Lidija Zadnik Stirn

DYNAMIC, FUZZY AND AHP PROCEDURES IN A MULTI-CRITERIA DECISION PROCESS: AN APPLICATION TO ECOSYSTEM MANAGEMENT

Abstract

In this paper a multi-criteria, fuzzy and long term management problem in the frame of an ecosystem is introduced. As an aid to solve this problem, a hierarchical, discrete, dynamic and multi-criteria decision support model (DSM) is generated. In the DSM the process is defined in terms of time periods, states, decisions and weighted values of objective functions. For subjective and uncertain variables fuzzy methods are used. Further, SWOT analysis, analytic hierarchy process and analytic network process are employed to evaluate the conflicting objective functions by several decision makers. In the subsequent chapters, the problem is considered as a discrete, multi-objective, and dynamic problem which is presented in a form of a network. Finally, the optimal policy is determined by Bellman's iteration method for the solution of sequential decision processes. To illustrate the problem and the DSM developed some computational experiences are presented.

Keywords

Ecosystem management, multiple criteria problem, decision support model, discrete dynamic programming, fuzzy parameters, AHP, ANP, cumulative utility.

Introduction

Ecological crisis and social demands for the environment play an active role in many public discussions. These issues, along with the existing economic criteria, have become a key part of the modern concept of any ecosystem (for example, arable land, forest, recreational land, etc.) management. This concept includes the protection and use of the ecosystem. The state or the owner of an ecosystem should maintain and use it according to the principle of sustainability, while the society as a whole benefits from the amenity value of that ecosystem. Therefore, the ecosystem management problem consists of decisions on how to schedule the activities for an existing ecosystem over a long time horizon. These decisions include the management of the ecosystem while maximizing the expected profit for the landowner, and guaranteeing the present and future needs of the society as a whole, referring to ecological and social objectives, which is clearly shown by Venn diagram in Figure 1. Consequently, in ecosystem management, the decision-maker is challenged with a large-scale and complex decision problem which is long-term, dynamic, multi-objective and stochastic. Traditional approaches to this problem employ methods which are not based on newly developed multiple-criteria decision-making methods but rather on data processing and/or public survey results which rank choices by level or degree of importance [1, 8, 18, 19, 4, etc.].

Taking into account the multiple criteria ecosystem management problem, we have generated a discrete dynamic, multiple-criteria, fuzzy and hierarchical decision support model (DSM) which is intended as an aid for decision makers participating in ecosystem management process.

In the DSM, the process is defined in terms of time periods, states, decisions and weighted values of objective functions [3, 21, 22, 26]. Because the state, decisions and objectives of the system are also described with subjective and uncertain variables we use for these uncertainties and imprecision fuzzy methods [28]. Further, SWOT analysis, analytic hierarchy process and analytic network process are used to evaluate the conflicting objective functions by landowners, experts and the public [2, 13, 16, 25, 5, 27]. As soon as the assessment of decisions in accordance with different objectives is completed, we elicit the "total" evaluation of each decision, also assigned as "return", joint utility or reward [6], i.e., an acceptable trade-off between conflicting objective functions, using the composite utility values of a decision defined through analytic hierarchy process. The problem is then considered as a discrete, multi-objective, and dynamic problem which is presented in the form of a network. Finally, the optimal policy, the one that maximizes the utility over all time periods, is determined by Bellman's iteration method for the solution of sequential decision processes [3]. To illustrate the problem and the DSM developed we present some computational experiences from a case study in Slovenia [11, 24].

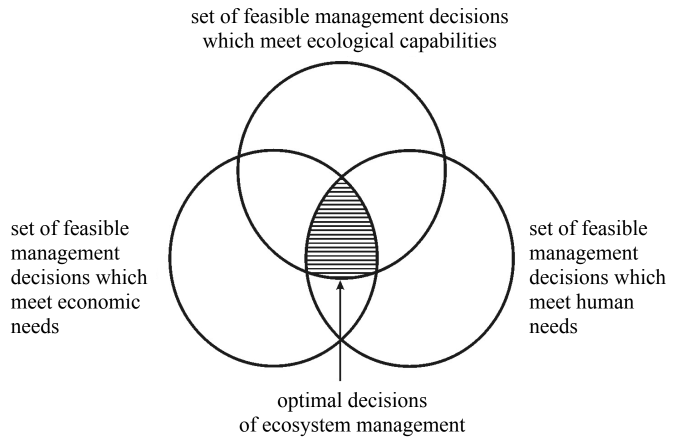

Figure 1. Venn diagram of optimal ecosystem management

1. A multiple-criteria decision support model (DSM) based on dynamic, fuzzy and AHP procedures – methodology

1.1. Discrete dynamic programming

Thus, in the problem presented, we are acquainted with a complex system which has to be led by a sequence of decisions from the existing state to the goal state, over several phases or periods according to multiple criteria. The common idea of generating the DSM is presented in Figure 2 which shows the period i with one decision.

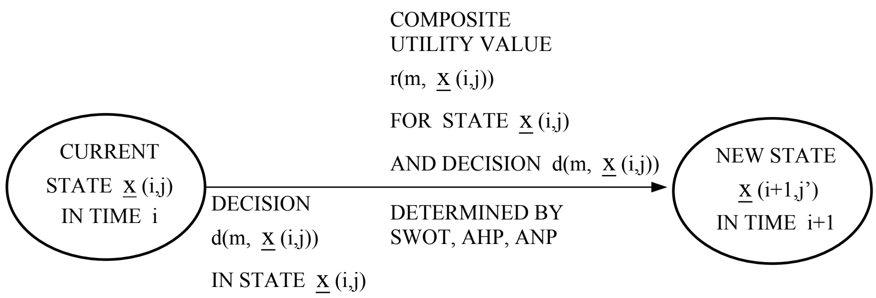

Figure 2. The time period i in the DSM

The planning horizon is divided into periods, defined by a finite and discrete time variable i (i=0,1,2,…, i, i+1, ..,I). Thus, the time variable i defines the time periods (1, 2, …, i, i+1, … ,I) in which the decisions are made.

Each time i is associated with a number of states. The state of a given system at each time i is described in terms of properties (components) of the elements which comprise the system. These are represented by variables (parameters) $s_1, s_2, ... s_s$, (for example: area, the level of conservation, the amount of products, labor force, machinery, financial resources, ecological conditions, recreational possibilities, number of visitors, etc.). Some parameters cannot be expressed precisely since we deal not only with parameters defined by numerical variables but also with subjective assessments and value judgments. Thus, fuzzy logic is used for descriptive (linguistic) parameters [28], i.e., a fuzzy set and its membership function are derived for each linguistic parameter. The limit values for each individual linguistic parameter are defined by means of certain rules – as "acceptable" values. In Figure 3, an example with a triangular membership function with limit values x_1, x_2 and x_3 is presented. The fuzzy and non-fuzzy parameters which define the possible state of the system at time i form a state vector $\underline{x}(i,j) = x(i, s_1, s_2, ... , s_s)\in X(i)$, where X(i) is the set of all possible state vectors at the time i. We suppose that there is a finite number of such vectors (j=1,2,…,J) at each time i. Thus, in practice, the set X(i) is a finite and discrete set of state vectors $\underline{x}(i,j)$. At this point, a considerable attention must also be paid to the determination of the goal state of the system $\underline{x}(I,j^*)=x^*(I, s_1^*, s_2^*, ... , s_s^*)$ which is designed to meet all the demands for optimal management of the system with which the owner, decision maker, experts, the public, etc. reach a compromise. In practice, the development of a goal state is a very important and difficult part of the decision process. The determination of the goal state requires an extremely high level of expertise, knowledge of environmental, economic and social issues, and above all a compromise among all parties involved in a decision process. It may even happen that for a particular system there does not exist any goal state which can fulfill the demands which, in general, are in conflict. In such a situation, the parties involved have to come to an agreement through a long set of negotiations to allow a goal state of the system to be defined. In such cases the Delphi method is often used to reach the agreement [14].

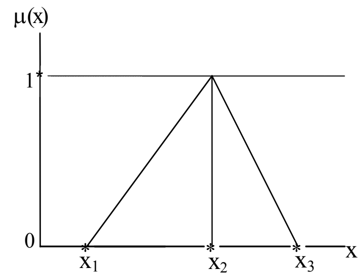

Figure 3. Triangular membership function for linguistic parameter with limit values x_1, x_2 and x_3

The decision maker can influence the existing state of the system, described by the state vector $\underline{x}(i,j) = x(i, s_1, s_2, \ldots, s_s) \in X(i)$, by invoking management decisions, expressed by decision variables $d(m,\underline{x}(i,j))$ (Figure 2). The decisions $d(m,\underline{x}(i,j))$ are determined on the basis of technical, financial, environmental and other possibilities [23]. The set of feasible decisions is further constrained by several environmental factors. Thus, at each time i, the state vector $\underline{x}(i,j)$ is associated with a finite discrete set of decisions $D(\underline{x}(i,j))$; $d(m,\underline{x}(i,j)) \in D(\underline{x}(i,j))$, m=1,2,...,M. The decisions are mutually exclusive for any given time i and its accompanying state $\underline{x}(i,j)$.

The decision variables are also called control variables, since the effect of the decision $d(m,\underline{x}(i,j))$ is to move the system from a time i and state $\underline{x}(i,j)$ to another state $\underline{x}(i+1,j')$ at the next time i+1 (Figure 2):

$$\underline{x}(i+1, j') = f(\underline{x}(i,j), d(m,\underline{x}(i,j))) \tag*{1)}$$

The transition function f is defined empirically [21].

1.2. Value of decision

To control the initial state vector over time periods towards the goal state, the objectives are used (Figure 2). They link state and decision variables. The objectives encapsulate several factors, represented by different attributes which cannot be easily identified, measured or quantified. Therefore, assessing the objectives according to the decision and the existing state is inherently a complex undertaking. Thus, SWOT analysis, fuzzy analytic hierarchy process (AHP) and analytic network process (ANP) are introduced to determine a composite utility value within a discrete dynamic programming process (Figure 2).

1.2.1. SWOT analysis

SWOT analysis means analysis of comparative strengths and weaknesses of a decision in relation to competitive decisions, and opportunities and threats which the decision under consideration may face. SWOT analysis is, as such, a systematic study and identification of those aspects of the decision that best suit, in our case, sustainability and maximum expected profit, referring to ecological objectives, and respecting the public's acceptance of the decision examined. SWOT should be based on logic and relational thinking so that the selected decision improves the decision's strengths and opportunities and at the same time reduces the weaknesses and threats [2].

Strength is a distinct superiority (competitive advantage) of technical knowledge, financial resources, skill of the people, the image of products and services, access to best network, of discipline and morale. Weakness is the incapability, limitation and deficiency in resources such as technical, financial, manpower, skills, image and distribution patterns of the decision under examination. It refers to constraints of and obstacles to the decision. Corporate weaknesses and strengths are a matter of how the decision can achieve the best results compared to other, similar competitive decisions. Weaknesses and strengths of the decision present internal forces and factors which have to be studied and assessed with the goal to evaluate and rank the decision under consideration. Opportunities and threats are the external factors of the decision examined. These factors are changing together with governmental, industrial, monetary and market policies, including the changes of legal and social environment. An environmental opportunity is an area in which a particular decision would enjoy a competitive advantage. A proper analysis of the environment, identification of new market, new and improved customer groups and new relationship could present an opportunity for the decision. A threat is an unfavorable environment for the decision. Increased bargaining power of users and suppliers, quick change of government policy, rules and regulations may pose a serious threat to the decision undertaken [27].

SWOT analysis is very important for decision making nowadays. Such an analysis can be undertaken effectively through brainstorming session with the participation of experts, owners and users of the environment, land, firm, etc. involved in the decision. SWOT analysis has many advantages. Within

SWOT, internal and external factors are analyzed and summarized in order to attain a systematic decision situation. There are also several shortcomings of using SWOT. SWOT results in the creation of a list of internal and external factors, and groups the factors in strength, weakness, opportunity and threat groups, but it is not able to identify or analytically determine the most significant factor or group in relation to the examined decision. In order to get a quantitative information, to yield analytically determined priorities for the factors and groups included in SWOT analysis and to make them commensurable, Pesonen et al. [13] suggested to integrate the analytic hierarchy process (AHP) with SWOT analysis.

1.2.2. AHP and ANP analysis

In problems dealing with multiple and conflictive objectives (goals, factors) of the decisions, and above all with objectives of different importance, Saaty's analytic hierarchy process (AHP) is employed to determine the best decision. AHP can incorporate mixed data that may include both qualitative and quantitative judgments, and is capable of analyzing multiple factors (www.decisionlens.com, 19 June 2008). AHP is based on a gradual mutual comparison of two objectives (pairwise comparison) at the same level. A scale from 1 to 9 is used for making the comparison, where, for example, 1 means that two objectives are of equal importance, 3 means that judgments slightly favour one objective over another, …, 9 means that favouring one objective over another is of the highest possible order of affirmation, 2, 4, 6 and 8 are intermediate values, while the reciprocals of these values tell that if objective k has one of reasonable assumptions of the above non-zero numbers assigned to it when compared with objective j, then j has the reciprocal value when compared with k. Comparisons between individual objectives are gathered in a pairwise comparison matrix A. Each objective k is associated with a weight w_k. The weight ratio of the objectives k and j is written as intensity of importance:

$$a_{kj} = \frac{w_k}{w_j} \tag{2}$$

The matrix $A = [a_{kj}]$, $(k = 1, 2, \ldots K, j = 1, 2, \ldots K)$ if there are K objectives. By entering the estimated values a_{kj} into the matrix we get the pairwise comparison matrix A. The matrix A is a square, positive and reciprocal matrix, its diagonal values equal 1 and symmetrical values are inverse. Since, in practice, we never encounter perfectly consistent estimations [16], we proved the consistency as described in Winston [20], using the consistency index. Further, the vector of weights $w = (w_1, w_2, \ldots, w_K)$ is calculated by squaring the matrix A several times to the satisfactory exponent, i.e., A, A^2, $(A^2)^2$, etc. Then the lines are summed up, and finally the values are normalized [20]. The vector of weights $w = (w_1, w_2, \ldots, w_K)$ is therefore scaled between 0 and 1, $\sum w_k = 1$, and calculated by the following equation:

$$w_k = \sum_{j=1}^{K} a_{kj} / \left(\sum_{k=1}^{K} \left(\sum_{j=1}^{K} a_{kj}\right)\right) \tag{3}$$

The procedure to be followed for the evaluation of the decision is presented in a hierarchical structure [25]. The hierarchy is organized around the concept of objectives (in our case SWOT groups: strengths, weaknesses, opportunities, threats), and attributes (in our case SWOT factors), within a two--level hierarchy (Figure 4). The first level is viewed as objective/group level. These groups are not directly measurable by themselves, but are presented by factors which are found at the second level. The factors define the cumulative effect of the SWOT group. Further, because the evaluation of a decision, as presented in Figure 4, involves the interaction and dependence among the levels of objectives and attributes, the analytic network process (ANP) is introduced into the model to solve the problem. ANP is the framework that allows to include all the factors and criteria, tangible and intangible, which have bearing on making a best decision. The key concept of the ANP is that influence does not necessarily have to flow only downwards, as is the case with the hierarchy in the AHP. Influence can flow between any two factors in the network. The ANP allows both interaction and feedback within clusters of elements (inner dependence) and between clusters (outer dependence). Such feedback best captures the complex effects of interplay, especially when risk and uncertainty are involved. The ANP, developed by Saaty [15], provides a way to input judgments and measurements to derive ratio scale priorities for the distribution of influence among the factors and groups of factors in the decision. Thus, the AHP is a special case of the ANP. ANP models have two parts: the first controls the interactions in the system under study; the second determines the degree of impact or influence between the criteria and attributes, i.e. the pairwise comparisons (www.decisionlens.com, 19 June 2008) which are then gathered in a so-called unweighted supermatrix. It must be stochasticized into columns. This is performed so that the blocks of the unweighted supermatrix are weighted using the corresponding priorities of the clusters. In this way we obtain a column stochastic matrix, called weighted supermatrix.

Then, the weighted supermatrix is raised to limit powers until the weights converge and remain stable (limit supermatrix).

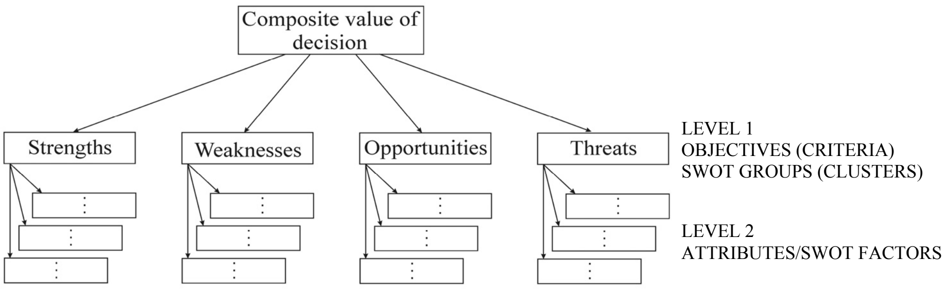

Figure 4. The hierarchy of objectives and attributes for composite value of the decision

In the numerical example of this study, the ANP process was simplified and it was used only on the objective level (Figure 4) for interdependencies among SWOT groups. The judgments for the weighted supermatrix were in this case obtained in the interview with the experts. Finally, the relative importance weights regarding the perception of independency and dependency in SWOT groups by decision makers, experts, general public, etc., i.e. all who participated in interviews, was expressed by synthesizing the AHP and ANP results in the sense of two levels (independent and dependent).

1.2.3. Cumulative effect – composite utility value of decision

Hence, the impact of factors on the group to which they belong must be aggregated. That is, the composite value of objective/group is measured based on a number of attributes/factors. The factors define suitable reference conditions for a group and therefore constitute the primary source of data or information for assessing the composite value of the decision because the latter reflects the cumulative effects of all SWOT groups (Figure 4). In this paper, a simple method of aggregation involving the linear combination of all factors and groups is used. This method was chosen because of its simplicity and transparency. The cumulative effect is in this method, namely, aggregated by simply adding the individual effects of all factors on the first level and groups on the second level. In the aggregation process, we also consider the fact that some factors, respectively some groups, must be viewed as relatively more significant as the others. Therefore, the aggregation of the effects of all factors, respectively groups, must also take into account their weights.

Some of the impacts of the factors on groups are only subjective judgments. Thus, they need to be defined in the interview with experts [26]. The impact values are normalized between 0 and 1 and reflect varying degrees of favourability to the group. In other words, the extent or impact of the factor on the SWOT group may be difficult or impossible to evaluate. It can only be judged in terms of the degree to which they lead to a favourable value of the group, in terms of the membership function f(x). Factors close to one imply being close to "favourable composite value of the group". In the paper, we use a linear function of a trapezoidal form (Figure 5), but some complex functions may also be used:

$$f(x) = \left\{ \begin{array}{ll} \frac{x}{a} & \text{for } 0 \le x \le a \\ 1 & \text{for } x \ge a \end{array} \right\} \quad \text{if factors represent strengths or opportunities} \qquad (4)$$

and

$$f(x) = \left\{ \begin{array}{ll} 1 & \text{for } 0 \le x \le b \\ \frac{1}{c-b}(-x+c) & \text{for } b \le x \le c \\ 0 & \text{for } x \ge c \end{array} \right\} \quad \text{if factors represent weaknesses or threats} \qquad (5)$$

where a, b, c are parameters representing limits or threshold values of the factors with regard to their favourability to the SWOT group, and x is the current value of the factor, i.e., the mean value obtained from surveys.

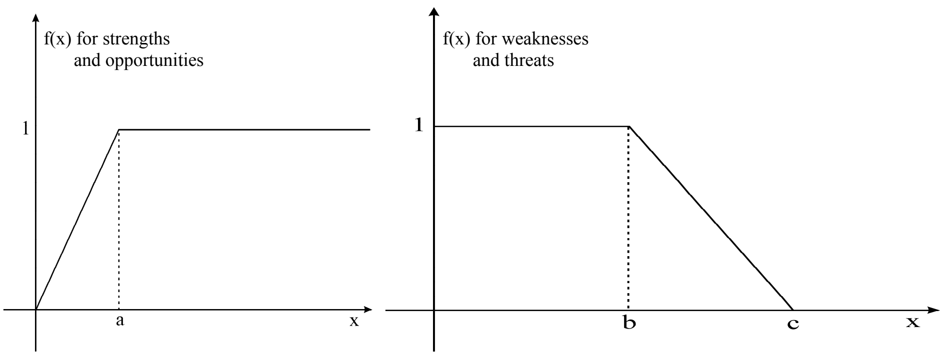

Figure 5. Impact (membership) functions f(x) of SWOT factors

In the next step, the analysis involves estimating the cumulative impacts of attributes (SWOT factors) that are calculated as a sum over all products of the impact function f(x) of the attribute (equation 4 and equation 5) and its relative importance (weight), obtained from AHP as w_k for the attribute k which has the value x:

$$c_n = \sum w_x f(x) \tag{6}$$

c_n provides the cumulative impacts of all factors on the favourability of objective n, i.e. the SWOT group n, to the composite value of the decision $d(m, \underline{x}(i,j))$. The values of c_n are also between 0 and 1. Its value close to 1 implies that the objective n is favourable to the composite value of the decision, while its low value implies that the objective contributes poorly to the composite value of the decision.

At the second level, the cumulative impacts of objectives, i.e. SWOT groups (strengths, weaknesses, opportunities, threats) for the decision $d(m, \underline{x}(i,j))$ are calculated by combining the values from both levels (Figure 4 and Figure 2):

$$CV = r(m, \underline{x}(i,j)) = \sum s_n c_n \tag{7}$$

where s_n are the weights of SWOT groups obtained by AHP and ANP.

1.2.4. Graph of the process and Bellman's principle of optimality

As soon as the decision-maker (analyst) determines the time periods for the described system, for each time period the possible states, for each state the possible decisions, the transition function expressed by (1), the objectives, assessed by CV (formula 7), he/she is able to show all these elements of DSM in form of a network [3, 20]. In the network (Figure 6), the states are designated by nodes (circles). The transitions from the state $\underline{x}$(i,j) in the time period i to the state $\underline{x}$(i+1,j') in the next time period under the decision d(m,$\underline{x}$(i,j)) are designated by the connection of two nodes, while the supposed goal state is presented as the final node. At the end of the connection of the nodes the composite value CV of belonging decision is noted. The optimal sequence of decisions for multi-objective problem subject to (1) with regard to the generated network is found recursively using the theory of discrete dynamic programming based on Bellman's principle of optimality, and Bellman's recursive equations [3].

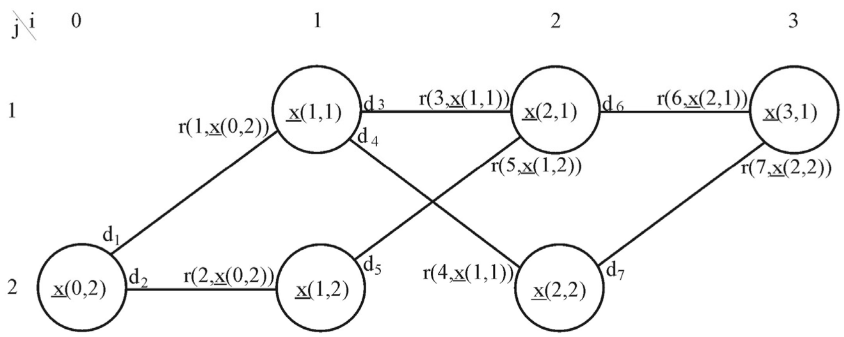

Figure 6. A network to demonstrate the multi-objective dynamic procedure

2. Numerical example for the presented problem and model

The presented DSM is illustrated with the management problem of a rural area which lies in the western part of Slovenia and covers a total area of 384 ha (forests, meadows, trails, recreational areas). This area is open to the general public. A trail was built to attract more visitors (young and adult) to this area in order to educate them about nature in many ways. The trail is also used for recreation (walking, running, …) and commercial uses (transportation of all kinds of material). Thus, the area is very important for the owners, experts, scientists, and the general public from the economic, ecological and social point of view. For the sake of simplicity, however, and with the aim to serve only for illustration, the management of the area is presented and treated here in a restricted way. We will consider here only three possible decisions (scenarios, alternatives):

– d_1, which increases the economic and recreational development of the area,
– d_2, which intends to increase the knowledge about nature and ecological awareness of the public,
– d_3, which emphasizes the preservation of nature [23, 24].

All three decisions pursue sustainable development of the area, maximum profit, ecological objectives and respect the public's acceptance of the management decision. The decisions are competitive and only one of them could be selected in one time period. Three time periods were observed (Figure 7). The present state of the area was determined according to the description of the area by Papež [11]. To evaluate the decisions according to the current state of the area SWOT/AHP/ANP were used.

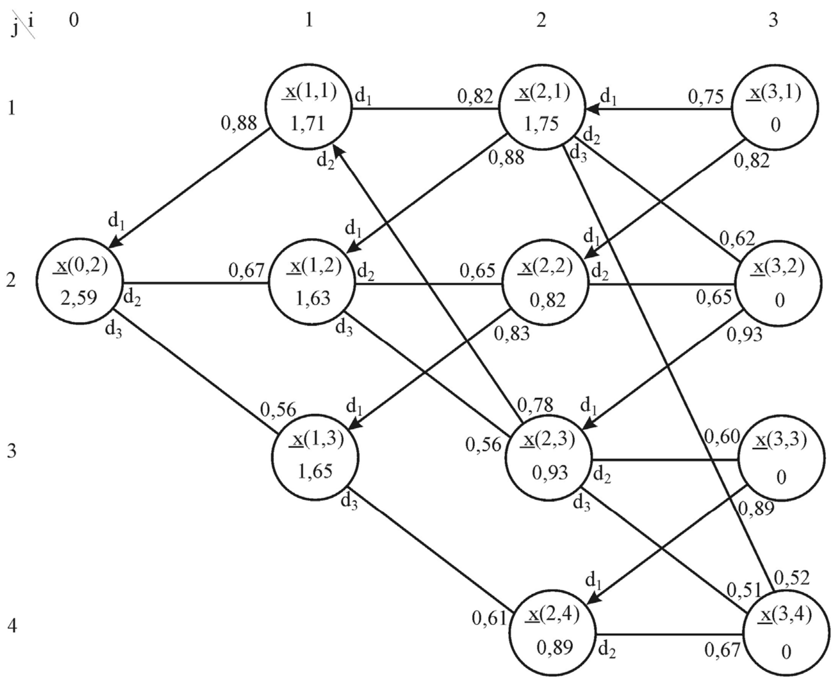

Figure 7. The network for 3 periods, states, decisions and values of decisions with the optimal sequence of decisions determined by Bellman's principle of optimality

For each of the three decisions regarding the state in which the decision should be undertaken the SWOT factors were generated. Because the factors should take into account the socio-economic, educational and environmental effects of the decision, as well as engineering feasibility and match the characteristics related to the location, physical size and level of operation, i.e. physical aspects, natural resources, land use, socio-economic, demographic, institutional, local and regional development conditions, a critical concern in the identification of all the actors involved in the decision under consideration was expressed. The actors were identified by a variety of means, such as educational degrees, professional memberships, peer recognition and even self-proclamation. Two types of actors were identified as potentially useful in generating the SWOT factors. The first type belongs to the representatives of a sub-population whose attitudes or actions influence the project under consideration. These types of participants are used, for example, in surveys and in the Delphi-like methods. The second type of participants has extensive special knowledge and experience about the research topic of concern. Discussion, conferences, brainstorming, the Delphi method, and similar methods were used. Here we summarize only the SWOT factors for d_1, undertaken in the state $\underline{x}(0, j$ (describes the current state of the area)) at the beginning of the first period (i=0). As presented in Figure 8, two SWOT factors were generated for SWOT group strengths (employees with knowledge in natural sciences, available financial resources), three factors for SWOT group weaknesses (lack of knowledge in advertising, lack of seasonal workers, low market prices of products from the area), three factors for SWOT group opportunities (location close to bigger cities – public interest for the area, governmental and institutional support, good cooperation with other areas) and finally two factors for SWOT group threats (increased competition in products and recreation, changes in financial policy). Similar factors were generated for the other two alternatives according to different area states.

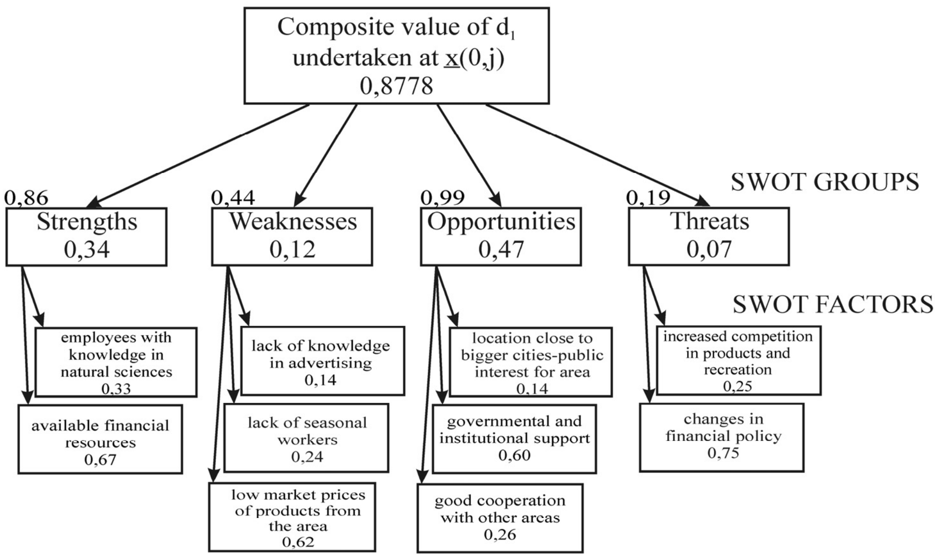

Figure 8. SWOT factors and groups for decision d_1 and their AHP priorities

Further, in order to assess this decision by the SWOT/AHP model the experts were asked to make their judgments by pairwise comparisons between four SWOT groups, and within SWOT groups, i.e., pairwise comparisons of two factors of strengths, pairwise comparisons of three factors of weaknesses, pairwise comparisons of three factors of opportunities, and pairwise comparisons of two factors of threats. The estimates from their pairwise comparisons are given in matrices, where group strengths are denoted by S, weaknesses by W, opportunities by O, threats by T, employees with knowledge in natural sciences by EK, available financial resources by AF, lack of knowledge in advertising by LK, lack of seasonal workers by LW, low market prices of products from the area by LM, location close to bigger cities – public interest for the area by PI, governmental and institutional support by GI, good cooperation with other areas by GC, increased competition in products and recreation by IC and changes in financial policy by CF. Here we show the data and results of the relative weights $w_{SWOT(AHP)}$ for four SWOT groups, and relative weights w_x for all SWOT factors, according to the AHP theory:

$$\begin{array}{c} \\ \mathrm{S} \\ \mathrm{W} \\ \mathrm{O} \\ \mathrm{T} \end{array} \begin{array}{c} \begin{array}{cccc} \mathrm{S} & \mathrm{W} & \mathrm{O} & \mathrm{T} \end{array} \\ \begin{bmatrix} 1 & 6 & 1/3 & 4 \\ 1/6 & 1 & 1/2 & 2 \\ 3 & 2 & 1 & 5 \\ 1/4 & 1/2 & 1/5 & 1 \end{bmatrix} \end{array} \rightarrow \cdots \rightarrow \begin{bmatrix} 0{,}34 \\ 0{,}12 \\ 0{,}47 \\ 0{,}07 \end{bmatrix} = w_{SWOT(AHP)} \qquad \begin{array}{c} \\ \mathrm{EK} \\ \mathrm{AF} \end{array} \begin{array}{c} \begin{array}{cc} \mathrm{EK} & \mathrm{AF} \end{array} \\ \begin{bmatrix} 1 & 1/2 \\ 2 & 1 \end{bmatrix} \end{array} \rightarrow \cdots \rightarrow \begin{bmatrix} 0{,}33 \\ 0{,}67 \end{bmatrix} = w_{xS}$$

$$\begin{array}{c} \\ \mathrm{LK} \\ \mathrm{LW} \\ \mathrm{LM} \end{array} \begin{array}{c} \begin{array}{ccc} LK & LW & LM \end{array} \\ \begin{bmatrix} 1 & 1/2 & 1/4 \\ 2 & 1 & 1/3 \\ 4 & 3 & 1 \end{bmatrix} \end{array} \rightarrow \cdots \rightarrow \begin{bmatrix} 0{,}14 \\ 0{,}24 \\ 0{,}62 \end{bmatrix} = w_{xW} \qquad \begin{array}{c} \\ \mathrm{PI} \\ \mathrm{GI} \\ \mathrm{GC} \end{array} \begin{array}{c} \begin{array}{ccc} PI & GI & GC \end{array} \\ \begin{bmatrix} 1 & 1/2 & 1/4 \\ 2 & 1 & 5 \\ C4 & 1/5 & 1 \end{bmatrix} \end{array} \rightarrow \cdots \rightarrow \begin{bmatrix} 0{,}14 \\ 0{,}60 \\ 0{,}26 \end{bmatrix} = w_{xO}$$

$$\begin{array}{c} \\ \mathrm{IC} \\ \mathrm{CF} \end{array} \begin{array}{c} \begin{array}{cc} \mathrm{IC} & C\mathrm{F} \end{array} \\ \begin{bmatrix} 1 & 1/3 \\ 3 & 1 \end{bmatrix} \end{array} \rightarrow \cdots \rightarrow \begin{bmatrix} 0{,}25 \\ 0{,}75 \end{bmatrix} = w_{xT}$$

The results of AHP are shown in Figure 8 within the group and factor boxes.

Next, we consider interdependencies among groups. When we think about SWOT groups, we cannot concentrate only on one group, but must consider the other groups with it. Therefore, we need to examine the impact of all the groups on each group by using pairwise comparisons. The relationship of interdependence among groups is shown in Figure 9. We obtain the weights through expert group interviews [24]. The interdependence matrix of groups is assigned as $w_{SWOT(ANP)}$, where, for example, we see that strength's degree of relative impact for weakness is 0.2, the weaknesses' degree of relative impact of threat is 0.1, and the opportunities' degree of relative impact for threat is 0.4.

$$\begin{array}{c c} & \begin{array}{cccc} S & W & O & T \end{array} \\ \begin{array}{c} S \\ W \\ O \\ T \end{array} & \begin{bmatrix} 1 & 0.2 & 0 & 0 \\ 0 & 0.5 & 0 & 0.1 \\ 0 & 0.3 & 1 & 0.4 \\ 0 & 0 & 0 & 0.5 \end{bmatrix} \end{array} = w_{SWOT(ANP)}$$

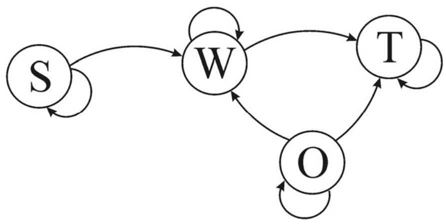

Figure 9. Interdependent relations among SWOT groups

The interdependence priorities of the criteria (SWOT groups) s_n are then obtained by combining the results from AHP and ANP, i.e., $w_{SWOT(AHP)}$ and $w_{SWOT(ANP)}$:

$$s_n = w_{SWOT(ANP)} \cdot w_{SWOT(AHP)} = \begin{bmatrix} 1 & 0.2 & 0 & 0 \\ 0 & 0.5 & 0 & 0.1 \\ 0 & 0.3 & 1 & 0.4 \\ 0 & 0 & 0 & 0.5 \end{bmatrix} \cdot \begin{bmatrix} 0.34 \\ 0.12 \\ 0.47 \\ 0.07 \end{bmatrix} = \begin{bmatrix} 0.364 \\ 0.067 \\ 0.534 \\ 0.035 \end{bmatrix}$$

Finally the overall priority of the decision d_1 is calculated. Questionnaires containing twenty questions about the importance of the internal and external factors of the area and response forms were distributed to fifty respondents (experts, investors, representatives of NGO's, residents and visitors). The five--point Likert scale was used, where in questions on strengths and opportunities 1 means that the question is of absolutely no importance to the respondent, while 5 means that the question is extremely important to the respondent, and vice versa for the questions on weaknesses and threats. The questionnaire, the answers, and the statistics of the answers are published in detail in Zadnik [24]. Table 1 summarizes the average scores of the factors (x values) according to the decision and SWOT groups, the values a, b and c, which represent the limit values of the factors with regard to their lowest and their highest observed values (given by the experts), f(x) for factors, calculated on the basis of formulas (4) and (5), and weights w_x. Given the data in Table 1 (f(x) and w_x), and using formula (6), the impacts of SWOT factors on the SWOT groups are calculated: $c_{1(S)} = 0.86$ for strengths, $c_{2(W)} = 0.44$ for weaknesses, $c_{3(O)} = 0.99$ for opportunities and $c_{4(T)} = 0.19$ for threats. These impacts can be found in Figure 8 above the SWOT groups. Further, using the weights s_n for SWOT groups and formula (7) the composite value CV = $r(d_1, \underline{x}(0,j))$ for the decision d_1 in state $\underline{x}(0,j)$ is calculated. It amounts to 0.8778 (Figure 8) ≈ 0.88.

The composite values for the other decisions which are under consideration in the corresponding state of the area were determined according to the same procedure and are given in Figure 7 which presents the dynamic problem during 3 periods, all possible states, decisions and values of decisions in the form of a network. Figure 7 also demonstrates the optimal sequence of decisions over all three periods according to Bellman's principle of optimality.

The optimal sequence is shown in bold in Figure 7, i.e., in the current state $\underline{x}(0,2)$ the decision d_1 has to be chosen and the state $\underline{x}(1,1)$ is reached. Then, with the optimal decision d_2 the state $\underline{x}(2,3)$ is reached. In the third period d_1 is suggested to be optimal. It transforms the area state $\underline{x}(2,3)$ to the final state $\underline{x}(3,2)$, which for this area is also the compromise goal state according to all demands of owners, experts and the public.

Table 1

Calculation of c_n for SWOT groups obtained from 50 respondents (equation (6))

	Factor values, limit values, function, weight / Factor	**X**	**A**	**b**	**c**	**f(x)**	**w_x**
S	Employees with knowledge in natural sciences	2.37	4	–	–	0.59	0.33
S	Available financial resources	4.08	4	–	–	1	0.67
W	Lack of knowledge in advertising	3.97	–	1	4	0.01	0.14

Table 1 contd.

	Factor values, limit values, function, weight / Factor	X	A	b	c	f(x)	w_x
W	Lack of seasonal workers	3.29	–	1	4	0.24	0.24
W	Low market prices of products from the area	2.13	–	1	4	0.62	0.62
O	Location close to bigger cities – public interest for the area	2.93	3	–	–	0.97	0.14
O	Governmental and institutional support	4.01	3	–	–	1	0.60
O	Good cooperation with other areas	3.25	3	–	–	1	0.26
T	Increased competition in products and recreation	3.50	–	0.5	3	0	0.25
T	Changes in financial policy	2.35	–	0.5	3	1	0.75

Concluding remarks

Theoretical as well as computational aspects of determining the optimal sequence of decisions/scenarios for the management of an existing system were introduced through a DSM. The problem is obviously of great complexity. The conclusion we can draw from the methodology and calculations presented is that the problem can be readily solved by means of SWOT analysis, analytic hierarchy process, analytic network process and interviews with experts.

The approach presented in this combination of methods is relatively new, as it encompasses the SWOT analysis, analytic hierarchy process, analytic network process, and analysis of the surveys.

The decision support models are, in general, concerned with how to choose from a set of decisions. Therefore, they usually fall short in framing the problem and setting the goals. In the DSM presented, this drawback is overcome by interaction with decision makers, experts, residents and visitors. The interviews conducted with economists, sociologists, politicians, environmentalists, community activists, NGOs, and other experts that emerge through a snowball sampling technique in the case study area, identified the objectives of the individuals or groups and provided input for the DSM generated. The results obtained by the use of the DSM proposed confirm the expectations of the decision makers (experts, residents, NGOs, etc.), as their preferences regarding the area are of economic and educational nature. Further, the optimal decisions derived from the application of the DSM are also consistent with the EU legislative framework. A substantial component of the legislation is devoted to public participation in decision making, particularly with regard to spatial planning and environmental matters. Further, it outlines the protection of air, soil, water, as well as the promotion of education. The results obtained in the application of the DSM developed confirm that the model presented is appropriate for practical use.

The paper shows a simplified computational example. In further research, it is planned to present an application of a more real-world character and extensive problem. In this context it could be argued that users might not be inclined to use sophisticated methods because of the complicated and extensive calculations. However, recent surveys indicate that the use of mathematical models is becoming more prevalent with the availability of commercial software packages such as Expert Choice, Decisionlens, Excel, etc., which also holds true for the DSM presented.

References

[1] Adams D., Alig R., McCarl B.A.: *Forest and Agricultural Sector Optimization Model* (*FASOM*). US Environmental Protection Agency, Washington, DC 1994.

[2] Bhattacharya S.C.: *Strategic Management: Concepts and Cases*. Wheeler Publisher, New Delhi 1998.

[3] Bellman R.: *Dynamic Programming.* Princeton University Press, Princeton-New York 1957.

[4] Buongiorno J., Gilless J.K.: *Forest Management and Economics*. MacMillan, New York 2004.

[5] Erdogmus S., Aras H., Kot E.: *Evaluation of Alternative Fuels for Residential Heating in Turkey Using Analytic Network Process* (*ANP*) *with Group Decision Making*. "Renewable and Sustainable Energy Reviews" 2006, 10-3, pp. 269-279.

[6] Gong P.: *Multiobjective Dynamic Programming for Forest Resource Management*. "Forest Ecology and Management" 1992, 48, pp. 43-54.

[7] Kouba J.: *Das Leben des Waldes und seine Lebensunsicherheit*. "Forstwissenschaftliches Centralblatt" 2002, 121, pp. 211-228.

[8] Kurth H.: *Forsteinrichtung – Nachhaltige Regelung des Waldes*. Deutscher Landwirtschaftsverlag, Springer, Berlin-Heidelberg 1994.

[9] Loehle C., MacCracken J.G., Runde D., Hicks L.: *Forest Management and Landscape Scales.* "Journal of Forestry" 2002, 100/6, pp. 25-33.

[10] Nute D.E., Rosenberg D., Nath S., Verma B., Rauscher H.M., Twery M.J., Grove M.: *Goals and Goal Orientation in Decision Support Systems for Ecosystem Management*. "Computers & Electronics in Agriculture" 2000, 27 (1-3), pp. 355-375.

[11] Papež J.: *Panovec. Občina Nova Gorica in Zavod za gozdove, Območna enota Tolmin.* "Nova Gorica" 2001, 199.

[12] Prabhu R., Colfer C.J.P., Dudley R.G.: *Guidelines for Developing Criteria and Indicators for Sustainable Forest Management*. Center for International Forestry Research, Jakarta, Indonesia 1999.

[13] Pesonen M., Ahola J., Kurttila M., Kajanus M., Kangas J.: *Applying A'WOT to Forest Industry Investment Strategies: a Case Study of a Finnish Company in North America*. In: *The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making.* D. Schmoldt et al. (eds). Kluwer, Boston 2001, pp. 187-198.

[14] Ronde P.: *Delphi Analysis of National Specificities in Selected Innovative Areas in Germany and France*. "Technological Forecasting & Social Change" 2003, 70, pp. 419-448.

[15] Saaty T.L.: *The Analytic Network Process: Decision Making with Dependence and Feedback*. RWS Publications, Pittsburgh, PA 2001.

[16] Saaty T.L.: *The Analytic Hierarchy and Network Processes for the Measurement of Intangible Criteria and for Decision-Making*. In: *Multicriteria Decision Analysis*. J. Figueira et al. (eds). Springer International Series in Operations Research and Management Science, New York 2005, pp. 345-406.

[17] Shields D.J., Martin I.M., Martin W.E., Haefele M.A.: *Survey Results of the American Public's Values, Objectives, and Attitudes Regarding Forests*. USDA Forest Service, Fort Collins, Co 2002.

[18] Sleavin K.: *SPECTRUM.* USDA Forest Service, Fort Collins, Co 1996.

[19] Twery M.J., Rauscher H.M., Knopp P.D., Scott A.T., Nute D.E., Potter W.D., Maier F., Wang J., Dass M., Uchijama H., Glende A.: NED-2: *An Integrated Forest Ecosystem Management Decision Support Syste*m. *Proceedings on Decision Support for Multiple Purpose Forestry*. IUFRO and Institute of Silviculture, BOKU, Vienna, April 23-25, 2003, pp. 1-16.

[20] Winston W.L.: *Operations Research: Applications and Algorithms*. Duxburry Press, Bellmont, CA 1994.

[21] Zadnik Stirn L.: *Adaptive Dynamic Model for Optimal Forest Management*. "Forest Ecology and Management" 1990, 31, pp. 167-188.

[22] Zadnik Stirn L.: *Interactive, Dynamic and Multi-Attribute Technique for Modeling in Forest Planning*. Publication No. FWS 1-96, Virginia Polytechnic Institute and State University, Blacksbourg, VA 1996, pp. 129-138.

[23] Zadnik Stirn L.: *MEDMONT WP 9.1*. University of Ljubljana, Ljubljana 2003.

[24] Zadnik Stirn L.: *MEDMONT WP 9*.2. University of Ljubljana, Ljubljana 2004.

[25] Zadnik Stirn L.: *Cluster Analysis and Fuzzy Logic in Multi-Criteria Decision Analysis – a Case of Production*. In: *Proceedings of the 10th International Conference on Operational Research – KOI 2004* [*Trogir, Croatia, September 22-24, 2004*]. R. Sčitovski, D. Jukić (eds). Department of Mathematics University of Osijek, Croatian Operational Research Society, Osijek-Zagreb 2005, pp. 87-97.

[26] Zadnik Stirn L.: *Integrating the Fuzzy Analytic Hierarchy Process with Dynamic Programming Approach for Determining the Optimal Forest Management Decisions*. "Ecological Modeling" 2006, 194, pp. 296-305.

[27] Zadnik Stirn L.: *Evaluation of Environmental Investment Projects Using a Hybrid Method* (*SWOT/AHP*). In: *Proceedings of the 11th International Conference of Operational Research, KOI2006, Pula, Croatia*. V. Boljunčič et al. (eds). Croational Operational Research Society, Zagreb, Croatia 2008, pp. 245-255.

[28] Zimmermann H.J.: *Fuzzy Sets, Decision Making and Expert Systems*. Kluwer, Boston 1987.