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Multi attribute decision model for orchard renewal – case study in Bosnia and Herzegovina

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The fruit production in Bosnia and Herzegovina (BIH) is slowly returning to normality after Balkan wars. Due to favorable climatic and soil conditions it represents a clear business opportunity for family farms. The decision which fruit species/variety to grow is a complex decision and should be made on the basis of sound empirical analysis. This paper presents a multi criteria model for planning and decision making on fruit farms in BIH. The model combines financial cost benefit analysis and multi attribute decision making methodology based on expert system DEX-i. In the first stage the technological and financial cost benefit analysis were conducted for each fruit production alternative. The results were further evaluated with expert system DEX-i considering all possible criteria influencing the fruit grower decision. In the case of a sample family farm the plum yielded with best multi criteria evaluation, followed by apple and pear, while sour cherry gave unsatisfactory outcome.

Key words: cost benefit analysis, fruit production, multi attribute decision modeling, expert system DEX-i

INTRODUCTION

The time of Balkan wars was devastating for Bosnia agriculture and its fruit production which is now slowly returning to normal frames. Bosnia and Herzegovina has relative good conditions for intensive fruit production. Before 1992 the plum was predominant fruit species contributing 50% to the total fruit production. Apples and pears contributed another 33% of a total fruit production. Long term prospects for fruit production in Bosnia and Herzegovina are prosperous. The agro-climatic conditions are relatively suitable for fruit production, the costs of available labor force are low and the demand for fresh fruits is also high. The supply of fresh fruit for Bosnian market is covered mostly by the import from different countries. The fruit production therefore represents a clear business opportunity for farmers. However, due to high investments related to intensive fruit production, the information on its economic feasibility is a necessity before the decision on a particular project (in this case orchard establishment) is undertaken.

Decision-making techniques at the project level have long been dominated by the financial cost benefit analysis (CBA), on the basis of net present value, defined as a difference between the sum of projects discounted cash flows and investment costs. Ćejvanović and Rozman (2004) consider capacity of financial CBA for orchard planning and decision making in Bosnia and Herzegovina. However, 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 (Tiwari et al. 1999). CBA is also sometimes criticized for the limitation that it does not generally take into account of 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 and Bruen 1998). This is the point where the Multi-Criteria Decision Analysis (MCDA) appears in the planning process. The multi-criteria methods unlike monetary ones attempt to take into consideration the multiple dimensions of a decision problem in a balanced matter. Project effects are treated in their own dimensions. Rogers and Bruen (1998) consider the capacity of multi-criteria analysis to take account different

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yet relevant criteria-even if these cannot be related to monetary outcomes- to be its main advantage. Establishing and managing an orchard requires making a numerous decisions over the long productive life of fruit trees. The recent work on decision support systems in fruit production used a variety of research approaches. Childs et al. (1983) presents a decision support system for orchard renewal which is based on a combined model (simulation and optimization). The model is used for calculating the optimal time for orchard renewal. Attkins et al. (1992) develop a decision support system ORCHARD 2000 for orchards in New Zealand while Rozman et al. (2002) combine simulation modeling and mathematical programming for selection of best apple orchard system. All these studies used financial criterion as prevailing criterion in the decision process. The application of multi criteria decision modeling has been applied by Alvisi et al. (1992) who presents a MULTIFRU model for multiple criteria decision making in orchard management. The decision which fruit species to grow is besides financial implication also related to technological and ecological factors (which are difficult to include into the CBA analysis). At this point in the decision making process, the analyst should consider a multi-criteria decision analysis (hereinafter MCDA) which combines different mathematical based methods - the most common known approaches are utility theory and analytical hierarchical process (hereinafter AHP). Both methods evaluate alternatives in an empirical manner. In contrast, the approach, based on expert system for multi attribute decision making DEX- i, reported by Bohanec et al. (1995) and Bohanec et al. (2000) uses qualitative variables for alternative evaluation (for instance acceptable or unacceptable).

The aim of this paper is the development and presentation of multi attribute decision model which could be used as a decision support tool in planning new orchards in Bosnia and Herzegovina. The model combines financial cost benefit analysis and multi attribute decision making using an expert system shell DEX-i methodology approach. The DEX-i combines elements of multi criteria decision making with some elements of expert systems and machine learning.

METHODOLOGY

As mentioned earlier the decision which fruit species and variety to grow on selected location represents a typical farm management decision problem. Furthermore, this problem could be described as typical multi criteria decision problem since many conflicting criteria must be taken into consideration. The main idea of the approach lies within interrelating financial cost benefit analysis with multi attribute decision methodology. In the first stage of the decision making process for each alternative analyzed the financial cost benefit analysis is conducted. The main concept of a financial cost benefit analysis (hereinafter CBA) is the computation of the net present values (hereinafter NPV) and internal rate of returns (hereinafter IRR) for every analyzed alternative. Clearly, in order to conduct the cost benefit analysis one needs sufficient input data (annual cash flows caused by the investment). In our case the data base of "Brcko District – Department of Agriculture" was used in order to make the analysis. In fact, spread sheet Excel CBA models for each individual alternative have been developed. The local enterprise budgets (the data of "Brcko District – Department of Agriculture") were used as main input data for cost benefit analysis of investment into production 4 different fruit species (calculation of orchard establishment costs and annual cash flows). This database was also used to determine values of numerical decision attributes (for instance labor).

For the purpose of developing the multi attribute decision model for orchard establishment in Bosnia and Herzegovina the DEX-i decision expert system was used. The DEX-i is a Windows version of DEX (Decision Expert) and was developed by the University of Maribor; Faculty of Organizational Sciences (Bohanec et al. 1995 and Bohanec et al. 2000) and Jozef Stefan Institute (Jereb et al. 2003). This is an expert system shell for multi-attribute decision making that combines the "traditional" multi-attribute decision making with some elements of Expert Systems and Machine Learning. The basic approach in the DEX-i methodology is a multi-criteria decomposition of the problem: the decision problem is decomposed into smaller and less complex decision problems (sub-problems). In this way we get a decision model consisting of attributes that represent individual subproblems. The attributes are organized hierarchically (Figure 1) and are connected with the utility functions. The utility functions evaluate each individual attribute with respect to their immediate descendants in the hierarchy. The main characteristic of DEX-i method (and also its main difference from other utility function methods which in most cases use weighted sum or similar quantitative approaches) is its capability to deal with qualitative models. Instead of numerical variables, which typically constitute traditional quantitative models, DEX-i uses qualitative variables; their values are usually represented by words rather than numbers, for example "low", "appropriate", "unacceptable", etc. Furthermore, to represent and evaluate utility functions, DEX-i uses if-then decision rules. The decision rule can be for instance: "if the net present value is negative then the alternative is not acceptable" or "if the labor usage in the investment project is low then the alternative is excellent". In contrast, in DEX-i modeling this can also be carried out in a numerical way, using weights or similar indicators of attributes' importance. DEX-i can be used for solution of various decision problems (from simple problems such as selection of new car to more sophisticated decision problems such as selection of best business alternative) (Bohanec and Rajkovič 1999). The DEX-i decision modeling is conducted in three stages:

- problem identification, determination of decision attributes and their qualitative databases
- setting up decision rules (definition of utility functions)
- analysis of each alternative

The interrelation of CBA and DEX-i decision modeling was conducted through the following steps:

Step 1: Problem structuring

We can structure the problem as follows: an individual farmer has a potential location that could be used for fruit growing (orchard establishment). Our decision problem is the decision which species and variety to grow on the selected location.

Step 2: Identification of alternatives

The identification of alternatives consisted of the 4 basic options, i.e. 4 main fruit species produced in Bosnia and Herzegovina (apple, pear, sour cherry and plum).

Step 3: The financial cost benefit analysis for each alternative

Using the given district data base (CBA models and enterprise budgets), the net present values and internal rates of return are calculated for each alternative. For the base CBA analysis it was assumed that standard yields and prices would be achieved in the productive period of orchard life-cycle. Cash flow variability over time is difficult to predict since yield and prices vary trough years. Clearly, the NPV sensitivity analysis should provide us with some answers but this would, on the other hand, provide us with many possible scenarios which occurrence is uncertain. The base NPV calculations are therefore conducted under assumption of full yields and successful marketing. Possible cash-flow variability is thus expressed with the attributes such as suitability of a selected location (yield variability) and market (revenue achieved) included into the decision model.

Step 4: Identifying objectives and criteria

Different techniques can be used in order to identify all possible criteria that must be taken into the consideration during the analysis. Without exception, all multi-criteria methods call for the identification of the key factors which will form the basis of an evaluation. Most of MCDA methodological approaches use a hierarchical criteria structure (for instance analytical hierarchical process) in the tree form (Belton and Stewart 2002). The DEX-i methodology is no exception, the attributes are presented in the tree form. The attribute tree (presented in Figure 1) shows the most relevant criteria identified by the discussion between different experts (experts of Brcko District Department of Agriculture and the analysts – experts from Faculty of Agriculture, University of Maribor and Faculty of Agriculture, University of Zagreb).

The main decision attributes are divided into financial, technological, market and ecological attributes. The financial attributes consist of investment costs (also related to availability of capital) and net present value (which are both numerically measurable attributes). Although it could be argued here that investment costs are already contained in the computation of NPV and therefore should not be defined as individual sub-attribute, it must be stressed out that investment costs represent one of the major constraints when deciding for orchard establishment. Hence, the sub-attribute "investment costs" must be taken into consideration as independent. The technological attribute consists of technology and storage possibilities (which are described only by qualitative measurements) as well as labor intensity (which can be divided into home and hired labor; both can be measured numerically). The market attribute reflects attractiveness of each fruit species and variety to the consumers (qualitative) as well the number of possible ways to market the product. Finally the attribute "Suitability of selected location" describes ecological conditions (soil, inclination and spring frosts probability) given on the selected location. After the attribute tree has been identified each attribute is assigned with a list of values (for instance the NPV can have the following qualitative values: negative, low, average, high). The values can either be described by words or by numbers (for instance: for instance engine horse power when selecting the tractor, etc.). The values are organized either increasing (from the worst value to the best) or decreasing (from the best to the worst) and are classified as negative (-), neutral or positive (+). For instance, very high labor input would be classified as negative and conversely low labor input would be classified as positive. Likewise, the values are determined for the decision problem as a whole (for instance, decision alternative can obtain values not acceptable, acceptable and recommendable). The attributes and sub-attributes are organized in the tree structure (attribute tree).

Since the DEX-i operates with qualitative values the classification must be performed. The process of classification determines qualitative value according to the defined list of values for each attribute. The following classification was used in order to determine a list of values for each attribute (Table 1). It should be mentioned here that table 1 represents only numerical attributes.

Table 1. Classification table for numerically measured attributes.

Investment costs (€/ha)	Qualitative Values
0-5000 5000-10000 > 10000	Low High Extra high
NPV (€/ha)	
< 0 0-20000 20000-40000 > 40000	Negative Low High Extra high
Home labor (hours)	
0-500 500-1000 > 1000	Low Average High
Hired labor (hours)	
0-200 200-400 > 400	Low Average High

The main problem is assigning values to attributes which cannot be measured on a numerical scale (such as technological requirements, storage possibilities, market criteria, etc.). In that case some kind of qualitative scale must be defined which is used for determination of qualitative values of each attribute. The following qualitative scale was used for non numerical sub-attributes (Table 2).

Table 2. Qualitative values for non numerical sub-attributes.

Technology	very demanding; demanding; simple;
Storage possibilities	short; long
Market criteria	poor; good; excellent
Soil	unsuitable; suitable; very suitable
Inclination	unsuitable; suitable; very suitable
Spring frost probability	high; low

Step 5: Determination of decision rules in DEX-i software

After each attribute is assigned with its qualitative value database the decision rules are derived. As mentioned in the description of DEX-i methodology, the DEX-i uses qualitative values for decision alternatives evaluation. The utility function for the whole project (investment into orchard establishment) consists out of many partial utility functions which are defined for aggregate attributes. These utility functions are defined by "what if decision rules". For the orchard planning problem a series of 81 decision rules has been identified estimating the overall project evaluation for each possible value combination of aggregate attributes (Table 3). Similarly, the decision rules have been determined for each aggregate attribute. The "what if" decision rules represent the knowledge base that is ultimately used by the DEX-i software for evaluating decision alternatives. The connection of the decision model through utility functions can be gleaned in Figure 1.

The decision rules are presented in aggregate form: in the table, an asterisk '*' represents any value, and '≥' means 'better or equal. Similar decision rules (utility function) have been identified for each aggregate attribute.

After decision rules have been established the analysts puts in qualitative values for each attribute corresponding to each decision alternative. Once the values have been inserted the DEX-i performs the analysis for each decision alternative. Ultimately, the "what if" analysis can be performed (observing change in different model input parameters and their impact on the evaluation results).

THE COMPUTER MODEL

The basic NPV models for each business alternatives and classification are provided in MS Excel. The calculated NPV as well as home and hired labor are then transferred into another Excel file containing a simple algorithm classification program where all attributes are classified according to the rules determined by the analyst. Clearly, classification boundaries for each numerical attributes can be changed by the analyst. After basic CBA analysis and classification are completed, the attribute values for each decision alternative are transferred into the DEX-i input table where the analysis is ultimately undertaken.

RESULTS AND DISCUSSION

The developed model was applied on a sample farm in Bosnia and Herzegovina (Table 4). A case study approach was necessary since the CBA model results cannot be generalized.

Table 3. Decision rules for orchard planning problem.

Financial criterion	Technological criterion	Suitability of selected location	Market	Orchard planning
poor	*	*	≥ good	unsuitable
*	*	unsuitable	≥ good	unsuitable
poor	*	≥ suitable	*	unsuitable
*	*	≥ suitable	poor	unsuitable
poor	≥ suitable	*	*	unsuitable
*	≥ suitable	unsuitable	*	unsuitable
*	≥ suitable	*	poor	unsuitable
≥ good	*	unsuitable	*	unsuitable
≥ good	*	*	poor	unsuitable
good	*	suitable	good	acceptable
≥ good	unsuitable	suitable	≥ good	acceptable
≥ good	unsuitable	≥ suitable	good	acceptable
excellent	unsuitable	≥ suitable	≥ good	acceptable
poor	unsuitable	unsuitable	poor	suitable
good	unsuitable	very suitable	excellent	suitable
good	≥ suitable	suitable	excellent	suitable
≥ good	suitable	suitable	excellent	suitable
good	≥ suitable	very suitable	good	suitable
≥ good	very suitable	very suitable	good	suitable
excellent	suitable	suitable	≥ good	suitable
excellent	≥ suitable	suitable	good	suitable
excellent	very suitable	≥ suitable	good	suitable
≥ good	≥ suitable	very suitable	excellent	very suitable
excellent	suitable	very suitable	≥ good	very suitable
excellent	very suitable	≥ suitable	excellent	very suitable

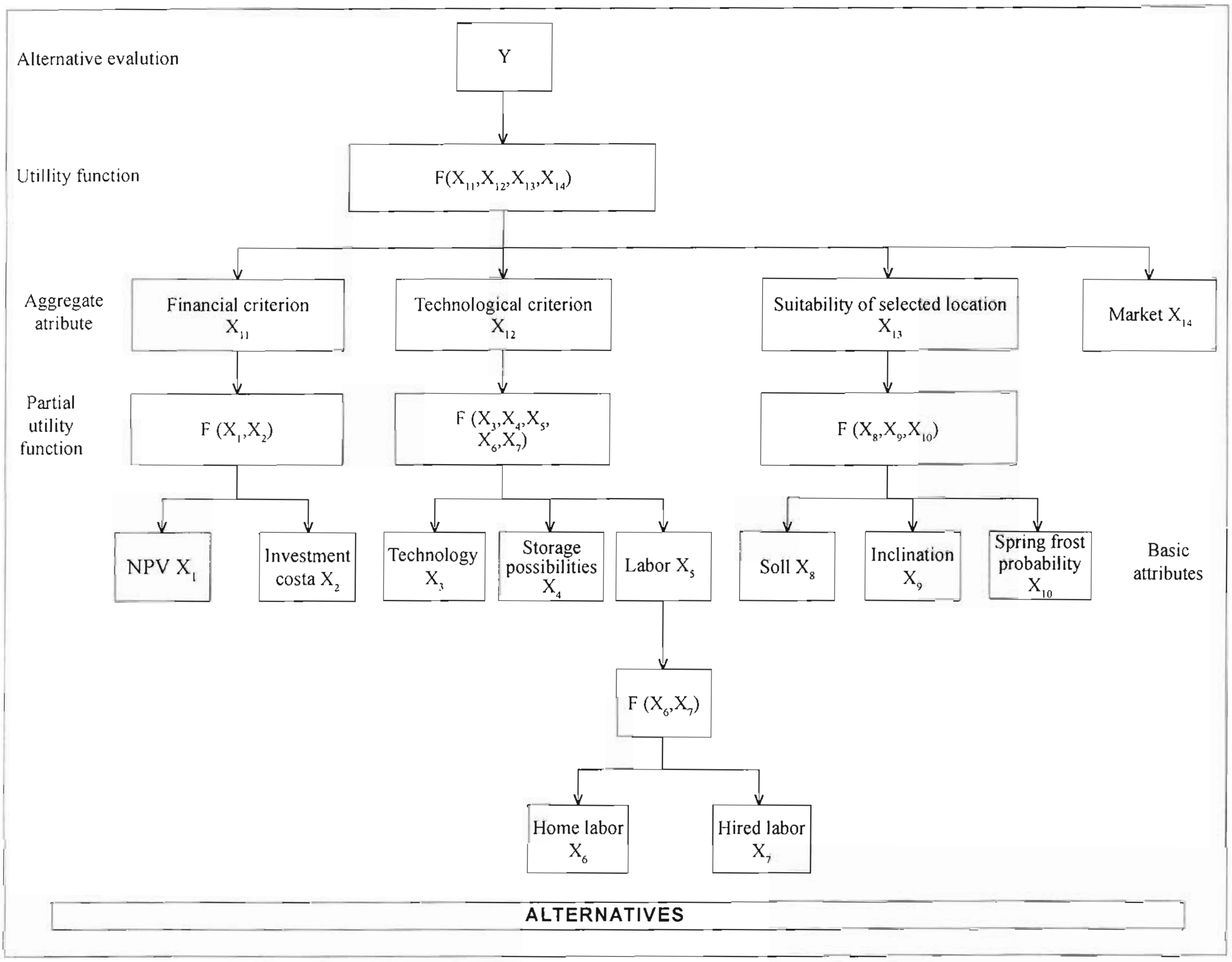

Fig. 1. The orchard planning problem: the structure of a decision model.

Table 4. Characteristics of selected location for fruit production on sample farm.

Orchard area	5 ha
Soil type	Silt
Inclination	South east
Spring frost probability	High (pear, apple), low (sour cherry, plum)

The general characteristics determine suitability of selected location for each analyzed fruit species. The prevailing soil type is silt which theoretically makes it acceptable for all selected fruit species. However, this subject should be analyzed further (organic matter, lime, water capacity, etc.) and on this basis the attribute value of soil must be determined for each fruit species on analyzed location. The inclination (south east) is suitable for all 4 fruit species. The spring frost probability is usually interrelated with the above sea level. However, the spring frost probability is in this case high for apple and pear. For sour cherry and plum the spring frost probability is lower due to later flowering period.

The CBA was conducted for 15 years at 6% discount rate (Table 5). The CBA results show that investment into all 4 major fruit species would be financially feasible; assuming that expected prices and yields would be achieved and successfully marketed.

Table 5. The results of financial CBA analysis of fruit production on sample farm.

	Apple	Pear	Sour cherry	Plum
Investment costs (€/ha)	9878	8089	10134	10134
NPV (€/ha)	39430	40623	34682	45794
Home labor (hours)	632	632	1200	880
Hired labor (hours)	280	280	480	400

The results of CBA analysis and data on labor used in the individual production are in the next stage of decision analysis run through the classification algorithm. Other non numerical attributes were derived on the basis of qualitative scale or were derived analytically as for attribute technology (Table 6).

Table 6. Analytical derivation of qualitative value for subattribute "technology".

	Number of spraying	Thinning	Harvesting procedure	Attribute value
Apple	12-13	Yes	Manual, sorting	Very demanding
Pear	10	If necessary	Manual, sorting	Very demanding
Sour cherry	8	No	Shaking, manual	Acceptable
Plum	9	No	Manual, sorting	Demanding

The similar approach is used for marketing and storage possibility attributes (Table 7).

Despite the plum has similar market channels as sour cherry the value of its marketing attribute was estimated as excellent due to traditional characteristics of Bosnian plum and its products (slivovitz).

The results of classification and analytical derivation (values of each sub-attribute) are then fed into the DEX-i input table where the analysis is finally performed (Table 8).

The DEX-i software also enables graphical representation of evaluation of alternatives as well (Figure 2).

The model returns site evaluation for each fruit species. Clearly, when a fruit species is selected, the problem should be further decomposed, which means that evaluation of different varieties of selected fruit species should be evaluated using similar decision model. However, the selection of a

Table 7. Analytical derivation of market attribute and storage subattribute.

	Possible market channels	Qualitative value	Storage (months)	Qualitative value
Apple	fresh apple fresh apple after storage processing industry on farm processing: cider, vinegar, brandy, dry apple, juice	Excellent	Variety dependent	Long
Pear	fresh pear fresh pear after storage processing industry on farm processing: brandy, dry pear	Excellent	Variety dependent	Long
Sour cherry	fresh sour cherry processing industry on farm processing: cherry wine, brandy	Good	Max one week	Short
Plum	fresh plum processing industry on farm processing: dried plums, brandy	Excellent	Max one week	Short

Table 8. DEX-i evaluation results for orchard planning problem on selected sample farm in Bosnia and Herzegovina.

Orchard planning problem	Apple	Sour cherry	Pear	Plum
Evaluation	acceptable	unsuitable	acceptable	suitable
Financial criterions	good	poor	good	good
Investment costs	high	extra high	high	extra high
NPV	high	high	extra high	extra high
Technological criterion	unsuitable	unsuitable	unsuitable	suitable
Technology	very demanding	demanding	very demanding	demanding
Labor intensity	average	high	average	average
Home labor	average	high	average	average
Hired labor	average	high	average	average
Storage possibilities	long	short	long	short
Market criteria	excellent	good	excellent	excellent
Suitability of selected location	suitable	suitable	suitable	suitable
Soil	suitable	suitable	suitable	suitable
Inclination	suitable	suitable	suitable	suitable
Spring frost probability	high	low	high	low

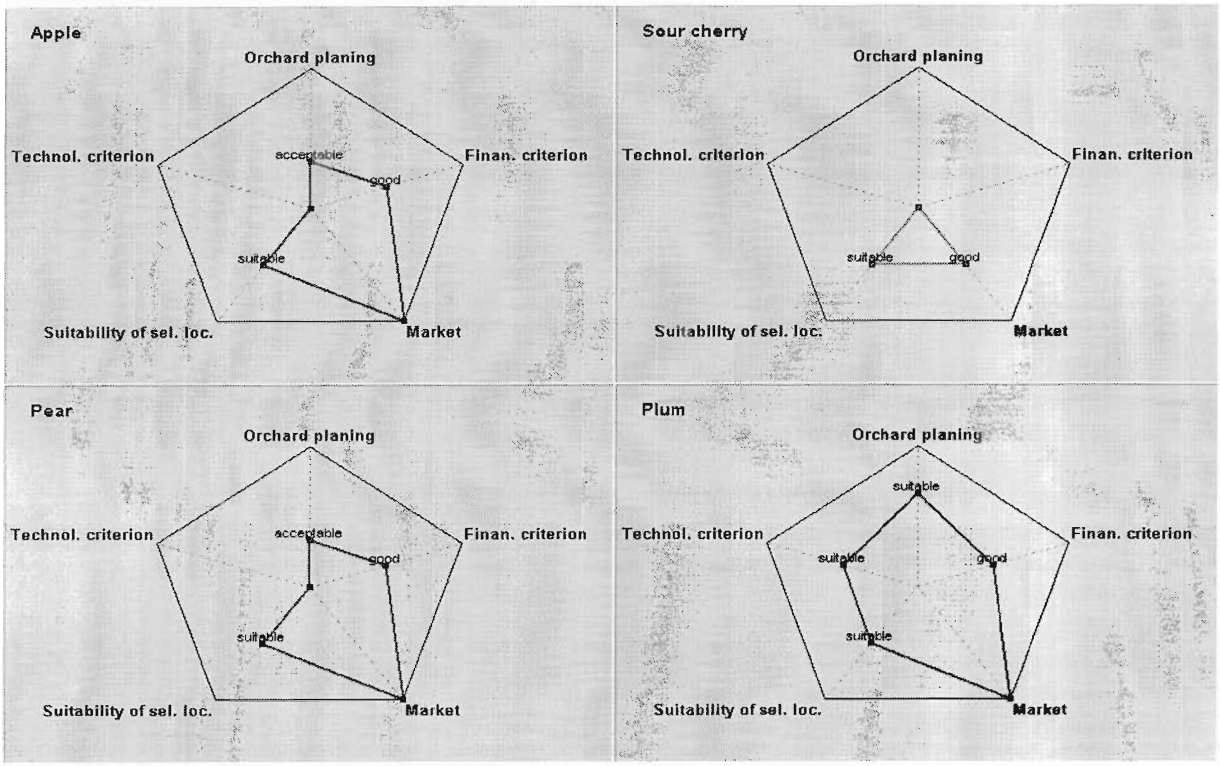

Fig. 2. Graphical presentation of available fruit production alternatives.

fruit species to be grown could be classified as a strategic decision, since it will determine farm production for next 10 - 15 years. In the case study of a hypothetical Bosnian family farm, the plum yields with best evaluation, apple and pear production yields with acceptable evaluation and sour cherry production amounts to unsatisfactory outcome. Relatively high labor usage in sour cherry production and poorest values of some other relatively important attributes contributed to poor evaluation of sour cherry. As it can be gleaned from table 8 and chart 1 the plum has the highest values of most important attributes. The decision model should be further developed in the direction of integrated computer supported decision support system for fruit farms in Bosnia and Herzegovina. Furthermore, the interrelation of simulation models and multi attribute decision model would enable analysis of different technological solutions and would in this light further improve the "power of information" provided by the system developed. Other MCDA methods should be tested simultaneously in order to find the optimal multi criteria decision model for fruit farms in Bosnia and Herzegovina.

CONCLUSIONS

The main goal of the research was to find adequate methodology for fruit production investment projects evaluation on Bosnian fruit farms. The methodological framework presented in the paper combines financial cost benefit analysis and DEX-i multi criteria decision analysis approach. The local fruit production enterprise budgets database and financial cost benefit analysis were used in the first stage of a research in order to conduct financial and technological analyses of each analyzed fruit species. The results of enterprise budgets and CBA represented some of the input parameters for DEX-i decision model which was ultimately used for the analysis of 4 possible fruit species that could be produced in Bosnia and Herzegovina.

The application of multi attribute decision model on a sample fruit farm in Bosnia and Herzegovina showed that under given assumption the plum production would be most suitable solution for location on the selected sample farm.

A combination of CBA and multi criteria decision model represents a powerful decision support tool which can choose between different fruit production investment projects. Furthermore, the decision model combines quantitative and qualitative approach to the decision problem observed. This study also gives a proposal of procedure for multi criteria decision making on fruit farms in Bosnia and Herzegovina. We believe that application of the proposed decision support system would increase the accuracy of information needed for developing fruit farm business plans.

REFERENCES

1. Alvisi F, Malagoli C, Regazzi D. "MULTIFRU – Multiple-criteria decision making in orchard management." ISHS Acta Horticulturae 1992;313,1, (http://www.actahort.org/books/313/313_29.htm).
2. Attkins TA, Laurenson MR, Mills TM, Oglivie DK "ORCHARD 2000: Towards a Decision Support System for New Zeland's Orhard Industries." ISHS Acta horticulturea 1992;313: III International Symposium on Computer Modelling in Fruit Research and Orchard Management. (http://www.actahort.org/books/313/313_20.htm).
3. Belton V, Stewart TJ. Multiple criteria decision analysis. An Integrated Approach. Massachusetts: Kluwer Academic Publishers, 2002;369p.

4. Bohanec M., Rajkovic B. "Multi Attribute Decision Modeling: Industrial Application of Dex." Informatica 1999;23:448-491.
5. Bohanec M, Rajkovic B, Semolic B, Pogacnik A. "Knowledge – based portfolio analysis for project evaluation." Information & Management 1995; 28: 293-302.
6. Bohanec M, Zupan B, Rajkovic V. "Applications of qualitative multi – attribute decision models in health care." International Journal of Medical Informatics 2000;58-59:191–205.
7. Bohanec M, Zupan B. "A function - decomposition method for development of hierarchical multi – attribute decision models." Decision Support Systems 2004; 36: 215-233.
8. Cejvanovic F, Rozman C. "Financial evaluation of competitive ability of fruit growing in Bosnia and Herzegovina." Ekonomski anali (Ekonomska Fakulteta u Beogradu) 2004;161:193-203.
9. Childs RA, Milligan A, White GB, Stilles WC. "A dynamic programming approach to apple orchard replacement." Agricultural Economics Research 1983: 83-11. Department of Agricultural Economics, Cornell University, Ithaca, 74.
10. Jereb E, Bohanec M, Rajkovic V. DEX-i – Računalniški program za večparametrsko odločanje (DEX-i – Computer system for multi attribute decision making). Ljubljana: Moderna organizacija 2003:91.
11. Ramos A. Walnut production manual. Oakland: University of California, Division of Agriculture and Natural Resources, 1998, California. Publication 3373,311
12. Rogers M, Bruen M. "A new system for weighting environmental criteria for use within ELECTRE III." European Journal of Operational Research 1998;107:552-563.
13. Rogers M, Bruen M. "Choosing realistic values of indifference, preference and veto thresholds for use with environmental criteria within ELECTRE." European Journal of Operational Research 1998;107:542-551.
14. Rozman C, Tojnko S, Turk, J, Par V, Pavlovic M. „Die Anwendung eines Computersimulationsmodells zur Optimierung der Erweiterung einer Apfelplantage unter den Bedingungen der Republik Slowenien." Berichte über Landwirtschaft 2002;80/4:632-642.
15. Tiwari DN, Loof R, Paudyal GN. "Environmental-economic decision-making in lowland irrigated agriculture using multi-criteria analysis techniques." Agricultural Systems 1999;60:99 -112.

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