INTEGRATING THE FUZZY ANALYTIC HIERARCHY PROCESS WITH DYNAMIC PROGRAMMING APPROACH FOR DETERMINING THE OPTIMAL FOREST MANAGEMENT DECISIONS

Lidija Zadnik Stirn
University of Ljubljana

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1. INTRODUCTION – PROBLEM STATEMENT AND LITERATURE OVERVIEW

2. THEORETICAL APPROACH TO THE MODEL – time periods, state variables, decision variables, objectives, optimal policy

3. ILLUSTRATIVE EXAMPLE

4. CONCLUSIONS

1. INTRODUCTION – PROBLEM STATEMENT AND LITERATURE OVERVIEW

PROBLEM OF FOREST MANAGEMENT DEALS WITH
LONG TIME HORIZON, TECHNICAL, ECONOMIC, ECOLOGICAL AND SOCIAL ISSUES, SUSTAINABILITY AND PUBLIC'S ACCEPTANCE OF THE FOREST MANAGEMENT DECISIONS.

THUS, SELECTING AN OPTIMAL FOREST MANAGEMENT DECISION GENERATES A MULTICRITERIA OPTIMIZATION PROBLEM WHICH IS ILL-DEFINED.

THEREFORE, THE PROBLEM OF FOREST MANAGEMENT DEMANDS FOR A DECISION SUPPORT MODEL.

FEW DECISIONS IN FORESTRY ARE MADE WITHOUT REFERRING TO MODELS - INFORMAL, CONCRETE, ABSTRACT (BUONGIORNO AND GILLES, 2002).

MOST KNOWN AND ALSO USED MODELS WERE DEVELOPED IN USA. THE LIST OF REFERENCES IS FOUND IN BARE ET AL. (1984), KENT ET AL. (1994), SCHMOLDT ET AL. (2001), SHIELDS ET AL. (2002);

THE LIST OF MODELS MORE EUROPE ORIENTED IS FOUND IN VALSTA (1993), KURTH (1994), VON GADOW (2004).

THE MODELS DEVELOPED EMPLOY LP – FORPLAN (KENT ET AL., 1985), DDDP (ZADNIK STIRN, 1990, HOF, 1993), MULTI-OBJECTIVE METHODS (KANGAS, 1993, LOEHLE ET AL., 2002), STATISTICAL METHODS AND SURVEYS FOR PUBLIC VALUES (PRABHU ET AL., 1999, SHIELDS ET AL., 2002), ECONOMETRIC METHODS (ADAMS ET AL., 1994, SLEAVIN, 1996), HEURISTIC AND STOCHASTIC METHODS FOR SUSTAINABILITY AND BIODIVERSITY (LIN AND BUONGIORNO, 1998, MENDOZA AND PRABHU, 2000).

WITHIN DESCRIBED FRAMEWORK WE HAVE GENERATED A MODEL WHICH ENABLES:

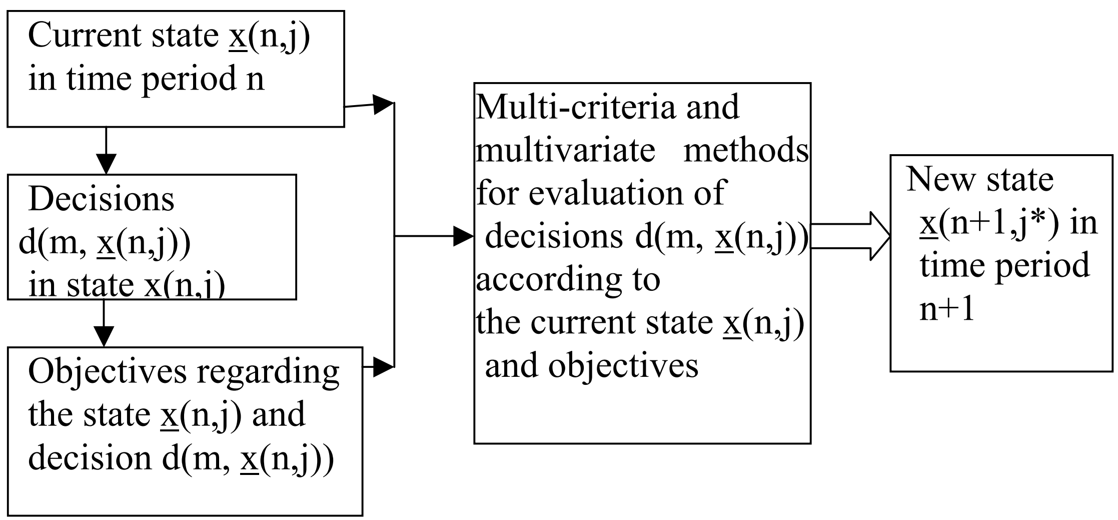
- TO DETERMINE THE CURRENT, THE GOAL AND THE TRANSITIONAL STATES OF THE FOREST UNDER CONSIDERATION
- TO DETERMINE IN COOPERATION WITH AN INTERDISCIPLINARY TEAM THE FEASIBLE FOREST MANAGEMENT DECISIONS
- TO ESTABLISH A SET OF CRITERIA FOR RANKING THE SELECTED DECISIONS AND TO UTILIZE THE METHODS FOR MEASURING THESE CRITERIA REGARDING THE DECSION
- TO USE FUZZY APPROACH AND AHP METHOD KNOWING THAT THE CRITERIA ARE IN CONFLICT, AND THAT SEVERAL INFORMATION ARE UNCERTAIN AND IMPRECISE
- TO PRESENT THE PROBLEM IN A FORM OF NETWORK AND TO USE THE BELLMAN’S PRINCIPLE OF OPTIMALITY TO DETERMINE THE OPTIMAL SEQUENCE OF FOREST MANAGEMENT DECISIONS.

2. THEORETICAL APPROACH TO THE MODEL – time periods, state variables, decision variables, objectives, optimal policy

TIME PERIODS

THE PLANNING HORIZON IS DIVIDED INTO TIME PERIODS**,** n (n=0,1,2,...,N).

THE DECISION SUPPORT MODEL FOR OPTIMAL FOREST MANAGEMENT IN TIME PERIOD n



STATE VARIABLES

THE FUZZY AND NON-FUZZY PARAMETERS WHICH DEFINE THE POSSIBLE STATE OF THE FOREST SYSTEM AT TIME n FORM A STATE VECTOR $\underline{x}(n,j)= x(n, s_1, s_2, \ldots , s_s) \in X(n)$,

A CONSIDERABLE ATTENTION MUST ALSO BE PAID TO THE DETERMINATION OF THE GOAL STATE OF THE FOREST-SYSTEM $\underline{x}(n^*,j^*)=x^*(n^*, s_1^*, s_2^*, \ldots , s_s^*)$.

DECISION VARIABLES AND TRANSITION FUNCTION

AT EACH TIME n, FOR STATE VECTOR $\underline{x}(n,j)$ EXISTS $d(m,\underline{x}(n,j)) \in D(\underline{x}(n,j))$,

$\underline{x}(n+1, j^*)=f(\underline{x}(n,j), d(m,\underline{x}(n,j)))$; TRANSITION FUNCTION f IS DEFINED EMPIRICALLY.

OBJECTIVES

OWNERS, STAKEHOLDERS, AS WELL AS PUBLIC BENEFIT OR LOSE FROM THE DECISION. THUS, THE OBJECTIVES ARE MULTIPLE AND CONFLICTING.

AHP PROCEDURE IS USED TO ASSESS THE DECISIONS ACCORDING TO THE OBJECTIVES. AHP CAN ACCOMMODATE VARIOUS GROUPS AND CAN INCORPORATE QUALITATIVE AND QUANTITATIVE DATA.

THE COMPOSITE UTILITY VALUE I_j OF THE OBJECTIVE j OF THE DECISION IS DETERMINED WITHIN A TWO LEVEL HIERARCHY PROCESS:

$$I_j = \sum w_x \mu_x$$

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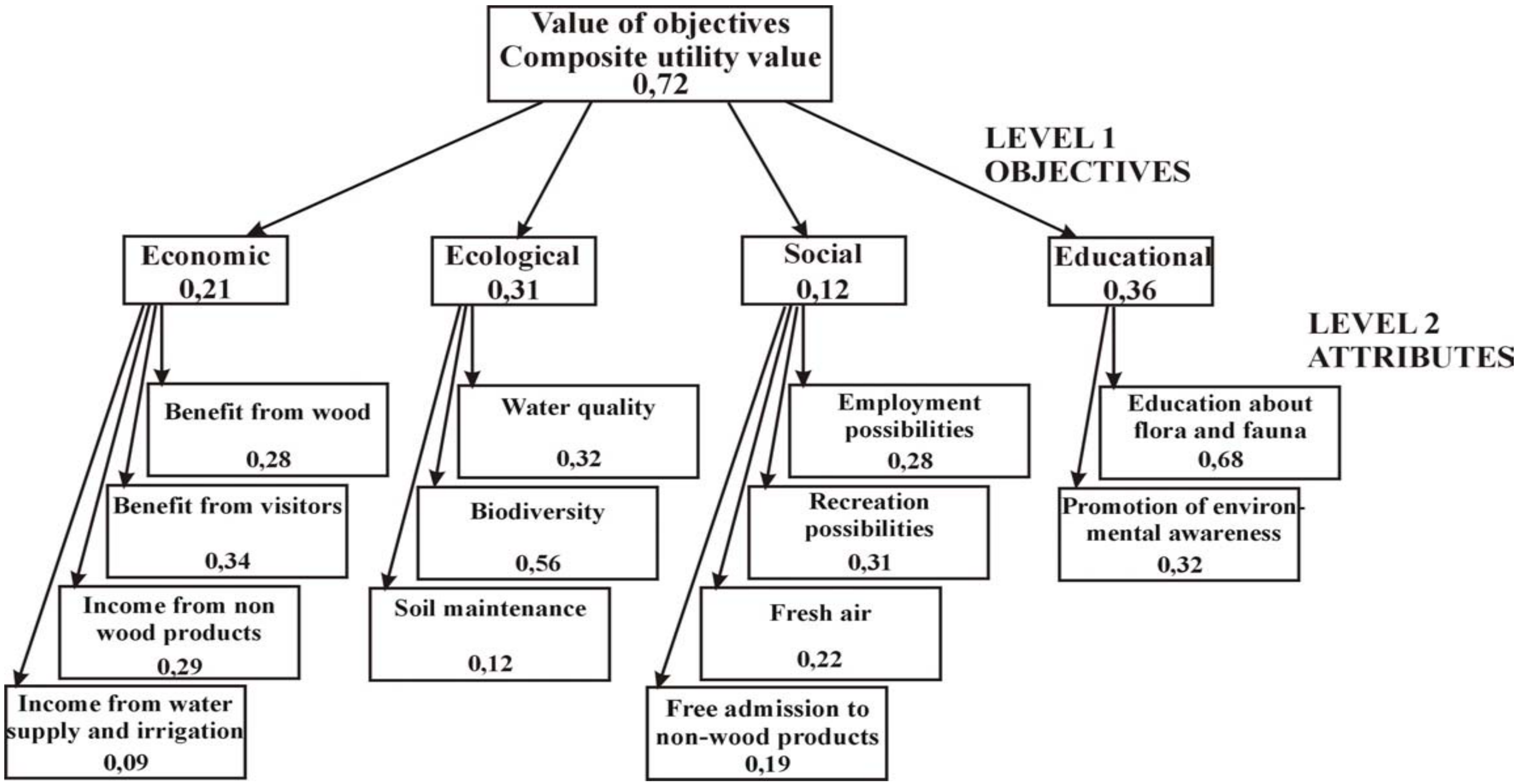
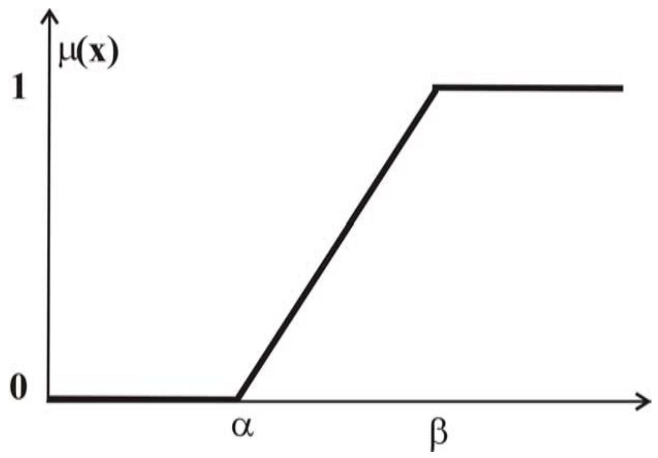

Value of objectives
Composite utility value
0,72
LEVEL 1
OBJECTIVES
Economic
0,21
Ecological
0,31
Social
0,12
Educational
0,36
LEVEL 2
ATTRIBUTES
Benefit from wood
0,28
Benefit from visitors
0,34
Income from non wood products
0,29
Income from water supply and irrigation
0,09
Water quality
0,32
Biodiversity
0,56
Soil maintenance
0,12
Employment possibilities
0,28
Recreation possibilities
0,31
Fresh air
0,22
Free admission to non-wood products
0,19
Education about flora and fauna
0,68
Promotion of environ-mental awareness
0,32

$$I_j = \sum w_x \mu_x$$

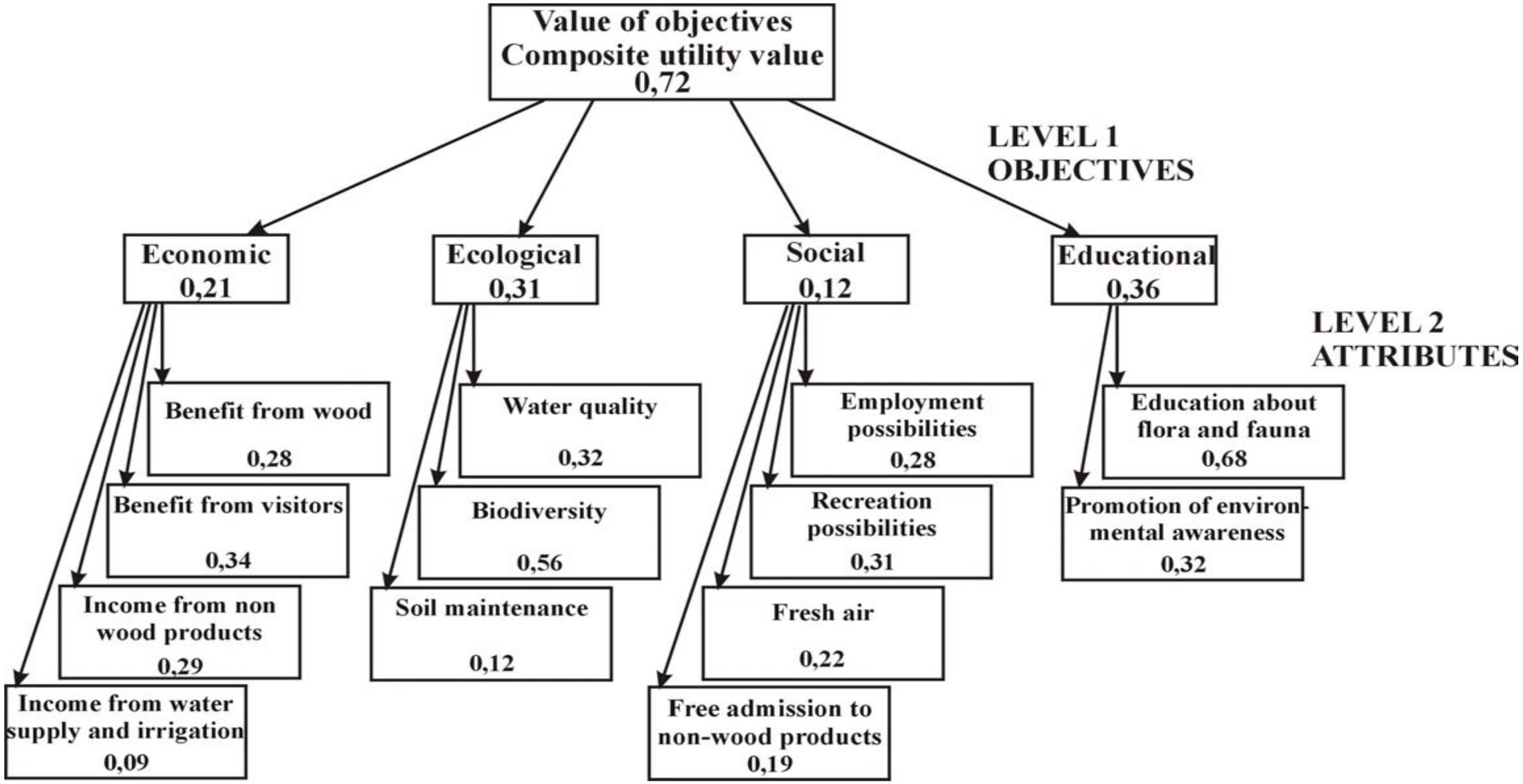
WEIGHTS W_X ARE CALCULATED BY AHP PROCEDURE AND μ_X IS A MEMEBERSHIP FUNCTION, WHICH CAN BE LINEAR, AS FOR EXAMPLE:

$$\mu(x) = \begin{cases} 0 & \text{for } x < \alpha \\ 1 - \dfrac{\beta - x}{\beta - \alpha} & \text{for } \alpha \le x \le \beta \\ 0 & \text{for } x > \beta \end{cases}$$



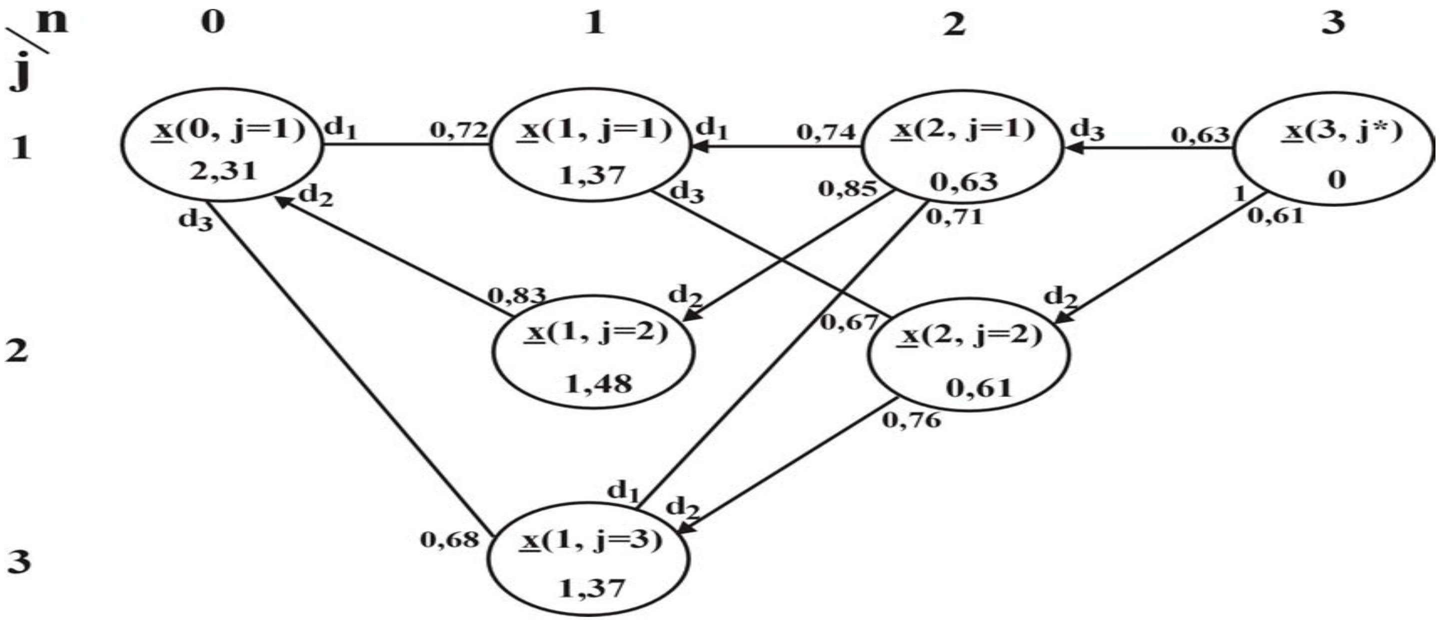
OBJECTIVES AND ATTRIBUTES HIERARCHY FOR A COMPOSITE UTILITY VALUE CUV:

$$CUV = \sum s_j I_j$$



OPTIMAL POLICY

AS SOON AS THE DECISION-MAKER (ANALYST) DETERMINES FOR THE DESCRIBED FOREST MANAGEMENT PROBLEM THE TIME PERIODS, IN EACH TIME PERIOD THE POSSIBLE STATES, FOR EACH STATE THE POSSIBLE DECISIONS, THE TRANSITION FUNCTION, THE OBJECTIVES, ASSESSED AS CUV, HE/SHE IS ABLE TO SHOW ALL THE ELEMENTS IN A FORM OF NETWORK: AND BELLMAN'S PRINCIPLE OF OPTIMALITY IS USED TO DETERMINE THE OPTIMAL FOREST MANAGEMENT POLICY.



3. ILLUSTRATIVE EXAMPLE

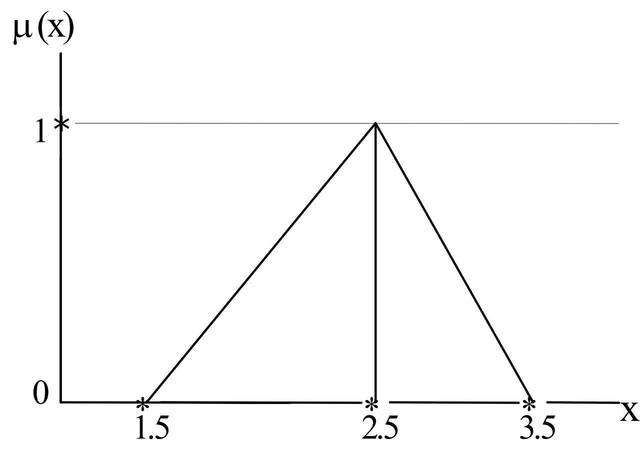
IN THE CASE STUDY WE CONSIDER THE FOREST PANOVEC BY NOVA GORICA – IN A RESTRCITED WAY.

3 MANAGEMENT PERIODS ARE TREATED n=0,1,2,3.

THE CURRENT STATE OF PANOVEC IS IN DETAILS DESCRIBED BY PAPEŽ (2001). SOME OF THE PARAMETERS ARE DESCRIBED AS FUZZY.

SUCH IS THE RECREATIONAL LEVEL/NUMBER OF VISITOR-DAYS/YEAR:

$$\mu(x) = \begin{Bmatrix} 0 & \text{for } 1.5 > x > 3.5 \\ x - 1.5 & \text{for } 1.5 \le x \le 2.5 \\ -x + 3.5 & \text{for } 2.5 < x \le 3.5 \end{Bmatrix}$$



11 MANAGEMENT TASKS REGARDING THE INVESTMENT, TYPE OF SILVICULTURE, QUANTITY OF CUTTING, STORAGE QUANTITY, ETC. WERE GENERATED.

FOR THESE 11 TASKS 13 QUESTIONS USING 5-POINT LIKERT SCALE WERE GENERATED.

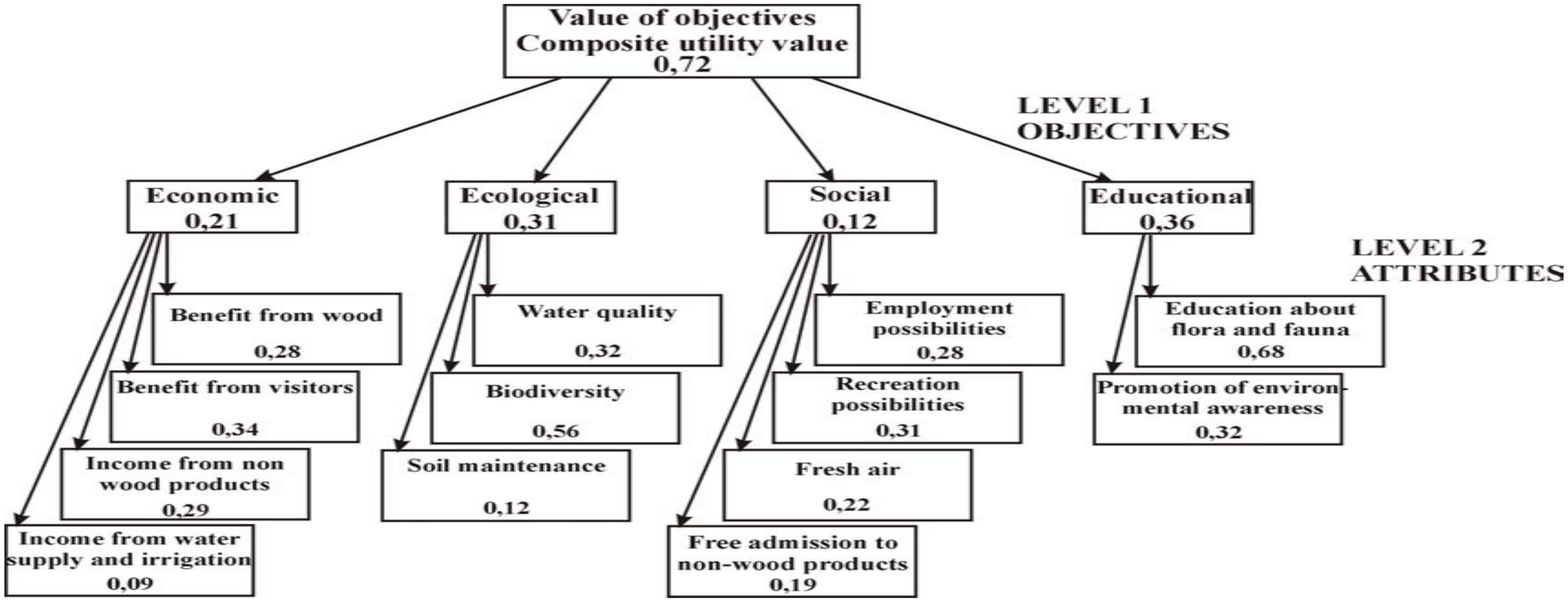
The average results of five surveys with 13 questions for 11 tasks

	Q1	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	**Q11**	**Q12**	**Q13**
P1	3,75	3,00	1,00	3,75	3,25	3,25	2,75	1,75	2,50	2,00	3,75	1,50	2,50
P2	4,00	3,25	1,00	3,75	3,25	3,25	2,75	1,75	2,50	2,00	3,75	1,50	2,50
P3	3,00	2,75	1,25	3,50	3,00	3,25	3,00	1,75	2,25	2,00	3,75	1,50	2,75
P4	4,75	3,75	1,00	3,50	3,50	1,00	1,00	1,75	1,50	1,25	3,50	1,75	2,75
P5	3,00	2,50	1,00	3,00	3,50	1,00	1,00	1,75	1,50	1,25	3,00	1,00	1,50
P6	1,50	2,50	3,75	2,25	1,25	3,75	3,00	2,25	1,50	1,00	2,75	1,75	2,75
P7	3,75	3,25	1,00	2,50	1,75	1,00	1,00	1,75	1,00	1,00	3,00	2,00	2,00
P8	4,00	3,75	1,50	2,75	1,50	1,25	1,00	1,50	1,50	1,00	3,00	1,00	3,25
P9	3,75	3,50	1,75	2,75	1,50	1,00	1,00	1,75	2,00	1,00	3,00	2,25	3,00
P10	2,75	2,00	1,50	2,75	3,25	1,00	1,00	1,75	2,25	1,00	2,75	1,00	1,50
P11	2,00	1,25	1,75	1,75	1,50	1,00	1,00	1,50	1,25	1,00	2,75	1,00	1,00

USING SPSS PROGRAM WE PRODUCED THE DENDROGRAM BASED ON WARD METHOD, WHERE 3 DECISIONS - CLUSTERS ARE CREATED:

THE FIRST DECISION, d_1, MAY BE INTERPRETED AS ECONOMICALLY ORIENTED, THE SECOND DECISION, d_2, IS ECOLOGICALLY ORIENTED, WHILE THE THIRD DECISION, d_3, IS EDUCATIONALLY ORIENTED. FURTHER, WE EXPLAIN ONLY THE ANALYSIS OF DECISION d_1.

THE PROBLEM OF PANOVEC DEALS WITH 4 OBJECTIVES AND 13 ATTRIBUTES.



THE WEIGHTS FOR ATTRIBUTES ARE CALCULATED BY AHP METHOD. FOR THE ECOLOGICAL OBJECTIVE, FOR EXAMPLE:

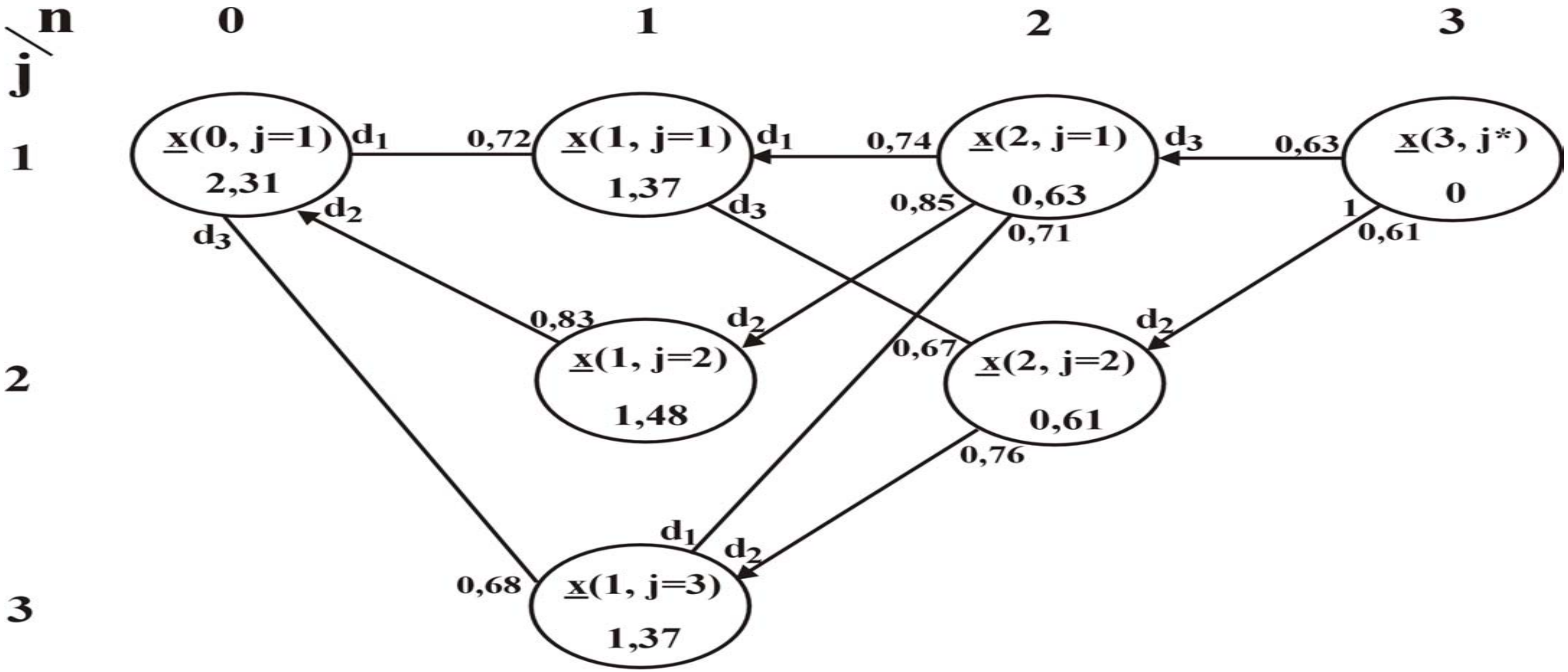
$$A = \begin{array}{c} \\ Q \\ P \\ H \end{array} \begin{array}{c} \begin{array}{ccc} Q & P & H \end{array} \\ \begin{bmatrix} 1 & 1/2 & 3 \\ 2 & 1 & 4 \\ 1/3 & 1/4 & 1 \end{bmatrix} \end{array} . \rightarrow A^2, \quad (A^2)^2, \quad \ldots\ldots \quad \rightarrow \begin{bmatrix} w_1 = 0.32 \\ w_2 = 0.56 \\ w_3 = 0.12 \end{bmatrix}$$

Summary statistics of attributes regarding $\underline{x}(0,j=1)/d_1$

Attribute \ Decision	d_1	α	β	$\mu(x)/d_1$	w_x
Benefit from wood	2.67	1.82	4.50	0.32	0.28
Benefit from visitors	3.69	1.60	4.30	0.77	0.34
Income from non-wood products	3.54	1.22	4.20	0.78	0.29
Income from water supply and irrigation	2.42	1.08	3.80	0.49	0.09
Water quality	4.50	2.30	4.60	0.96	0.32
Biodiversity	3.27	2.45	4.80	0.35	0.56
Soil maintenance	2.77	1.82	3.95	0.45	0.12
Employment possibilities	3.13	1.90	4.05	0.57	0.28
Recreation possibilities	4.50	2.10	4.90	0.88	0.31
Fresh air	3.69	2.10	4.65	0.62	0.22
Free admission to non-wood products	3.40	1.80	4.10	0.82	0.19
Education about flora and fauna	4.15	2.15	4.25	0.95	0.68
Promotion of environmental awareness	3.83	2.10	4.15	0.84	0.32

GIVEN THE DATA IN ABOVE TABLE (u(x)/d_1 AND w_x), AND USING FORMULA FOR I_k, THE IMPACTS OF ATTRIBUTES ON THE OBJECTIVES ARE CALCULATED, AND FINALLY CUV IS CALCULATED; CUV=0.72.

THE DATA OF THE ATTRIBUTES AND OBJECTIVES FOR THE OTHER TWO DECISIONS/STATES ARE OBTAINED IN A SIMILAR WAY. ALL THESE DATA ARE GATHERED IN A NETWORK:



7. CONCLUSIONS

THE SOLUTION TO THE MULTIPLE-USE FOREST MANAGEMENT PROBLEM INVOLVES THE INTEGRATION AND COORDINATION OF MULTIPLE DECISION MAKERS AND CAN NOT BE OBTAINED BY THE SOLE USE OF ONLY ONE OPERATIONS RESEARCH METHOD.

IT ACCOMMODATES INTERACTIONS WITH THE STAKEHOLDERS AND PUBLIC. THE END USERS OF A PRESENTED DECISION SUPPORT MODEL MIGHT BE FOREST INSTITUTIONS OR ENTERPRISES IN CHARGE OF PUBLIC WOODLAND MANAGEMENT, RURAL DEVELOPMENT INSTITUTIONS, PRIVATE OWNERS OF WOODLANDS, AND MIXED FARMS USING THEIR LAND FOR BOTH FORESTRY AND AGRICULTURE.

AS SOON AS PREFERENCES OF THE DECISION MAKERS, AND/OR PUBLIC CHANGE, THE FEEDBACK IN THE DECISION SUPPORT MODEL SHOULD BE OBSERVED.