented an account of the historical development of MCDM techniques and evaluating criteria used in the modelling of agricultural systems.

More recently, Kangas at al. (2001), Pukkala (2002) and Kangas and Kangas (2005) reviewed MCDM methods in forest management planning. These reviews show that interactive use of the methods greatly improves the efficiency of the planning process and that it is better to use more than just one MCDM method or a hybrid approach. The review also indicates that there is now a greater interest on MCDM not only of the researcher but also decision-makers and planners outside the scientific community. Sheppard (2005) reviewed MCDM methods in sustainable forest management but this review was limited only to Canadian studies.

The above reviews are weak in terms of empirical information, including comparison of different criteria and weighting methods used and applicability to group decision making problems (Howard, 1991; Smith and Theberge, 1987). All available MCDM reviews, except the review by Hayashi (2000), Pukkala (2002), Kangas and Kangas (2005) and Sheppard (2005) were carried out nearly a decade ago. Only the reviews by Howard (1991), Romero and Rehman (1987), Pukkala (2002), Kangas and Kangas (2005) and Sheppard (2005) examined the MCDM techniques with reference to forestry. Hence there is a gap in the literature on applications of MCDM in forestry in recent years, specifically focusing on empirical challenges and the pros and cons of alternative MCDM techniques.

This review has applications rather than theoretical orientation, and integrates many techniques in a simplified framework. Unlike previous reviews, this review is based on an exhaustive survey of a larger number of journal articles and text books published on MCDM applications in forest management. The review includes both developed and developing countries and covers a longer period, from 1975 to 2008. It focuses on the decision context, problem formulation, and implementation and covers novel features used recently such as the use of visualization techniques for forest landscapes, hybrid methods and new ways to elicit responses under incomplete information which is particularly useful in forestry where full information is often difficult to obtain. The review provides valuable information for policy makers to choose the most appropriate methods for a given forest management problem.

This paper is organized as follows. Section 2 provides a brief introduction to the MCDM approach. The AHP and its variants are discussed in Section 3. In Section 4, the MAUT/MAVT approaches are discussed in detail. Section 5 examines the outranking methods, fuzzy methods and descriptive approaches. Section 6 provides concluding remarks.

## 2. The MCDM approaches

### 2.1. Theoretical foundations of MCDM

MCDM is a structured framework for analysing decision problems characterized by complex multiple objectives (Nijkamp et al., 1990; Zeleney, 1984). MCDM can also deal with long-term time horizons, uncertainties, risks and complex value issues. The MCDM process typically defines objectives, chooses the criteria to measure the objectives, specifies alternatives, transforms the criterion scales into commensurable units, assigns weights to the criteria that reflect their relative importance, selects and applies a mathematical algorithm for ranking alternatives, and chooses an alternative (Howard, 1991; Keeney, 1992; Hajkowicz and Prato, 1998; Massam, 1988).

MCDM methods are well suited to deal with forest management and planning problems. There has been a growth in research studies conducted using MCDM approaches in recent times (Keefer et al., 2004). MCDM has been used in environmental management (Bell, 1975; Bakus et al., 1982; Janssen, 1992), energy policy analysis (Haimes and Hall, 1974; Keeney, 1975; Keeney et al., 1995), farm management (Herath et al., 1982; Xu et al., 1995; Prato et al., 1996), food security (Haettenschwiler, 1994), forest management (Kangas and Kuusipalo, 1993; Kangas, 1994a; Penttinen, 1994; Ananda and Herath, 2003a,b, 2005, 2008), protection of natural areas (Gehlbach, 1975; Sargent and Brande, 1976; Smith and Theberge, 1986, 1987; Anselin et al., 1989), water management (Keeney et al., 1996), ecosystem management (Prato et al., 1996; Prato, 1999a), soil and water management (Prato and Hajkowicz, 2001) and wildlife management (Kangas et al., 1993; Prato et al., 1996), wetland management (Herath, 2004) and national parks management (Prato, 2006).

New techniques and developments of existing techniques, including fuzzy preferences, ways of dealing with interactions among criteria, use of interactive computer software, incorporating visualization have emerged during the last two decades (Fishburn, and Lavalle, 1999; Mendoza and Prabhu, 2005). Empirical MCDM techniques continue to be fine tuned and their application to forestry problems expanded. As applications expand, new insights are gained about how to improve MADM approaches.

### 2.2. Classification of MCDM techniques

Hajkowicz et al. (2000b) classify MCDM methods under two major groupings namely continuous and discrete methods, based on the nature of the alternatives to be evaluated (Janssen, 1992). Continuous methods aim to identify an optimal quantity, which can vary infinitely in a decision problem. Techniques such as linear programming, goal programming and aspiration-based models are considered continuous. Discrete MCDM methods can be defined as decision support techniques that have a finite number of alternatives, a set of objectives and criteria by which the alternatives are to be judged and a method of ranking alternatives, based on how well they satisfy the objectives and criteria (Hajkowicz et al., 2000a). Discrete methods can be further subdivided into weighting methods and ranking methods (Nijkamp et al., 1990). These categories can be further subdivided into qualitative, quantitative, and mixed methods. Qualitative methods use only ordinal performance measures. Mixed qualitative and quantitative methods apply different decision rules based on the type of data available. Quantitative methods require all data to be expressed in cardinal or ratio measurements (Hajkowicz et al., 2000a).

Value and utility-based approaches use mathematical functions to assist decision-makers to construct their preferences. Multi-attribute value theory (MAVT), multi-attribute utility theory (MAUT), and the Analytic Hierarchy Process (AHP) are the most common approaches within this school. The Analytic Hierarchy Process (AHP), developed by Saaty (1977, 1980), uses the same paradigm as MAVT. However, the AHP uses a different approach to estimate relative values of criteria (weights) and score alternatives over these criteria. The AHP is the source of several other variants, such as the geometric mean approach (Barzillai et al., 1987), REMBRANDT[1] (the multiplicative variant of AHP), and various modifications to incorporate risk and fuzzy concerns.

Many MCDM classifications also distinguish between risk and riskless (certainty) models. MAVT belongs to the quantitative riskless category and MAUT and ELECTRE (Elimination and (Et) Choice Translating Reality) belong to the quantitative risk category. The foundations of decision analysis under risk and uncertainty are provided in expected utility theory (Pollak, 1967; Keeney, 1968;

[1] Basic ideas of the REMBRANDT method are outlined in Lootsma (1993).