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APPLICATION OF ANALYTICAL HIERARCHY PROCESS IN AGRICULTURE

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SUMMARY

Hierarchical decision models are a general decision support methodology aimed at the classification or evaluation of options that occur in decision-making processes. Decision models are typically developed through the decomposition of complex decision problems into smaller and less complex subproblems. This paper presents an approach to the development and implementation of multicriteria decision model based on Analytical Hierarchy Process – AHP (Expert Choice, EC). Likewise, the AHP is used as a potential multicriteria decision making method for application in agriculture. In order to show the implementation of explained MCDA methods in real situation in agriculture, the application of AHP on a sample model farm is presented in the second part of the article.

Key-words: multicriteria decision analysis - MCDA, analytical hierarchy process – AHP, decision support system, agriculture

INTRODUCTION

The methodology of hierarchical decision models (DM) has been developed and extensively applied in relation to decision support. There, the decision-makers are often faced with the problem of choice: to choose an option from a set of available options so as to satisfy best the decision-maker's goals. In complex real-life decision processes, the problem of choice can be extremely difficult, mainly because of complex, interrelated or even conflicting objectives. To support the decision-maker, a decision model is designed to evaluate the options. Also, it can be used for the analysis, simulation, and explanation of decisions. In practice, this approach has been most often used for technical or economical decision problems, such as project or investment evaluation, portfolio management, strategic planning, knowledge management (Ngai and Chan, *in press*) and personnel management (Bohanec et al., 2000). However, DM are widely discussed in many studies (Kljajić et al., 2000; Doumpos and Zopounidis, 2003; Recio et al., 2003; Rozman et al., 2005).
A multi-criteria evaluation approach enables decision makers investigating a number of different alternatives (projects) involving multiple criteria and conflicting priorities.Despite the development of a large number of defined multi-criterion decision aid (MCDA) methods, none can be considered as the 'super method' appropriate to all decision making situations. However, the Analytic Hierarchy Process (AHP) and its variants have long been used in numerous scientific MCDA applications. The AHP is best illustrated by Saaty (1980). The AHP is a decision support tool which can be used in solving complex decision problem. It uses a multi-level hierarchical structure of objectives, criteria, subcriteria and alternatives. Interest for multi-criterial assessment in agriculture has been growing rapidly (Tiwari et al., 1999; Herrero et al., 1999; Mazetto and Bonera, 2003; Rozman et al., 2005). The potential of a wide range of possible farm business alternatives must be evaluated in order to determine their obstacles and characteristics, as well as the benefits with corresponding opportunities which they contribute to the production farm system. The cost benefit analysis (hereinafter CBA) for each farm alternative is therefore a necessity before the decision has been made. The data availability required for conducting CBA for defined alternatives can be a serious limitation in the planning

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process. Experiences described in literature (Rozman et al., 2002; Hester and Cacho, 2003; De Toro and Hansson, 2003; Lisson et al., 2003 and Romera et al., 2003) emphasize that a variety of agricultural problems can be solved with computer modeling. This includes decision problems and project solutions, which have long been predominated by the aforementioned CBA analysis. As reported by Tiwari et al. (1999), reality is complex, and the use of CBA alone may not be sufficient when the decision situation involves consideration of variables which cannot be easily quantified into monetary units and the decision-making process is likely to be influenced by multiple competing criteria. CBA is sometimes also criticized for the limitation that does not generally take into account the interactions between different impacts. The main difficulty when applying a CBA method is that the evaluation of a project must relate to an unambiguous monetary uni-dimensional criterion, since a comprehensive cost-benefit approach requires all project option effects to be transformed into a single monetary dimension (Rogers et al., 1999). At this point in the decision-making process, the analyst should consider aforementioned multi-criteria (objective) decision analysis approach (hereinafter MCDA), which combines different mathematically based methods - the most commonly known approach is aforementioned analytical hierarchical process.
The paper is organized as follows. The first part describes the methodology, development and implementation of multicriteria decision model based on analytic hierarchy process for solving the farm planning problem on a sample model farm. The conclusions and proposals for further study in the second part conclude this paper.

METHODS

Hierarchical decision models

In the first phase in MCDA development the structure of decision hierarchy from the top through the intermediate levels to the lowest level which usually contains the list of alternatives must be performed. The hierarchical decision model is composed of attributes X_i and utility functions F_i (Figure 1). Attributes (sometimes also referred to as performance variables or parameters) are variables that represent decision subproblems. They are organized hierarchically so that the attributes occuring at higher levels of the hierarchy depend on lower-level attributes. In theory, a hierarchy is represented by a directed acyclic graph, but in practice it is usually simplified to a tree. According to their position in the hierarchy, we distinguish basic attributes (leaves or terminal nodes) and aggregate attributes (internal nodes, including the roots of the hierarchy). Figure 1 shows an abstract decision model that consists of seven basic attributes X_1–X_7, and five aggregate attributes, X_8-X_{12} and Y. For each aggregate attribute there is a corresponding utility function F that determines the dependency of that attribute with respect to its immediate descendants in the hierarchy. Options are represented by value a_i of basic attributes. The evaluation of options is performed by an aggregation carried out from bottom to the top of hierarchy according to its structure and defined utility functions. The overall evaluation (also called utility) of an option is finally represented by the value of one or more root attributes (Y in Figure 1).

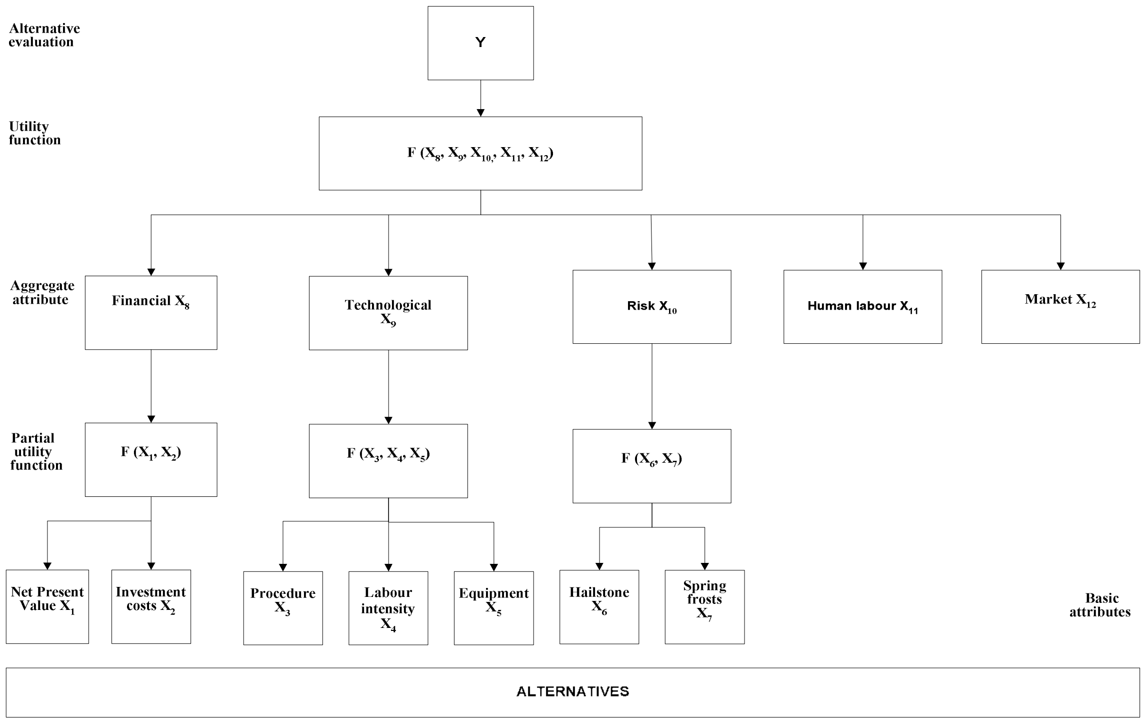

Figure 1. The MCDA hierarchy structure for evaluating farm planning problem
Slika 1. Struktura višekriterijskog modela za problem izbora poslovne alternative na gospodarstvima

A majority of current multi-attribute decision methods is aimed at the development of quantitative decision models. In such models, all the attributes are continuous, and utility functions are typically defined in terms of attributes' weights, for example as a weighted-average of lower-level attributes. In the next situation we highlight the theory and application of AHP, the most widely used MCDA method.

Analytic Hierarchy Process (AHP)

The AHP, developed by the mathematician, Thomas L. Saaty (1980), is a practical and effective method for solving multi-criterial decision problems. It is a flexible and powerful tool for handling both qualitative and quantitative multi-criteria problems. Its decision model is based on structuring the elements of the observed problem in terms of how the alternative solutions influence decision criteria, satisfaction of which will show how much particular solution contributes to the accomplishment of the main objective of a decision problem. The AHP uses a multi-level hierarchical structure of objectives, criteria, sub-criteria and alternatives. The typical problem examined by the AHP consists of a set of decision criteria. The pertinent data are derived by using a set of pairwise comparisons. These comparisons are used to obtain the weights of importance of the decision criteria and the relative performance measurements of the alternatives in terms of each individual decision criterion. The hierarchical organization structure of the AHP arranges a decision problem in clusters at different levels; higher level elements transmit influence to lower ones, or lower level elements contribute to the functioning of the higher level ones (Guo and He, 1999). In case that pairwise comparisons are not perfectly consistent, then it provides a mechanism for improving consistency. One of the reasons, which contribute the application of AHP in decision making process, is the development of the Expert Choice ^{TM2000} software (EC). The EC, computer software package, used to structure the decision into criteria and alternatives, measure the criteria and alternatives using pairwise comparisons, synthesize criteria and subjective inputs to arrive at a prioritized list of alternatives, and report on the sensitivity analysis.
Saaty (1980) developed the following steps for applying the AHP:

1. Define the problem and determine its goal.
2. Structure the hierarchy (Figure 1) from the top (the objectives from a decision-maker's viewpoint) through the intermediate levels (criteria sub-sequent levels depend on) to the lowest level which usually contains the list of alternatives. This classifies the goal and all decision criteria and variables into tree levels. The highest level (level 1) of the hierarchy is the overall goal, level 2 represents the criteria and sub-criteria and level 3 contains the decision alternatives that affect the ultimate selection of the decision problem. All criteria and sub-criteria ultimately contribute to the goal.
3. Once the AHP model is set up, the priorities need to be derived. Weights are assigned to each criterion and sub-criterion. These weights are assigned through a process of pairwise comparison. In pairwise comparison, each objective is compared at a peer level in terms of importance. Construct a set of pair-wise comparison matrices (size n x n) for each of the lower levels with one matrix for each element in the level immediately above by using the relative scale measurement shown in Table 1. The pair-wise comparisons are done in terms of which element dominates the other.
4. There are n (n – 1) / judgments required to develop the set of matrices in step 3. Reciprocals are automatically assigned in each pair-wise comparison.
5. Hierarchical synthesis is now used to weight the eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.
6. Having made all the pair-wise comparisons, the consistency is determined by using the eigenvalue, λmax, to calculate the consistency index, CI as follows: $CI = (\lambda max - n) / (n - 1)$, where n is the matrix size. The CI is acceptable, if it does not exceed 0.10. If it is more, the judgment matrix is inconsistent. To obtain a consistent matrix, judgments should be reviewed and improved.
7. Steps 3 - 6 are performed for all levels in the hierarchy.

In order to formulate the AHP model, it is necessary to identify the factors that influence the decision makers (farmer) choice. After discussions with expert group and decision maker the tree identification must be performed. To simplify the application of the AHP decision model, the corresponding software was used (Expert Choice TM2000). The Expert Choice (EC) software was used to make corresponding AHP priority calculations for the observed problem. The Expert Choice simplifies the implementation of the AHP's steps and automates many of its computations (Al – Harbi, 2001). The expert group compared relative importance of each objective in the pair-wise manner using 1-9 (comparison scale where 1 means that importance of two objectives is the same, while 9 means that one criterion is extremely more important that the other, Table 1).

Table 1. Judgment scores for the importance/preference of criteria using AHP
Tablica 1. AHP skala prioriteta

Verbal Judgement	Numerical rating
Extremely important / preferred	9
Very strongly to extremely important / preferred	8
Very strongly important / preferred	7
Strongly to very strongly important / preferred	6
Strongly important / preferred	5
Moderately to strongly important / preferred	4
Moderately important / preferred	3
Egually to moderately important / preferred	2
Equally important / preferred	1

The EC software allows us to enter the data for each alternative into the so-called Data Grid, where individual objectives can be entered directly. The use of the Data Grid combines the power of the hierarchy and the pair-wise comparison process with the ability to evaluate hundreds or even thousands of alternatives. Pair-wise comparisons are still used to evaluate the elements in the hierarchy itself, but not for evaluating the alternatives. Alternatives' priorities are established relatively to each covering objective by using ratio scaled rating intensities (scales). This procedure can be particularly useful with large number of alternatives to be evaluated; there is no need to compare alternatives in the pair-wise manner; the values are put directly into the Data Grid and priorities are calculated based on pair wise comparison of intensities.

A case study: application of AHP for organic farm decision making support

The AHP is a powerful and flexible decision – making process. It can help the farmer (decision maker) set priorities and make the best decision when both qualitative and quantitative aspects of a decision need to be considered. In order to develop an AHP decision model, the first thing that must be determined are alternatives. Three alternatives on a sample farm were analyzed in AHP decision model. A sample organic farm in Northeast Slovenia was considered to apply the Expert Choice multi-objective decision model. The sample farm is a mixed organic farm (size = 8 ha) with a combination of field crop, livestock and fruit production from a traditional grassland orchard. The following business alternatives were identified and evaluated (using decision model based on AHP methodology as described in Figure 1):

Alternative 1: Traditional grassland orchard fruit processing. The average size of a grassland orchard is 2 ha (apples, plums and pears). Possible processed organic fruit products are: apple vine, apple juice, apple cider, apple brandy, dry fruit (apples, plums and pears) and plum brandy.

Alternative 2: Goat milk processing into cheese (100 milking goats).

Alternative 3: Spelt processing (the spelt is produced on 1 ha) into two equal share of spelt products – spelt grain and spelt flour.

RESULTS AND DISCUSSION

The identified business alternatives were evaluated with integrated decision simulation system for food production and processing KARSIM 1.0 (DSM) (for details see Pažek et al., 2004) and the multi-objective models developed in AHP (EC) model. In the first step, a financial CBA was computed for three different business alternatives on the organic farm, using the KARSIM 1.0 decision support system. It should be mentioned here that the CBA was computed for 10 years at a 5 % discount rate. The KARSIM 1.0 model also enables technological analysis – i.e. calculation of main inputs used, such as human labour (Table 2).

Table 2. DSM results (NPV calculated at a 5 % discount rate; investment period of 10 years)
Tablica 2. DSM rezultati (5 % diskontna stopa; razdoblje investicije 10 godina)

	Alternative 1	Alternative 2	Alternative 3
Investment costs (€)	4942	41492	2917
NPV (€)	95088	-6066	10461
Human labour (hours)	882	9841	112

The CBA results (at 5 % discount rate and after 10 years) show financial feasibility of alternatives 1 and 3 while alternative 2 is, at given simulation input parameters, not financially feasible (NPV = -6066 €; mainly due to significantly higher investment costs). The highest NPV value was observed for traditional grassland fruit processing (alternative 1), followed by spelt grain (NPV = 10461 €). A relatively high NPV value for alternative 1 can be explained by higher selling prices of different fruit products and higher quantity of processed fruit products that can be produced (apple cider, juice, dry fruit, apple wine, plum brandy). The results of a simulation were further evaluated in the next step using the presented MCDA AHP approach.

In addition to the CBA analysis, the KARSIM 1.0 model provides many technical data for each project. This data is further used for evaluation of some attributes' values. The remaining attribute values are determined by an analyst, i.e. decision-maker (farmer). The assessment of sub-attributes NPV, investment costs, equipment, food processing techniques, and labour intensity was conducted by the computer model automatically. The sub-attributes spring frost probability and hailstone frequency and *market* objectives were assessed.

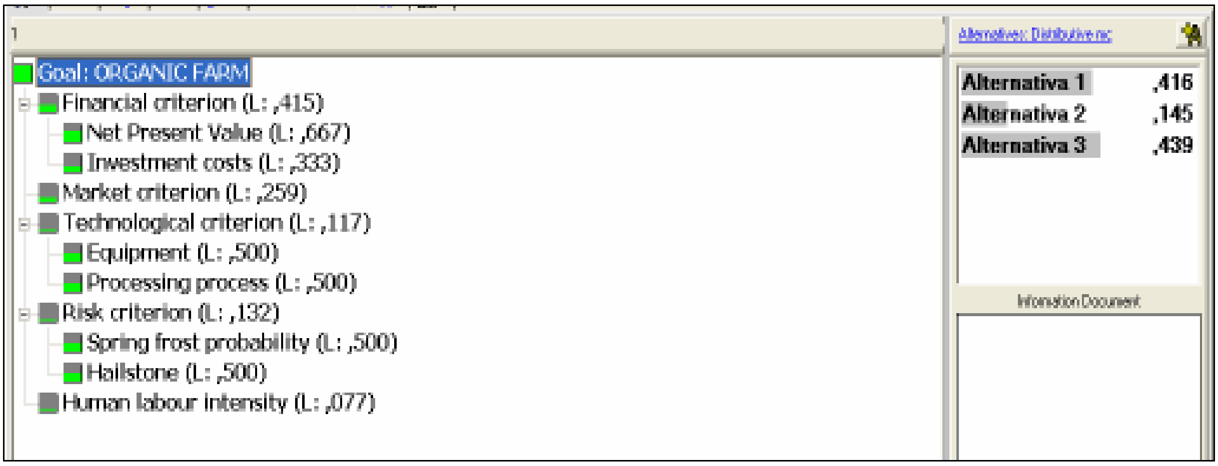

Figure 2. AHP (EC) priorities for observed farm planning problem on a sample model farm
Slika 2. AHP (EC) prioritete poslovnih alternativa na izabranom modelnom gospodarstvu

Table 3. AHP calculations through individual levels of the hierarchy
Tablica 3. AHP kalkulacije za individualne razine hierarhije

Alternative	Financial objective		
	NPV (W[1]=0.667)	Investment costs (W=0.333)	
	a[2]		∑Wa [3]
1	0.508	0.171	0.535
2	0.097	0.024	0.098
3	0.249	0.317	0.367
	Market objective		
1			0.218
2			0.090
3			0.384
	Technological objective		
	Equipment (W=0.500)	Processing process (W=0.500)	
	a		∑Wa
1	0.073	0.053	0.229
2	0.073	0.053	0.229
3	0.073	0.225	0.542
	Risk objective		
	Spring frost (W=0.500)	Hailstone (W=0.500)	
	a		∑Wa
1	0.132	0.269	0.305
2	0.132	0.269	0.305
3	0.245	0.269	0.391
	Human labour objective		
1			0.078
2			0.045
3			0.150

[1] *W - weight; [2]*a - alternative priority; [3] * ∑Wa - alternative priority with respect to individual objective (objectives with no sub-levels are assed directly from pair wise comparison matrices)

Table 4. Total priority calculations for the sample organic farm
Tablica 4. Kalkulacije ukupnih prioriteta poslovnih alternative

	Financial objective	Market objective	Technological objective	Risk objective	Human labour objective	Total
Weight (W^1)	0.415	0.259	0.117	0.132	0.077	
	a^2					$\sum Wa^3$
Alternative 1	0.535	0.218	0.229	0.305	0.078	0.416
Alternative 2	0.098	0.090	0.229	0.305	0.045	0.145
Alternative 3	0.367	0.384	0.542	0.391	0.150	0.439

1*W – weight; [2]*a - alternative priority; [3]* ∑Wa - total alternative priority

The applied AHP methodology should bring unequivocal clarity to the decision which food processing or business alternative should be favoured and implemented on an organic farm (Figure 2, Table 3 and 4). The presented paper is characterized by the most suitable alternative 3-spelt grain processing, which got the highest EC evaluation (0.439) followed by the alternative 1 (0.416) and alternative 2 yielding with the lowest evaluation (0.145). It should also be noted here that AHP method favored alternative 3, while the highest estimated NPV was revealed for alternative 1. The AHP based Expert Choice model presents different rankings of alternatives in comparison to CBA. Moreover, the overall consistency of the input judgements at all levels is within the acceptable ratio of 0.1. The use of AHP (EC) approaches can bring additional information into the decision-making framework.

CONCLUSION

Interest of MCDA in agricultural sector has been growing rapidly. There is no doubt that MCDA (AHP) has come to play an important role in planning and organization of farm business strategy and is a key issue for them. The presented combined methodological framework (AHP) for decision support on organic farms could provide additional information support, bring additional clarity to the decision, and could therefore play an important role in further development of decision support systems on organic farms. The integrated system takes into consideration different independent objectives and enables ranking of different farm business alternatives. Further research could be made in combinations with the AHP resource allocation theory (Forman and Selly, 2002), where calculated priorities could be used for optimal allocation of organic farm resources at constrained investment capital; naturally the AHP hierarchy should be changed correspondingly. The decision model should be also interrelated to the marketing information system (marketing attribute).

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UPORABA ANALITIČKOG HIERARHIJSKOG PROCESA U POLJOPRIVREDI

SAŽETAK

Hijerarhijski modeli odlučivanja su opće prihvaćena metodologija za klasifikaciju alternative, koje se javljaju u procesu odlučivanja. Modeli su razvijeni postupkom dekompozicije problema u manje kompleksne podprobleme. U ovom radu predstavljamo razvoj i implementaciju višekriterijskog modela, koji bazira na analitičkom hijerarhijskom procesu – AHP (Expert Choice. EC). U tom smislu AHP se javlja kao potencijalni metodološki pristup za potporu donošenju odluka u poljoprivrednom managementu. U radu je demonstrirana aplikacija AHP na realnom problemu odlučivanja u poljoprivredi na primjeru modelnog ekološkog gospodarstva.

Ključne riječi: višekriterijska analiza odlučivanja – MCDA, analitički hijerarhijski proces – AHP, sistem za potporu odlučivanju u poljoprivredi

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