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Application of Multi-Criteria Methods in Natural Resource Management – A Focus on Forestry

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1. Introduction

Natural resource management refers to the management of natural resources such as land, water, soil, plants and animals which in accordance with the concept of sustainable development, a distinct emphasis puts on the way the management affects both present and future generations. In management and utilization of forests and forest land, as one of the most significant natural resources, the principle of the sustainable development is incorporated in a way that adheres to biological diversity, productivity, regeneration capacity, vitality and potential of the forests to fulfil, now and in the future, its important economical, ecological and social functions.

Forest resources and benefits that derive from them represent an important part in fulfilling the needs of humanity for energy, raw materials and quality of life. These benefits cover a broad range of goods and services. Among other, they include: wood, recreation, water, soil preservation, clean air, game, scenic beauty, etc. Many of such benefits and services can be simultaneously gained from a single forest stand. And even though many countries have legislative regulations that prescribe the course of forest management and/or protection of certain forest functions, there are still many debates on the issue how to manage forests and to which purposes. In general, we could say that today the basic postulate of forest management is multifunctional or multiple use of forests. It represents the manner in which the most of many different functions of forests are being utilized. In that sense, forest management should enable the most prudent usage of forests and forest land to provide some or all of respective products and services, while ensuring productivity and stability of forest ecosystems at the same time. In realizing these goals careful planning and decision making play a major role, and are considered to be especially significant for effective natural resource management and achieving the principles of sustainable development.

Planning and decision making in forest management represent a very complex task mainly because of the multitude and a broad spectre of criteria enrolled in the decision making process. That means that any decision making is under many different influences, and that at the same time every decision made affects many criteria of different nature. These influences and criteria encompass (Diaz-Balteiro & Romero 2008):

a. economical issues – wood production, non-wood forest products (forest trees fruits and flowers, seeds, mushrooms, honey, resin, humus) livestock, game management, hunting;
b. ecological and environmental issues – soil erosion, watershed regulation, biodiversity conservation, carbon sink, scenic beauty, influence on climate;

c. social issues – recreational activities, tourism, level of employment, rural development, population settlement etc.

Moreover, the complexity of a large proportion of forestry issues is increasing due to the way in which different interest and social groups and organizations perceive the relative importance of specific criteria and appraise the management of forests, and thus judge the "quality" of forest resources management. The importance of specific criteria and evaluation of forest management in that sense depend on the personal standpoints and opinions of each individual i.e. group. Examples of such subjective assessments are often related to scenic beauty or recreational value of a certain forest area, or for example to game management and hunting. So, while someone preffers a specific game species and specific type of hunting, someone may want different kind of game and hunting, and someone else may be absolutely against hunting at all. Similar evaluations of forest management are related to the logging and creating certain revenue on the one hand and the protection and conservation of forests on the other hand.

All of the above mentioned daily increases the complexity of forest management, hinders the performance of forest operations and hardens the management conditions making the planning and decision making in forestry very demanding. And while in the past decision making and management in forestry have frequently been performed on the basis of common sense and/or past experiences, today's forestry with multiple criteria and functions calls for more flexible decision support. The complexity of today's business environment in forestry, the imperative of continuous increase of business and ecological efficiency, and multiple stakeholders with different interests impose the necessity to use new models and more precise methods. In that kind of a situation the joint use of multi-criteria decision making methods and different techniques of group decision making are becoming an important and potentially desirable way for solving forestry issues. It is considered that multi-criteria decision models and methods can provide to modern forestry, which has multiple aims and tasks, and multitude of interest groups with often conflicting interests, a strong and flexible support to decision making. Development and application of such methods that haven't traditionally been used in forestry could provide to management a new tool which can be a valuable aid both on strategic and operational level of decision making. The emphasis in doing so, is on the fact that decision proposals and decisions made must be based on the rational arguments.

This paper provides an overview of certain multi-criteria methods which can be used as a support for planning and decision making in forestry. Several methods of multiple-criteria decision making have been described and compared. Brief description and comparison presented in the paper includes following multi-criteria methods: Data Envelopment Analysis (DEA), Analytic Hierarchy Process (AHP), Multi-Attribute Utility Theory (MAUT), outranking methods, voting methods and Stochastic Multicriteria Acceptability Analysis (SMAA). The paper also gives a brief overview and analysis of problems and forest areas where multicriteria methods have been applied so far. The intention was to explain for which types of tasks and problems these methods can be applied in the field of forestry. That provides an insight into characteristics of the respective methods and a guideline to eventual choice of which method to apply. Many of the articles cited in the paper provide information on the existing experiences, reflect the actual role and significance of multi-criteria decision making in forestry and represent a valuable reference source that can be beneficial to students, researchers, experts and practitioners in forestry. The main aim of the paper is to raise the forestry profession's awareness about the importance and potential role that multi-criteria decision making can play in forestry. Concrete examples of the carried out investigations provide an insight into the possibilities, suitability and justification of the application of multi-criteria methods.

2. About decision making

Decision making process involves the choice of a specific solution among the set of different alternatives that solve a given problem. In a decision problem, there are goals to be achieved by the decision, the criteria used to measure the achievement of these objectives, the weights of those criteria that reflect their importance, and alternative solutions to a problem. Under the objective we consider the state of the system we want to reach by a decision, the criteria are the attributes that describe the alternatives and their purpose is to directly or indirectly provide information about the extent to which each alternative achieves the desired goal. In a given decision situation, the criteria are usually not equally important, and their relative importance is derived from the preferences of decision maker what is related to his system of values and other psychological characteristics. Data and information about these elements are with the appropriate actions summarized in one number for each alternative, and on the basis of these values the ranking of alternatives is determined. Figure 1 shows the basic procedures and steps in the process of decision making and problem solving.

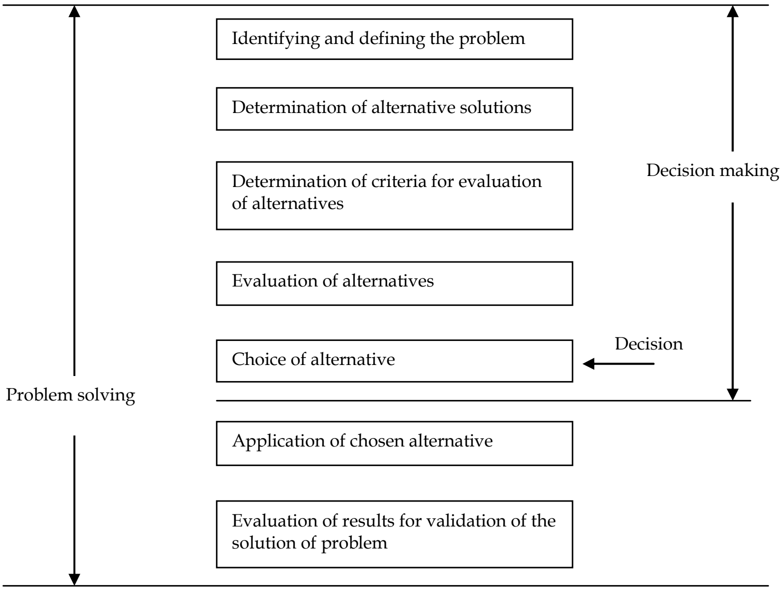

Fig. 1. Relationship between problem solving and decision making

Decision making is one of the major human activities, and one of the unavoidable tasks of managers. The decision situation is solved by adoption of a decision, which represents a selection of one action out of solutions available. The significance of decision making reflects in the fact that even if none of the possible solutions and actions have been chosen, the decision has been made - it has been decided not to choose or to do nothing.

3. Multi-criteria decision making approach

Multi-criteria decision making[1] falls within the wide range of operations research methods. As the name suggests, MCDM has been developed to enable analysis of multiple criteria situations and problems. It is usually applied in such cases where it is necessary to holistically consider and evaluate various decision alternatives, in which comprehensive analysis is particularly difficult due to a multiplicity of hardly comparable criteria and conflicting interests that influence the decision making process.

A number of MCDM methods have been developed, each of them with specific characteristics and different techniques that are applicable in appropriate circumstances and situations. For example, some methods are specially designed to manage risk and uncertainty, or for non-linear estimation, while others are focused on applications in conflict management tasks and objectives or on the use of incomplete or poor quality information. Many methods also come with a variety of settings and in different versions (eg, 'fuzzy' or stochastic versions, etc). Some are also slightly modified to better respond to tasks and problems in certain areas, including forestry. A detailed overview of operational research and multi-criteria decision making methods can be found in numerous sources (Vincke, 1992; Triantaphyllou, 2000; Koksalan & Zionts, 2001; Kahraman, 2008 etc).

The procedure of multi-criteria decision making involves the development of several alternatives that can no longer be improved by some criteria, while at the same time not ruined by the other criteria (Pareto optimality or efficiency). A comparison of selected alternatives is implemented considering all the previously set criteria and characteristics that influence the selection of a particular solution. As a result of a comprehensive comparison, the priority and rank of the observed alternatives is determined. In a group decision making individuals may, depending on their personal preferences, differently rank some alternatives. Comprehensive comparisons can also be made with assigning different weights to certain criteria, but also to opinions of individual participants. This includes the influence of different criteria and individual points of view which are taken into consideration together. In this way, MCDM methods can be used to analyze the situation of decision making and help in making the best possible or at least satisfactory decision.

Bearing in mind the above, it is considered that with the application of MCDM methods, many challenges in today's demanding and complex forest management planning can be facilitated and minimized. Many authors have written on that topic (Tarp & Helles, 1995; Krč, 1999, Kangas & Kangas, 2005; Herath & Prato, 2006 etc).

4. Main MCDM methods

This section gives a brief description of MCDM methods that can be applied in multifunctional forest management. Selected approaches represent different theories and schools as part of operational research. All presented methods have been tested and applied in forestry, and although many methods are not included in this paper, most of them are based on similar assumptions and theory as methods presented. For a more detailed study of specific methods and their application in forestry, relevant sources are given.

[1] Multiple Criteria Decision Making (MCDM) ili MCD Support (MCDS) ili MCD Aid (MCDA)

4.1 Data Envelopment Analysis (DEA)

In recent years DEA has become one of the central techniques in the analysis of productivity and efficiency. It was used in comparing organizations (Sheldon, 2003), companies (Galanopoulos et al., 2006), regions and countries (Vennesland, 2005). In determining business efficiency it was applied in banking (Davosir, 2006), education (Glass et al., 1999), agriculture (Bahovec & Neralić, 2001), wood industry (Balteiro-Diaz et al., 2006), forestry (Lebel, 1996; Kao, 1998; Bogetoft et al. 2003; Šporčić at al., 2008, 2009). DEA bibliography records more than 3200 papers published to 2001 (Tavares, 2002).

DEA is a methodology for determining the relative efficiency of production or non-production units (Decision Making Units, DMU) that have the same inputs and outputs, and vary according to the level of resources available and the activity levels within the transformation process. Based on the information about the actual inputs and outputs of all observed DMUs DEA constructs an empirical efficiency frontier and calculates the relative efficiency of each unit. The most successful units are those that determine the efficiency frontier, and the degree of inefficiency of other units is measured based on the distance of their input-output ratio in relation to the efficiency frontier.

While typical statistical methods are characterized as the central tendency approaches, which make their estimations based on the average production unit, DEA is based on extreme values and compares every DMU only with the best units. The basic assumption is that if some unit can produce Y outputs with X inputs, the other units should be able to do the same if they work efficiently. The center of the analysis lies in finding the 'best' virtual unit for every real unit. If the virtual unit is better than the original one, regardless if it achieves more outputs with the same inputs, or achieves the same outputs with less inputs, then the original unit is inefficient.

DEA relative efficiency scores are interesting to forestry experts, managers and researchers because of three DEA properties:

- direct comparison of units with multiple inputs and outputs with no need to know the explicit form of relation between inputs and outputs which can also be expressed in different units of measure,
- characterization of each organizational unit with one relative efficiency score,
- improvements which model suggests to inefficient units are based on actual results of organizational units that operate efficiently.

4.2 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is widely used and very popular method in many areas, including management of natural resources. Mendoza & Sprouse (1989), Murray & Gadow (1991), Kangas (1992) are among authors who have applied AHP in forestry, and the number of applications is steadily raising (Pykalainen et al., 1999; Ananda & Herath, 2003; Wolfslehner et al., 2005; Šegotić et al., 2003, 2007).

AHP has several advantages from the standpoint of multi-criteria and group planning. With the use of AHP, objective information, expert knowledge and subjective preferences can be considered jointly and simultaneously. It can also take into consideration qualitative criteria, while other methods usually require quantitative values for the selection of the alternatives. Solving a complex decision problems using this method is based on their decomposition into components: goal, criteria (sub-criteria) and alternatives. These elements are then taken into a multi-level model (hierarchical structure) where the goal is on the top, and the main

criteria represent the first lower level. The criteria can be broken down into sub-criteria, and on the lowest level of hierarhical structure, there are alternatives. Another important component of the method is a mathematical model which calculates the priorities (weights) of the elements on the same level of hierarchical structure. The method is based on comparisons of pairs of alternatives, each one with the other, while expressing the intensity and weight preferences of one alternative over another. The criteria are compared in the same way, whereby preferences are expressed by using Saaty's scale (Saaty 1977, 1980).
Negative aspect of the method is that it does not allow any reluctance and hesitation in the comparisons. In the management of natural resources, much of the information and data underpinning the planning and decision making is characterized by a certain level of insecurity and uncertainty. Furthermore, the number of comparisons significantly increases with the number of alternatives and criteria, which can be expensive and demanding. To overcome these limitations different AHP models have been developed. A'WOT combines AHP and well-known SWOT analysis (Kurttila et al., 2000), Analytic Network Process (ANP) is an extention of AHP (Satya, 2001) etc. Such hybrid models also have the same basic idea of pair-wise comparisons as practical, pedagogical and intuitive approach. Popularity of the method is primarily based on the fact that it is very close to the way in which individual intuitively solves complex problems by dismantling them into simpler ones.

4.3 Multi-Attribute Utility Theory (MAUT)

MAUT is a structured decision-making procedure for making a selection among different alternatives in relation to fulfilling a selected criteria. It is based on the utility theory that systematically seeks to validate and quantify the user's choice, usually on a scale 0-1 (Keeney & Raiff, 1976). Based on MAUT methodology there have been developed methods such as HERO and SMART, which rank given alternatives directly by assigning them numerical values proportional to their importance (Venter et al. 1998; Kajanus et al., 2004).
Simple Multi-Attribute Rating Technique (SMART) was developed in the early 1970s within the multiattribute utility theory. SMART methodology has many similarities with the basic idea of AHP method, but the main difference is that SMART does not use the comparison in pairs. Instead, the ranking of alternatives is carried out directly. Direct ranking means that the criteria are directly assigned numerical values proportional to their importance. Accordingly, alternatives are assessed with respect to each decision criterion by simply giving them relative numerical values that reflect their priorities. Most often, after the selection of criteria, the main criterion is determined and given a value 100. All other criteria are assigned values between 0 and 100, depending on their importance to the main criterion. According to the same principle each alternative is assigned a certain value in relation to individual criteria. The best alternative is given the value 100, while all other alternatives have values between 0 and 100 depicting their rank. When the importance of certain criteria and priorities among alternatives have been identified, SMART uses the same computational procedures as AHP. Examples of using SMART in natural resource management include Venter et al. (1998), Kajanus et al. (2004), etc.

4.4 Outranking methods

Outranking methods represent European or French School of MCDM. Many different methods have been developed, and among them PROMETHEE and ELECTRE have been applied in forestry (Kangas et al., 2001). These methods compare the alternatives in pairs, on the basis of so-called pseudo-criteria. Pseudo-criteria are two threshold values, the indifference threshold and preference threshold, which describe the difference in the severity of preferences between two alternatives. If the difference is less than the indifference threshold, the alternatives are considered to be indifferent in regard to that criterion. If the difference exceeds the preference threshold, better alternative is considered to be better without a doubt. If the difference is larger than the indifference threshold, but less than the preference threshold, priority between alternatives is uncertain.

Calculations are carried out in different ways in PROMETHEE and ELECTRE, and both methods have several versions to suit different situations. The main advantage of these methods is that they do not require as complete preference data as AHP. Disadvantage is that these are fairly obscure methods that are quite difficult to understand and interpret.

4.5 Voting methods

Voting is a familiar way of expressing opinions and influencing important matters. Voting techniques can be applied in MCDM when determining the criteria. The criterion that gets the most votes is considered the most important. Another example might be a vote on the suitability of alternatives with respect to certain criteria. Voting can be conducted under the principle "one man, one vote" or by giving a voter a certain number of votes. In Approval Voting voter gives a vote to each option deemed acceptable. In so-called Borda Count each voter gives n votes for the best option, $n - 1$ votes for the next, and so on until one vote remains for the worst option. These methods are some examples of many voting techniques.

Voting techniques have been developed to handle situations with the low quality of data on preferences. Simplicity and comprehensiveness of the voting techniques are their main advantage, especially in group planning and decision making. By including more information, they increasingly resemble to SMART method. The general attitude is that voting methods should not be modified and further complicated for applications for which there already exist specific multi-criteria methods. The Multi-criteria Approval method is based on approval voting and has been applied in forestry (Laukkanen et al., 2002, Kangas & Kangas 2004). Shields et al. (1999) and Hiltunen et al. (2008) also applied voting methods.

4.6 Stochastic Multicriteria Acceptability Analysis (SMAA)

Similar to SMART, SMAA actually represents a set of methods. They were originally developed for discrete multi-criteria problems with uncertain or inaccurate criteria data, and where, for some reason, it was not possible to obtain data on weights and preferences from the decision makers. SMAA methods are based on determining the weight values that would make each alternative the preferred one, or that would give a certain rank to an alternative. Key indicators of SMAA include so-called acceptability indices, which describe the probability of placing an alternative in a certain rank. If the weight values of the criteria are not predetermined, the acceptability indices show the dominance of alternatives among all possible weighting combinations. The overall acceptability index can be calculated as a weighted average of the probable alternative ranks, with the most weight for the first place, then second and so on. This method is close to forest management where, due to a strong uncertainty in the planning, usually none of the alternatives under consideration can be safely declared as the best one.

The first applications of SMAA methods in forestry have been implemented in the context of ecosystem management planning (Kangas et al., 2003, Kangas & Kangas, 2004). Since SMAA includes many useful characteristics it is increasingly gaining interest in today's forestry and natural resources management (Kangas et al. 2006; Diaz-Balteiro & Romero, 2008).

4.7 Comparison of MCDM methods

Presented methods significantly differ one from another. Neither of reviewed methods is universal or the best, not even applicable in all cases. In fact, to a different situations and problems best suite different methods. Selection of appropriate method requires knowledge of various methods, their preferences, strengths and limitations as well as the characteristics and requirements of specific situation and problem in planning and decision making. Table 1 shows the comparison of presented and some additional MCDM methods.

MCDM method	Cost of implementation	Data reqiurement	Ease of sensitivity	Economic rigor	Management under-standing	Mathematical complexity	Parameter mixing-flexibility
DEA	M	M	L	M	L	H	M
AHP	M	M	L	L	M	L	H
Expert systems	H	H	L	H	M	H	H
Goal program	M	M	M	H	L	H	L
MAUT	H	H	M	M	M	M	H
Outranking	M	M	L	M	L	M	M
Simulation	H	H	H	H	H	H	M
Scoring models	L	L	L	L	H	L	H

H- high; M - medium; L - low

Table 1. MCDM methods' characteristics (Sarkis & Weinrach, 2001)

Table 1 shows that none of the methods does not dominate over the other methods. For example, when compared to other methods DEA is moderately demanding regarding costs of implementation and data collection. Sensitivity to changes in data is small, and the managerial understanding of the method is relatively low, mainly due to its mathematical complexity. The results are easy to interpret because it ranks compared units by their efficiency while flexibility allows including more parameters and factors in the analysis.

It is generally difficult to directly compare different methods. Each method has its advantages and disadvantages. The application often depends on the decision environment, where the availability of data, time and costs influence the selection of specific method. In any case, when applying in analysis researchers, experts and managers should be aware of their characteristics, both advantages and limitations.

5. Applications of MCDM in forestry

Although MCDM has been present in forestry for more than 30 years (Field, 1973), some newer approaches and techniques of multi-criteria and group decision making have become more significant in the early 1990s (e.g. Kangas, 1992). In that time period, a significant number of papers dealing with various problems of forestry have been published. This section will present some examples of conducted investigations and MCDM applications in certain forestry areas. Conditionally determined areas of forestry in which MCDM methods have been applied so far can be defined as follows (Diaz-Balteiro & Romero, 2008):

- Harvesting
- Extended harvesting
- Forest biodiversity
- Forest sustainability
- Forestation
- Regional planning
- Forestry industry
- Risk and uncertainty

Forest harvesting and it's planning is the first forestry area in which MCDM paradigm has been widely applied (Kao & Brodie, 1979; Hallefjord et al., 1986). Howard & Nelson (1993) used MAUT methods for solving a specific problem of forest harvesting. Diaz-Balteiro & Romero (1998) used AHP in planning of forest harvesting, while Heinonen & Pukkala (2004) in harvest scheduling issues used a version of HERO method.

Extended forest harvesting besides timber and logging, includes the problems of non-wood forest products. Thus, Arp & Lavigne (1982) in proposed multi-criteria model included timber, recreation, hunting and wildlife. Hyberg (1987) set a MAUT model with two attributes: production of wood and aesthetic values. Rauscher et al. (2000) with regard to more non-wood criteria, evaluated four management alternatives using AHP. Laukkanen et al. (2002, 2005) applied different voting techniques to several problems of forest exploitation in Finland. Kangas et al. (2005) used SMAA method with recreational and environmental criteria, and Pauwels et al. (2007) compared several silvicultural alternatives of Larix stands with the use of ELECTRE.

The field of forest biodiversity has been, from the position of MCDM, associated with the management of national parks, reserves, etc., where the selection of management activities leads to application of different MCDM methods. For example, Kangas (1994) applied AHP in the management of protected natural areas in Finland. Rothley (1999) used MCDM methods for designing optimal biodiversity network in Canada. Kurttila et al. (2006) used MAUT to find the optimal compensation for forest owners who orient their forest management towards biodiversity conservation.

Efforts to connect issues of forest sustainability with MCDM approach are relatively new. Its applications in this area are mainly related to the assessment of management quality based on the analysis and aggregating of different sustainability indicators in a single index as an overall measure of forest systems sustainability (Mendoza & Prabhu, 2003; Manessi & Farrell 2004). Kant & Lee (2004) used voting techniques and Borda method for the evaluation and ranking of forest management plans with regard to sustainability. In a similar problem Mendoza & Dalton (2005) used AHP, and Huth et al. (2005) PROMETHEE.

In the area of re/af/forestation the first MCDM paper was published by Walker (1985) who developed a methodology for reforestation planning, taking into account several species, silvicultural treatments, etc. More authors combined MAUT and AHP in their approach to this issue (Kangas, 1993; Nousiainen et al., 1998). Liu et al. (1998) used AHP to assess regional forestation projects in China. Giliams et al. (2005) compared AHP, ELECTRE and PROMETHEE in choosing the best afforestation alternative in Belgium.

In the field of regional planning MCDM methods are represented in papers which deal with planning and efficiency of forest management practice in certain national or regional area (Buongiorno & Svanquist, 1982; Faith et al., 1996; Liu et al., 1998). Kangas et al. (2001) analyzed a forest management case in eastern Finland by three multi-criteria techniques:

MAUT, ELECTRE and PROMETHEE. By applying DEA method Kao (1998) measured the efficiency of forest districts in Taiwan, Vennesland (2005) measured the efficiency of subsidies in supporting regional development in Norway and Hiltunen et al. (2008) used five voting methods in strategic forest planning in state forests of Finland.

Considering forestry industry, most papers are related to efficiency evaluation with the use of DEA methods. For example, Yin (1998) analyzed efficiency of 44 paper companies in United States, Nyrud & Bergseng (2002) measured the efficiency of 200 sawmills in Norway, Sowlati & Vahid (2006) evaluated efficiency of Canadian wood product industry, Diaz-Balteiro et al. (2006) analyzed efficiency and innovation activities in Spanish wood industry.

Risk and uncertainty are strongly present in forest management where incomplete data and insufficient information in planning and decision-making often do not allow more accurate assessments and plans. MAUT techniques are therefore most widely used MCDM approach to problem of risk and uncertainty (Pukkala, 1998; Lexer et al., 2000; Ananda & Herath, 2005). Leskinen et al. (2006) used AHP to evaluate the uncertainty associated with the preferences of forest owners in Finland, Kangas (2006) used SMAA for analyzing risks in an actual decision making process.

Cited papers are just some examples of the conducted investigations. The number of MCDM papers in forestry has evolved significantly in the last years. Some authors give a survey of multi-criteria applications in forestry and list more than 250 papers published in major English language journals in the last 30 years (figure 2).

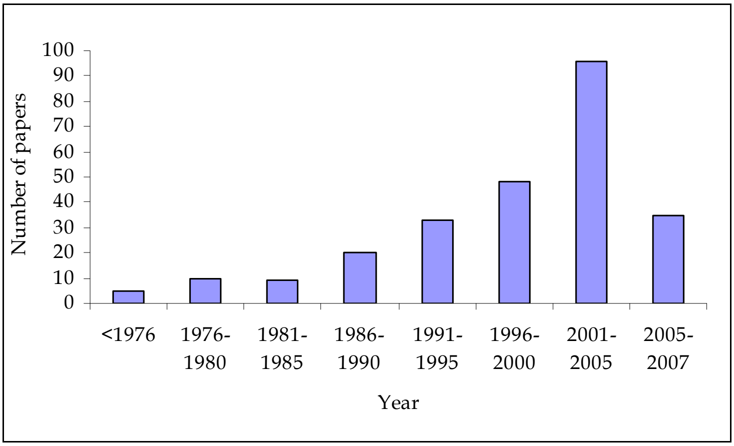

Fig. 2. Number of published multi-criteria papers in forestry (Diaz-Balteiro & Romero, 2008)

The literature also shows that MCDM methods have been applied to a wide range of forestry issues. The main forestry topics in which MCDM methods have been applied could be roughly categorized as already stated to: harvesting; extended harvesting; biodiversity; sustainability, etc. The classification itself cannot be precise because some papers can be divided into several areas or they use more than one method. Still, overview of published papers provides information on the investigated problems and applied MCDM methods in forestry. Figure 3 gives the number of multi-criteria papers in different forestry topics.

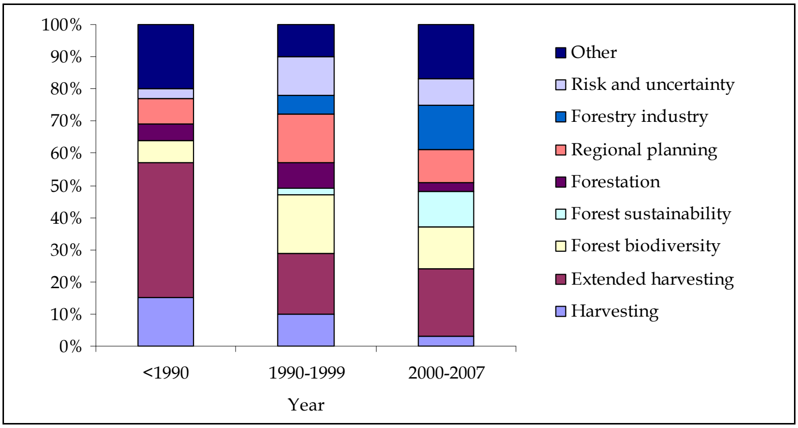

Fig. 3. Shares of MCDM papers in different forestry topics (Diaz-Balteiro & Romero, 2008)

6. Some examples of conducted investigations

This section gives more detailed overview of two investigations where MCDM approach was applied in forestry. Investigations were carried out within research projects and the needs of the state forestry company in the Republic of Croatia. One is related to biological parameters in the evaluation of natural resources (Posavec, 2005), and the other to efficiency of organizational units in forestry (Šporčić, 2007). The presented examples will point out the justification, and the applicability of multi-criteria methods in forestry.

6.1 Selection of biological parameters in the evaluation of natural resources

This research identified the values and value principles applied in evaluation of natural resources. The processed data are related to the Forest Management Unit "Gaj" of the Forest Administration Našice, Croatia. Using the potential method and the eigenvector method, the biological parameters that participate in the calculation of the total value of the natural forest resources were analysed. The adopted premise was that current methods have not been sufficiently exact, so that the new dynamic model should be used for the determination of the forest value. Conducted analysis and the development of new dynamic model included the application of AHP method.

The basic objective was to set up a scientific approach to evaluating a forest resources and establish a model applicable in practice. Parameters needed for forest value assessment, were evaluated by the experts (decision makers) from the field of forestry (Faculty of Forestry, University of Zagreb). Not all of the parameters in the evaluation had the equal weights. To the decision makers, a "verbal scale" for priority expression of one alternative related to another was available. In re-calculation of these verbal priorities into numerical ones, one of the twenty-seven most often used scales was used, as described in Saaty T.L. (1980). The following verbally expressed priorities were considered: Indifference; Moderate Priority; High Priority; Significant Priority; Absolute Priority, and their intermediate degrees, if a decision maker needed them in expressing priorities. Group decision as a potential method consisted of each group member defining their hierarchy, and a consensus at an alternative level (Čaklović et al., 2001). Thereby a group preference graph was made as

a "sum" of individual preference graphs, followed by a group potential. This makes sense particularly if the decision makers do not agree with the criterion choice. Another reason for using the model of group decision was the possibility of measuring the distances among decisions of group members. If group members have coinciding opinions on alternative ranking, there is no need to insist on adjusting the standpoints related to the criterion choice. The comparison by pairs was based on Analytical Hierarchy Process (AHP). The method is supplied by the programme Expert Choice that helps in decision-making on complex issues with several criteria and possible actions. It is designed to model our way of thinking and simplify the process of decision-making (Šegotić, 2001).
In order to be used in a dynamic model for determining the value of selected management unit, the calculated values have been classified in four basic management aims as presented in Figure 4: economic target, management, direct use and indirect use.

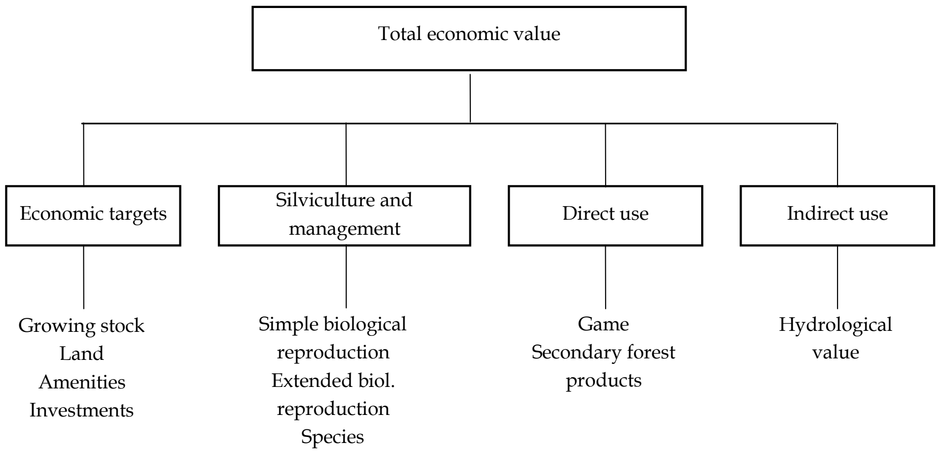

Fig. 4. Hypothetical criteria and parameters to be used in decision-making

Accordingly, forest value is the function of the economical, silvicultural/management, direct and indirect values expressed by the formula:

$$Vf = f\,(Ve + Vu + Vd + Vi)$$

Ve = economic value (Vgs + Vl + Va + Vi)
Vu = the value of silviculture and management (Vsbr + Vebr + Vspecies)
Vd = direct value (Vg + Vsfp)
Vi = indirect value (Vh + Vnwfp)
The presented aims and parameters of management represent parts of the common formula for determining the total value (Posavec, 2001). The total value of the management unit was presented through the total sum of the parameters and their weights (w):

$$Vt = (w1\ Vgs)+(w2\ Vl)+(w3Vsbr)+(w4\ Vebr)+(w5Vsfp)+(w6Vg)+(w7\ Vh)+(w8Va)+(w9Vi)+(w10\ Vnwff)+(w11\ Vspecies)$$

Vt = total forest value
Vgs =growing stock value

Vl = land value ($\sum_{i=1}^{i=n} V_z$)
Va = amenities value (reduced by amortisation)
Vi = investments value
Vsbr = value of simple biological reproduction
Vebr = value of extended biological reproduction
Vg = value of hunting management
Vsfp = value of secondary forest products ($\sum_{i=1}^{i=n} V_{sp}$)
Vh = hydrological value
Vnwff = value of non-wood forest functions
Vspecies= value of managed dominant forest species

In table 2, the results are the ranks of all parameters that contribute to forest value and were obtained by potential method. Variable X is the potential value of each parameter. The angle of 18.60 degrees is the measure of inconsistency within the allowed limits. One significant detail is that angle as a measure of group inconsistency does not have any impacts, although the programme displays it. It is significant to measure mutual distances between group members in terms of differences in individual preferences. The obtained distances make up the distance matrix as the basis for the clustering of the group. The sums of total weights form value 1, while individual parameters are presented by their size, which means that the highest priority in this case is the one of non-commercial forest functions.

- Group ranking -
Forest value

Members

Person 1	Person 2	Person 3	Person 4	Person 5	Person 6	Person 7
0.143	0.143	0.143	0.143	0.143	0.143	0.143

showWeights: groupAim base = 2 Options = weight

Level 2: alternatives
Comp_1

Weight = 1.000 InvInc = 0.337 (Angle = 18.60 deg)

Nodes:

nwff	0.121	(X= 0.453)
species	0.119	(X= 0.434)
vsbr	0.106	(X= 0.265)
vgs	0.103	(X= 0.230)
game	0.096	(X= 0.117)
vebr	0.090	(X= 0.022)
vsfp	0.088	(X= -0.008)
vl	0.085	(X= -0.059)
hv	0.082	(X= -0.101)
va	0.059	(X= -0.582)
vi	0.052	(X= -0.770)

Total weight = 1.000

Table 2. Group ranking of parameters by potential method

The AHP model in this case had a very simple structure (according to Figure 4). All parameters were alternatives, and were used for calculating total forest value. Supported by the eigenvector method, an attempt was made to obtain their weights. The basis for calculating the weights were estimates of the experts who carried out the comparisons per pairs of all given parameters. Supported by the programme Expert Choice, five rank lists with parameter weights for calculating forest value were made. An example of one expert's results is shown in Figure 5.

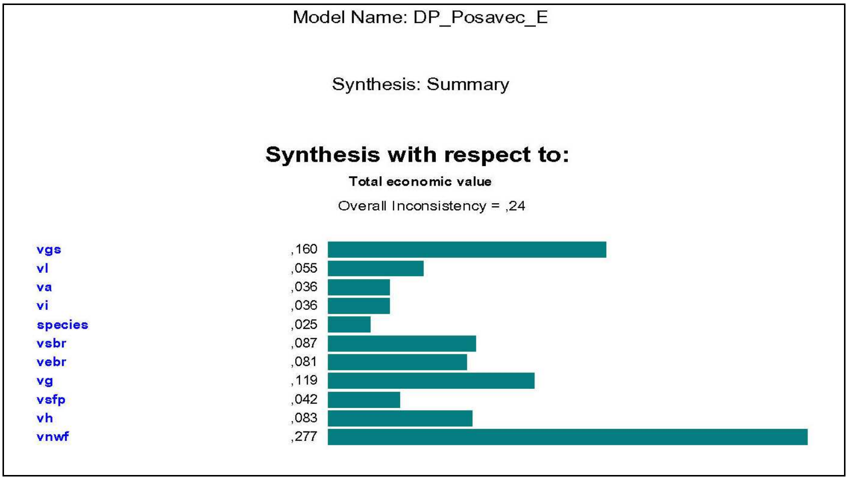

Fig. 5. Parameter rank list of the expert Posavec

If there are additional requirements for individual ranks (i.e. the feeling for forest value), a single rank can be adjusted to given reasons. A special programme can also calculate total forest value independently. In using the potential method, a constant exponential base is set (base value = 2). By changing this base, only relations between ranks can be changed, not their order. The total value of the management unit as calculated by the potential method amounted to 512,301,542.17 kunas (1 eur = 7.4 kunas). The total value calculated by the eigenvector method was 779,716,802.70 kunas. The difference between these two methods, depending on the estimate and parameter ranking, gave a value of 267,415,260.53 kunas. This result shows that a small difference in the size of the ranked parameter results in a great difference in final data. This relates particularly to calculations of the highly estimated non-wood forest values, which have the strongest impact on the final result.

The selected methods are based on pair comparison. Such comparison results in the development of a preference graph, while the number of comparisons per pairs grows in dependence of the given model. The advantage of the analysed dynamic model is obvious due to a decrease in input data. Another advantage of the analysed models is the possibility of clustering of particular groups, i.e. the measurements of the distances between the individual members and their preferences. The disadvantage of these methods is seen in subjective decisions made by individual experts (Posavec et al., 2006).

The developed dynamic models consider the characteristics of forest potentials, and follow the dynamics of the developing conditions within a forest stand, supporting the models of sustainable forest management. The method supports modern evaluation trends in forestry, using available computer program and multi-criteria methods in developing dynamic models for evaluation of forest resources' value.

6.2 Measuring efficiency of organizational units in forestry by nonparametric model

This research assesses the efficiency of basic organizational units in the Croatian forestry, forest offices, by applying Data Envelopment Analysis (DEA). Determination of efficiency is becoming increasingly important in many areas of human activity. Approach to this problem is particularly interesting when there are no clear success parameters, and when the efficiency of using several different resources/inputs is measured for achieving several different outputs. In forestry, the determination of efficiency of forestry companies is extremely complex because of multiple goals of forest management, i.e. its multiple inputs and outputs. In such conditions, the right evaluation method must be used in order to determine whether the resources are used efficiently.

The research included 48 forest offices. The selected forest offices were the representatives of four main regions in Croatian forestry: lowland flood-prone forests (I), hilly forests of the central part (II), mountainous forests (III) and karst/Mediterranean forests (IV). Each region was represented by two forest administrations i.e. by six forest offices from each forest administration (figure 6).

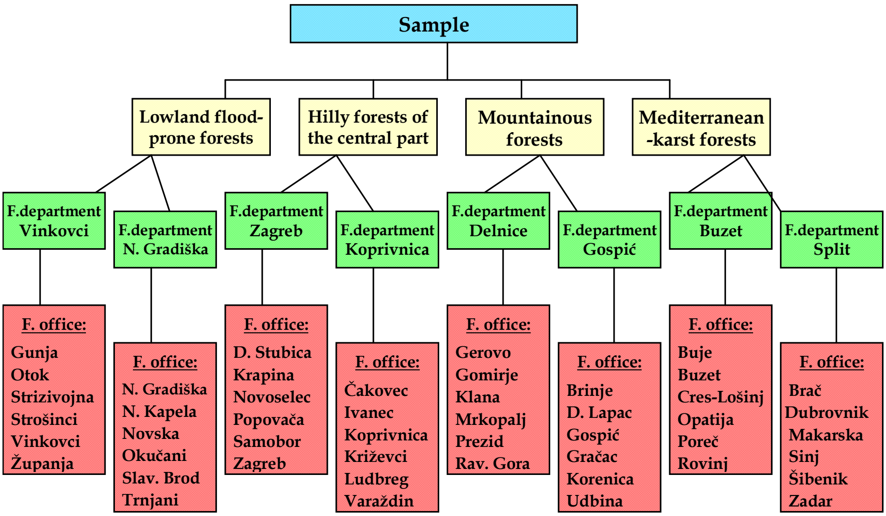

Fig. 6. Sample of the forestry organizational units involved in the research

The relative efficiency of compared forest offices was calculated with the most frequently used DEA models - CCR (Charnes-Cooper-Rhodes) and BCC (Banker-Charnes-Cooper) model. Since DEA was introduced by Charner, Cooper and Rhodes (Charnes et al., 1978) several analytical models have been developed depending on the assumptions underlying the approach. For instance, the orientation of the analysis toward inputs or outputs, the existence of constant or variable (increasing or decreasing) returns to scale and the possibility of controlling inputs. According to Farrell (1957), technical efficiency represents the ability of a decision making unit (DMU) to produce maximum output given a set of inputs and technology (output oriented) or, alternatively, to achieve maximum feasible reductions in input quantities while maintaining its current levels of outputs (input oriented). In this study, output oriented DEA was used, given it is more reasonable to argue that forest area, growing stock and other inputs should not be decreased. Instead, the goal should be increased outputs of forest management, and improved general state of forests. For computing the applied models, DEA Excel Solver software was used.

Given the selected orientation and the diversity of units characterizing the example, CCR model with constant returns to scale was applied first. Following Cooper et al. (2003), analysis began by the commonly used measure of efficiency (output/input ratio) and an attempt to find out the correponding weights by using linear programming. To determine the efficiency of *n* units (forest offices) *n* linear programming problems must be solved to obtain the value of weights (v_i) associated with inputs (x_i), as well as the value of weights (u_r) associated with the outputs (y_r). Assuming *m* inputs and *s* outputs and transforming the fractional programming model into a linear programming model, the CCR model can be formulated as (Cooper et al., 2003):

$$\text{Max} \qquad \theta = u_1 y_{10} + \ldots + u_s y_{s0}$$

$$\text{Subject to:} \qquad v_1 x_{10} + \ldots + v_m x_{m0} = 1$$

$$u_1 y_{1j} + \ldots + u_s y_{sj} - v_1 x_{1j} - \ldots - v_m x_{mj} \le 0 \quad (j = 1, 2, \ldots, n)$$

$$v_1, v_2, \ldots, v_m \ge 0$$

$$u_1, u_2, \ldots, \mu_s \ge 0 \tag{1}$$

Due to lack of information concerning the form of the efficiency frontier, an extension of CCR model, BCC model was also used. This model incorporates the property of variable returns to scale. The basic formulation of the model is as follows:

$$\text{Max} \qquad \theta = u_1 y_{10} + \ldots + u_s y_{s0} - u_0$$

$$\text{Subject to:} \qquad v_1 x_{10} + \ldots + v_m x_{m0} = 1$$

$$\mathrm{u}_1 \mathrm{y}_{1j} + \ldots + \mathrm{u}_s \mathrm{y}_{sj} - \mathrm{v}_1 \mathrm{x}_{1j} - \ldots - \mathrm{v}_m \mathrm{x}_{mj} - \mathrm{u}_0 \le 0 \quad (\mathrm{j} = 1, 2, \ldots, \mathrm{n})$$

$$\mathrm{v}_1, \mathrm{v}_2, \ldots, \mathrm{v}_m \ge 0$$

$$\mathrm{u}_1, \mu_2, \ldots, \mathrm{u}_s \ge 0 \tag{2}$$

Where u_0 is the variable allowing identification of the nature of the returns to scale. This model does not predetermine if the value of this variable is positive (increasing returns) or is negative (decreasing returns). The formulation of the output oriented models can be derived directly from models described in (1) and (2) (Cooper et al., 2003).

The identification of inputs and outputs is, besides the choice of the basic model, considered to be the only element of subjectivity in DEA. They were selected so as to reflect business activities of the investigated DMUs – forest offices as the basic organisational units of the Croatian forestry, which perform the basic professional and technical operations in forest management and where the most income and direct costs incur.

As inputs the model included:
- Land, I1 – forest area in thousand hectares
- Growing stock, I2 – volume of forest stock in cubic meters per hectare
- Expenditures, I3 – money spent in hundred-thousand croatian kunas (7,4 kn ≈ 1 EUR)
- Labour, I4 – number of employees in persons

As outputs the model included:
- Revenues, O1 - yearly income in hundred-thousand croatian kunas (7,4 kn ≈ 1 EUR)
- Timber production, O2 – timber harvested in cubic meters per hectare
- Investments in infrastructure, O3 – forest roads built in kilometres
- Biological renewal of forests, O4 – area of conducted silvicultural and protection works in hectares

Table 3 presents the descriptive statistics of the variables used in the analysis. A wide variation in both inputs and outputs is noticeable. Such variation is not unexpected, since the sample involves all representative areas managed by Croatian forests Ltd. However, it may also be a sign of bad management of resources in individual forest offices.

Variable	Mean	St. deviation	Min	Max	Total
Inputs					
Area, 10^3 ha	11.42	10.36	2.60	49.87	547.96
G. stock, m^3/ha	214.98	91.94	51.85	418.00	-
Costs, 10^5 kn	152.35	93.61	23.24	470.31	7312.99
Employees, N	42	21	8	100	2.007
Outputs					
Income, 10^5 kn	157.20	106.40	21.12	538.41	7545.68
Harvest, m^3/ha	3.06	2.19	0.00	8.78	-
Investments, km	2.24	4.29	0.00	22.59	107.48
B. renewal, ha	422.26	606.34	30.21	3846.34	20268.47

Table 3. Descriptive statistics of the variables used in the DEA model

Technical efficiency was determined individually for each forest office. The average CCR efficiency of the investigated forest offices was 0.829, which means that an average (assumed) forest office should only use 82.9% of the currently used quantity of inputs and produce the same quantity of the currently produced outputs, if it wishes to do business at the efficiency frontier. In other words, this average organisational unit, if it wishes to do business efficiently, should produce 20.6%[2] more output with the same input level. According to the BCC model, the average efficiency is 0.904. This means that an average forest office should only use 90.4% of the current input and produce the same quantity of output, if it wishes to be efficient. In other words, to be BCC efficient it should produce 10.6%[3] more outputs with the same inputs. Scale efficiency (ratio between CCR and BCC scores) shows how close or far the size of the observed unit is from its optimal size. The scale efficiency of 0.919 means that the analysed forest offices would increase their relative efficiency on average by 8% if they adapted their size or volume of activities to the optimal value. The main results obtained by the output-oriented DEA are given in table 4.

[2] It can be easily obtained that 20.6 % = (1 – 0.829)/0.829

[3] It can be easily obtained that 10.6 % = (1 – 0.904)/0.904

	CCR model	BCC model	Scale efficiency
Number of forest offices (DMUs)	48	48	48
Relatively efficient DMUs	15	24	16
Relatively efficient DMUs (in %)	31 %	50 %	33 %
Average relative efficiency, E	0.829	0.904	0.919
Maximum	1,000	1,000	1,000
Minimum	0.407	0.524	0.501
Standard deviation	1.170	0.129	0.138
DMUs with efficiency lower than E	23	18	12

Table 4. Results obtained with the base case DEA models

Based on the efficiency results of forest offices grouped according to their structural characteristics (surface area, growing stock, number of employees), it has been determined that the highest levels of efficiency were recorded for forest offices that manage 10 to 15.000 hectares, and for the forest offices with growing stock ranging between 200 and 300 m^3/ha i.e. over 300 m^3/ha. It has been also determined that the highest level of efficiency is achieved by forest offices with the highest number of employees, and that forest offices in the region of flood-prone forests have the highest efficiency scores.

DEA method gives to management the possibility to rank organizational units based on analysis and comparisons of their relative efficiency. For inefficient units the projections on the efficiency frontier and the sources of inefficiency are determined. In this way, potential changes in inputs/outputs required to achieve technical efficiency are determined, and the objectives which inefficient units should fulfil in order to become efficient are recognized.

7. Conclusion

In the last twenty years or so, the general framework of forest management has changed dramatically. Multiple goals are today typical for forestry. Forest management has to produce a certain revenues while at the same time it should promote protection and preservation of forests, recreational services, etc. In addition to harvesting and wood production, some other criteria are receiving increased attention in choosing the ways of forest management. In other words, forests are simultaneously used for multiple purposes. Multiple benefits and many advantages provided by forests as well as the non-market nature of a part of these products, make the planning and decision making in forestry especially demanding. This has led to a need for models that can be applied in multifunctional sustainable forest management. In particular, such support, through various methods and models is needed in planning and predicting, as well as in the analysis of forest management results.

Forest management involves the decision making related to the organisation, use and conservation of forests. Management decisions are made both for long-term planning and daily activities. Good forest management requires solution of the issues related to problems of energy, raw materials and life quality. Mathematical models are not new in forestry. The multiplicity of the available data on forests requires computer-aided mathematical methods. The problems of forest management involve a variety of different variables. They may be biological, such as growth and increment, type of soil; economic, such as the price of timber and labour costs; and social, such as ecological laws. All these variables and their interrelations make up a system. The complexity of forestry systems makes predicting of consequences of the decisions made a difficult task. This is where models come in use. Most models calculate the consequences of particular decisions. The models may be classified according to their properties. Thus, they may be deterministic, or stochastic; they may optimise one, or several goals and they use a particular algorithm. First models used linear programming. Many authors used dynamic programming as a method for making a series of optimal decisions (Amidon & Atkin, 1968; Brodie & Kao, 1979; Zadnik, 1990). Realising the necessity of stochastic methods in forest management, the Markov process was introduced into forestry (Hool, 1966). Multiple uses in forest management were first expressed through goal programming (Field, 1973; Mendoza, 1986). Goal programming uses the weights that are the reflections of the significances of each criterion. To join these weights is the greatest problem in goal programming, so that different authors suggested different methods (Bare & Mendoza, 1988; Gong, 1992; Howard & Nelson, 1993). Group decision is the most complex form of decision-making. It basically does not differ from the multi-criteria decision. The only difference is organisation of hierarchy and the sequence of taking the individual steps in the decision.

Planning and decision making in forestry is especially complex because of multiple objectives of forest management, and numerous wide ranging, often hardly comparable and conflicting criteria and interests that influence the decision making process. Multi-criteria methods can thereby facilitate the decision making process and reduce the risks and challenges in today's demanding and complex forest management planning. It is sure that MCDM and operations research can not resolve all issues and problems in forestry, but they can serve as a platform on which the results of different scientific fields can be used in a comprehensive decision-making process.

It should also be pointed out that managing any organization requires the ability to effectively assess and analyze information generated in the business process. For organizations, such as forestry companies, which manage natural resources and by business decisions affect the environment, that is from the viewpoint of ecological acceptability and environmental management even more critical. Development and application of methods that have not been traditionally used in natural resources management can provide a valuable assistance at the strategic, tactical and operational level of planning and decision making. Methods that have in this respect experienced a wide range of applications in recent years are for example AHP and DEA.

This paper, besides AHP and DEA also presents the other major MCDM methods: MAUT, ouranking methods, voting methods and SMAA. Paper gives the basic features of methods and a brief overview of forestry problems and areas where they have been applied so far. The aim was to provide information on existing experience, and thus contribute to making forestry profession aware of the significance and potential role that MCDM methods can play in forestry. Many cited articles can also be a valuable reference source for students, researchers, forestry experts and practitioners. The results show that in the last 30 years a significant number of forestry MCDM papers was published dealing with various forestry issues and problems such as harvesting, biodiversity, sustainability, regional planning, etc. Frequency of published papers shows that the number of such papers is increasing at a very high rate what indicates a trend of increased use of MCDM in forestry in recent years.

In this very dynamic period of natural resources management, when forestry experts face the challenges of professional and responsible management of forests and forest land, having to observe at the same time the protection requirements of their ecological, social and economic functions, as well as challenges of profitable management of forestry companies, managers need different models for converting natural, accounting, financial and many other variables and data into useful information. This paper points to the justification and possibilities of application of MCDM in multifunctional forest management, with the emphases on conservation of biodiversity, regeneration capacity and sustainable management. Paper also shows how multi-criteria methods can be used for analyzing the choice of the best or at least satisfactory decision, and thus contribute to more reliable planning and more objective decision making in forestry. It is generally considered that MCDM methods in forestry, as well as in other business systems, can be a very strong support to management and decision making.

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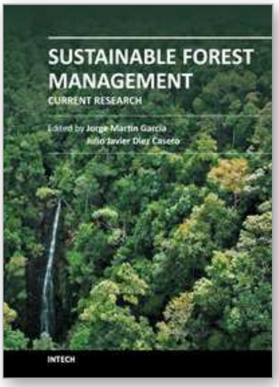

Sustainable Forest Management - Current Research

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Sustainable forest management (SFM) is not a new concept. However, its popularity has increased in the last few decades because of public concern about the dramatic decrease in forest resources. The implementation of SFM is generally achieved using criteria and indicators (C&I) and several countries have established their own sets of C&I. This book summarises some of the recent research carried out to test the current indicators, to search for new indicators and to develop new decision-making tools. The book collects original research studies on carbon and forest resources, forest health, biodiversity and productive, protective and socioeconomic functions. These studies should shed light on the current research carried out to provide forest managers with useful tools for choosing between different management strategies or improving indicators of SFM.