Evaluating Ecological Preservative Management in a Mountainous Maoli site of Taiwan by Multi-Stage Decision and FAHP Process

KUEI-YANG WU[a,*], WANN-MING WEY[a], WEN-ZER LIN[b]
[a] Department of Architecture, National United University,
Maoli, TAIWAN 36003, R.O.C.
[b] Institute of Earth Sciences, Academia Sinica, NanKang,
Taipei, TAIWAN 11517, R.O.C.
[*]E-mail: kyw@nuu.edu.tw http://www.arch.nuu.edu.tw

Abstract: The paper presents a fuzzy analytic hierarchy (FAHP) and multi-stage objective model for optimal ecological preservative management, which determines the decision sequences that jointly maximize economic, ecological and social objectives, respects prescribed constraints and imprecision, and takes the ecological preservative management system from its existing status to the goal state. The cumulative impacts of objectives are formulated on the basis of attributes as a sum over all products of their membership functions and their relative importance (weights). A case study involving the ecological preservative management in Tatung community in Maoli, Taiwan, is used to demonstrate the application of the presented model. The problem in that community is presented in a form of a network, and the optimal policy over three year periods is determined using the iteration method for the solution of sequential decision processes of Bellman's type. The results show that the optimal decision sequences over the period mentioned above consist of the biological diversity oriented decision in the first and second years, and consider environmental loading oriented decision in the third year. In order to solve this problem, several decision support systems and models were developed.

Key-words: FAHP, Ecological preservation, Multi-stage objectives model, Optimal policy, Network.

1. Introduction

The city development has been a major driver in the conversion of natural ecosystems. The management in mountainous community in Taiwan is becoming increasingly paramount for ecological conservation as world's natural environment promptly shrinks. Moreover this shifting process of rapid urbanization development and patterns from previous agricultural land uses to current urban one are not yet fully considered of the natural land condition as the base of cities because ecological conservation has long been neglected [6]. This advantage stems from the magnitude of intact ecosystems, a dynamic policy environment, and the increasing availability of biological and economic data needed to harmonize conservation with public endeavors.

Mansfeld Jonas [10] used the carrying capacity value stretch model incorporated into nominal group technique methodology to investigatie a rural community's determinants of sociocultural carrying capacity perceptions in the wake of rural tourism development. Christopher and Polasky [5] stressed that an important strategy to conserve biological diversity is to protect habitat through the establishment of a biological reserve system. Stirn et al. [15] revealed that a forest management problem consists of decisions on investment, silviculture and harvesting activities for an existing forestland over a long time horizon, while guaranteeing sustainability, maximizing the expected profit, referring to ecological objectives and the public's acceptance of decisions. Zamani et al. [19] stressed that raising community awareness could avoid slow-onset chronic hazards, such as extreme climate conditions and pollution; they used a multilevel theoretical framework based on the Conservation of Resources theory and the ecological analogy. Lee et al., [9] developed a system that provides great support to both the strategic and operational aspects of project management by integrating familiar network concepts with system dynamics to analyze the overall strategic and operational project performance.

Again, McAlpine, et al. [11] indicated that, based on the evaluation of the two regional plans, regional biodiversity conservation goals may be better achieved by implementing sustainable forest management practices across all ownerships and involving all stakeholders in the broader community. And eleven concepts were identified by Schulte, et al.[14], who expected to have some relevance to forest planning and management, including reserves, matrix management, coarse filter, mesofilter, fine filter, hotspots, diversity begets diversity, emulating natural disturbances, patchworks, networks, and gradients.

A method for assessing fishhabitat assemblages at multiple scales is proposed and tested by Boys, and Thoms [3] in a large Australian dryland river, the Barwon–Darling River. Six discrete mesohabitat types (large wood, smooth bank, irregular bank, matted bank, mid-channel and deep pool) nested within 10 km long river reaches were sampled. Costello and Polasky [4] used optimal and heuristic algorithms, by formulate this problem as a stochastic dynamic integer-programming problem, to analyze the problem of chosen sites through time to include in a network of biological reserves for species conservation.

In strategic management research, Lee, et al., and Montreuil, et al., [9, 13] pointed out a strategic framework for designing and operating management networks enables a collaboratively plan, controls and manages year-to-year contingencies in a dynamic environment. Implementing strategic project management would let project managers not only learn the relationships of different communities and work sequences in their entirety, but also realize the impact of how one event or decision could affect overall project performance. Wu, et al. [16-21] presented sustainable community strategy evaluation by using multivariable analysis method in Miaoli countryside of Taiwan. These strategic project managements are operational project management and can help administer getting a detailed operational analysis with the guidance of the strategies set forward at the strategic project management stage.

The study has tried to develop a model for a new integrated network-based simulation approach with a FAHP, and Multi-Stage Decision (MSDs) methodology. The purpose is to encompass both the strategic and the operational aspects of project management that can be updated in time by visitor opinions or experts to enhance managers' ability, and apply in a mountainous Tatung community of Maoli, Taiwan. We aim to investigate this community with a hope to transfer this experience for other communities in this county. The goals of this research are: (1) to study the three levels hierarchical indicators considered as strategy by integrating FAHP with MSDs analysis and by investigating the Tatung community of Miaoli city; (2) to analyze benchmarks by questionnaire survey from residents that would promote an ecological conservation in Tatung community.

2. Site and method

2.1 Site

The Tatung community is situated on the southwestern side of Tatung Li (neighborhood) with an administrative area of 0.121 square kilometer and is the smallest community in Miaoli City. Fig. 1 shows the location of Tatung community, where is near mountainous area and its development started relatively early with a population of about 800 residents. Because local residents have been alarmed that tourism activity could conflict with local environment in coming several years. Consequently Tatung community residents organized themselves to fulfill ecological preservation in a three-year period that was proposed based on questionnaire by using a multilevel theoretical framework. After surveying this community and its dwellers, we found two main problems when promoting to establish the community's ecological conservation planning: (1) it does not properly understand the environment carry capacity, conserving current natural landscape, and cultural-historical sites; and (2) there is no clear plan for maintaining environmental ecology for the community.

2.2 Method

Tatung community was regarded on its current environmental planning as not carrying out evaluation for the completed programming in details because they only used rules by their experiences after we interviewed 12 the officers and local residents of this community.

Eventually we chose environmental management, ecological conservation and environmental loading as the main phases for evaluation. The objective value for each phase can be expressed with Likert scale（n＝5, 4, 3, 2, 1). The local residents or experts made the judgment decision of ecological conservation management in considering three-year planning in this community. Each judgment contained left score (α) and right score (β), that can be transformed into the suitable total score (μ). With the transformation of this mode [11], the result can provide a suitable path for the decision maker.

This research aims towards ecological preservation and schedules on three years period, and the goal of the ecological preservation will avoid a conflicting with economical development. Each year, it is executed according to the repeated process of "comparing the relative importance in different variables and then making each decisions for three different stage (year)" during three years period. Table 1 shows the performance measurement for the three decisions in each process.

3.Multi-Stage Decision (MSDs) and Performance Value of the Goal

3.1 Multi-Stage decision planning

Dynamic programming is an operation technique of quantity that was developed by Richard Bellman [1] to analyze various and complicated multi-stage decision procedure for searching available strategy to solve sequential decision making problem. The solution for dynamic programming takes the complicated problem into several correlated sub-problems accordingly to simplify it, then analyze and consider them respectively in order to find out the optimal solution. During the process of multi-stage decision the most benefit decision for each stage is to offer the basis for next correlated stage decision. MSDs using dynamic programming must have four characteristics (Hillier and Ieberman [7]) including: (1) the problem can be divided into several stages and given one decision for each stage; (2) each stage has several stage vectors, stage means various possible situations for each stage of the problem in the system; and (3) the decision vector for each stage can make the vector for certain state transformed into state vector of next stage, and the decision vector is composed by one group of decision variables, and the state variable of current stage also contains the effect to the system by the decision of last stage.

Overall, this optimal problem of community's ecological conservation programming in this research can satisfy the above characteristics, and is suitable to use MSD programming in solving the problem.

3.2 Determination of dimension on state variable

For evaluating the community dynamic ecological conservation hierarchical system, the evaluation criteria or variable are created by collecting the opinions of experts and scholars and related documents [10, 12, 16-21]. Lastly we considered three dimensions including economic development, environmental ecology, and environmental carrying capacity perceptions. The dimension of "carrying capacity" thresholds of a given community might create antagonism among its members toward sustainable community etc. Using the case of tourism in a mountainous community of Maoli, this paper examines the perceptions and attitudes of local residents towards the development and operation of ecological conservation in Tatung community.

To decide the proper steps in the processing procedure is the main subject of this research although the procedure of decision is rather complicating. In this study the ecological conservation planning project in the operation period is set to three years. In each year, there are three items (decisions) were provided experts or local residents to make decision, which include economic development decision (d1), ecological conservation decision (d2) and environmental carrying capacity perceptions decision (d3). In the three-year decision process, decisions that are made would need to judge which stage can reach the greatest performance for total decision procedures.

4. Discussion

4.1 Decision of the criterion weight

The traditional AHP theory is simple and can effectively analyze complicated policy-making problems by using hierarchy structure. However, it does not make consideration on the subjectivity, uncertainly and vagueness of human minds. In order to overcome this shortcome, fuzzy AHP proposed by Satty was further developed and applied by Laarhoved & Pedrycz [8], and Buckley [2]. The AHP processes are summarized as: (1) to establish hierarchy analysis framework, pair comparison matrix, triangular fuzzy numbers, and fuzzy positive reciprocal matrix; (2) to calculate the fuzzy weight of positive reciprocal matrix, and examine the consistency of fuzzy matrix, then calculate the number of α-cuts; (3) to defuzzificate, normalize and combine hierarchy; and (4) to arrange all elements in order according to the calculated weight.

In this study we want to improve Buckly's [2] fuzzy analytic hierarchy process by combining the triangular fuzzy number [8] and gravity method of FAHP as a way to evaluate each aspects and index weights. Triangular fuzzy number uses three fuzzy numbers to represent the vagueness of the subjects, and this can assist the calculation of the study. After comparing the relatively importance of element *i* and element *j*, each subject would be evaluated differently in the analysis. Three numbers are picked out from the triangular fuzzy number *a*, *b*, and *c*, respectively. Number *a* is the smallest number which is evaluated by all subjects in comparing element i and element *j*. By contrast, number *c* is the biggest number, number *b* is the geometric mean, and both are evaluated by all subjects. Fig. 2 shows the parameter of "biologic conservation" of triangular membership function in Tatung community study. 2.17 is the smallest which is evaluated by the objection "biologic conservation" shown in Table3 in comparing related attribute. By contrast, 4.17 in horizontal axis is the biggest number, 3.67 is the geometric mean. It means the optimal value in the objection "biologic conservation" is established in "medium" value or "adequate" one, rather than choosing the biggest value that experts or local residents only focused on this single objection (decision) if ignore total decision.

This fuzzy subset *A* was featured the traits below: μ_A represents a sequential function, a convex fuzzy subset, and a normality of a fuzzy subset. Given a real number $x_0, \mu_A(x_0) = 1, x \in \mu$

$$\mu_A(x) = \begin{cases} 0, & x < a \\ \dfrac{x-a}{b-a} & a \le x \le b \\ \dfrac{c-x}{c-b} & b \le x \le c \\ 0, & x > c \end{cases}$$

The AHP system can be divided into three-level. The first level is goal, the second level is analyzing dimensions, and the third level is object/variable. Thus the AHP system can be established in this study as: (1) economic development: solid waste control, waste water control, waste collection, and air pollution management; (2) environmental ecology: biologic preservation, biodiversity, and forest and moist reserve area; and (3) environmental carrying capacity perceptions: streams and water quality pollution, and average water penetration rate, and mountain slope development area. To get exactitude, we carried out one time pre-questionnaire before performing AHP questionnaire that can ensure the effectiveness of evaluation objects, standards and variable. The interviewees can select the questionnaire, and then get the weight of each assessment criterion by means of pair wise comparative procedure. The calculation sums every weight distributed for each variable, experts or residents (responders) must fill the score for the contribution degree to reach final object for each property. The score for each case will be multiplied with variable weight to acquire total score of the decision (economic development, environmental ecology, and environmental carrying capacity loading).

The decision performance value (DPV) can be expressed as DPV= $\sum_{i=1}^{m} w_i r_{ik}$; where w_i = weight, r_{ik} = an index that provides the cumulative impacts of attributes $t(k)$ on the favorability of objective *k* to DPV. The score for each decision performance can be expressed with the sum of evaluation standard grade for each item and the relative weighted product. The multiple criteria evaluation system and its hierarchical structure in this research are shown in Fig. 3.

4.2 Integrating performance value of the goal and best path programming

Based on the direction of operation, it can be classified into forward and backward MSDs. For obtaining the optimal decision the formal calculation can start from the first stage to the last one; the latter from the last stage to the first stage. Both methods are to find out the best route. In our study we adopt the backward MSDs and the best route from last stage to first stage is made by recurrence relation [1]. In the community ecological conservation programming, economic development (d1), environmental ecology (d2), and environmental carrying capacity perceptions (d3) are the second level dimension. According to Stirn, et al. [15] the node (*N j)* and the contribution degree for the *L*(*j*) decisions can be calculated within several objects. By multiplying the objective weight, we can get the weighted performance value (Table 1).

Fig. 4 show that the sum of the optimal value in every state (year) is not the optimal path value in this study. For example, $\mu(x)/d_1$ in A-B2 is 0.44, actually its maximal value in this stage is 0.58. And $\mu(x)/d_1$ in B2-C3 is 0.75，its maximal value in this stage is 0.79, the $\mu(x)/d_1$ in B2-C3 is 0.50, its maximal value in this stage is 0.70. These parameters can be found in Table 1. Therefore, we will not get optimal decision path value if we ignore continual decision evaluations process. This indicates it is important to consider total paths, i.e. dynamic planning decision model in our study.

Shown in Fig. 5 node A is the starting point of the programming first year as decision was chosen. In second year, the expert must make the decision at the starting nodes in either B1, B2 or B3, and third year at these nodes in either C1, C2 or C3. Totally there are three kinds of decisions including environmental management, ecological conservation, and environmental loading that can be chosen in this network procedure. In Fig. 5with these values in Table 1, we can carry out dynamic programming in suitable procedure; the weighted performance value based on each route in the procedure can be solved by using dynamic programming and get the suitable path (Table 2). Eventually the best path for ecological conservation programming in this study is: A→B2→C1→D. The objective performance values are: object 1 (0.67), object 2(0.75) and object 3 (0.63). And the longest distance= DPV in the optimal ecological preservation management in Tatung community, Maoli, Taiwan=0.63+0.75+0.67=2.05 (shown in Fig.5). This parameter of DPV is similar to that of CUV (Composite utility value) proposed by Stirn et al. [15]. The process of community ecological conservation programming should be considered in environmental ecology (d2) in the first year, considered in environmental ecology (d2) in the second year, considered in environmental carrying capacity perceptions (d3) in the third year. Table 3 indicates summary statistics of attributes in the path A-B2.

5. Conclusion

The ecological conservation programming in this community can be regarded as route network programming problem. From the starting point to node before ending point, every point is the decision position. Meanwhile, it must consider the achievement of goal and the effect of uncertainty. Our major findings and recommendations of this study may be summarized as follows:

The problem of community ecological conservation programming is to determine the procedure of operation. Therefore it has the characteristics of route network. Moreover, the problem of community ecological conservation programming not only has to concern the problem of ecological conservation, but also stresses environmental carrying capacity loading and time sequencing in fulfillment in three-year schedule. Therefore it exists the nature of multiple-goal as well as fulfill-year planning. Due to the uncertainty of making decision, this research proposed fuzzy multiple-goal decision model to carry out the programming of suitable ecological conservation in this community.

Usually in the multiple-goal network programming, the weight of object will be measured by the whole network. Nonetheless before reaching the end point, different stage (scenarios) will face each node to make a decision. Thus this research takes each node as a decision point and each node has different weighted value in current stage in order to get the optimal decision performance value (DPV).

Based on the analysis of this research, ecological conservation programming in the community, the first priority benchmark in each year included in the first year residents concerning biodiversity in ecological conservation, in the second year in the ecological conservation, and the water quality pollution of stream in environmental carrying capacity in the third year.

In this paper, we first propose a network-oriented organizational strategy based on ecological preservation by dynamically organizes its management operations through the three-stage (year) decision integrating AHP in a distributed network of ecological preservation goal. And we present a collaborative relationship strategy as a contractual approach to implement operational networks. Also we introduce an operational strategy, showing how this networked collaborative approach can be used to manage year-to-year decisions and managements in a close-to-reality manner.

The fulfillment of "ecological preservation" in mountainous Tatung community represents a planning development and management approach for attaining an integrated and balanced tourism sector that takes consideration in ecological environmental interests, socio-cultural and not concerning economic development needs. In this strategic framework, rural areas will seek three main socio-cultural prerequisites, as a precondition for successfully managing in rural sustainable community objection. The first will stress environmental ecology instead of economical development concerning tourism; the second is managing local biology diversity; the third is a broad examination of the socio-cultural 'carrying capacity' which includes (1) streams and water quality pollution; (2) average water penetration rate in land; and (3) mountain slope development area ratio, in this community prior to any economic development such as tourism.

In summary, this study still needs to be improved for further work. By using 12 sets of data in our decision-making system is not enough to be a perfect database, the dataset should be improved and expanded. Regarding the factor's criteria in the hierarchical structure, this study simply collects relevant bibliography and expert opinions, but lacks extensive and comprehensive undertaking questionnaire design. Thus we propose that the questionnaire items can be systematically designed and explained in follow-up studies.

Furthermore, Maoli site of Taiwan and its ecological preservative management in mountainous land characteristics presented in this paper suggests that the major multi-stage decision on environmental conservation are linked to find optimal decision path value we must consider optimal value in sum of all stages rather than thought single or parts of stages decision evaluations process. This indicates it is important to consider total paths, i.e. dynamic planning decision model in our study. However, to plan the priority step executing "Economic Development", "Environment Ecology" and "Environmental Carrying Capacity Perceptions" are more complex, but further and more detailed examination of this dynamic method will be explored in a companion paper.

Acknowledgments

The authors thank the National Science Council (NSC 96-2415-H-239-002-SS3), Taiwan, for financially supporting this research.

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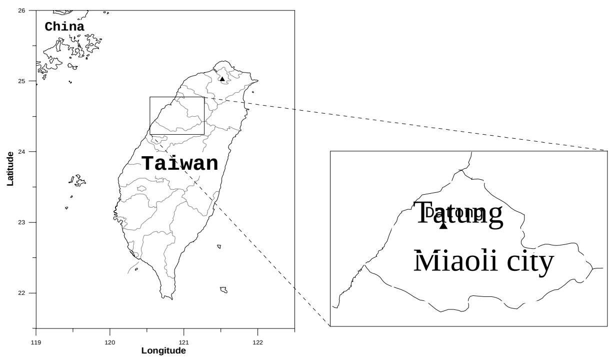

Fig. 1 Location of Tatung community in Miaoli city of Taiwan.

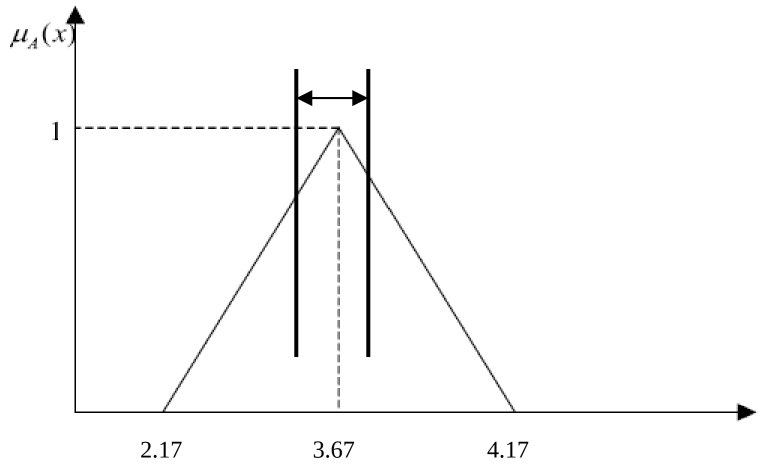

Fig. 2. Parameter of "biologic conservation" of triangular membership function in Tatung community study. 2.17 in horizontal axis is the smallest, 4.17 is the biggest number, 3.67 is the geometric mean. They were evaluated by the objection "biologic conservation" shown in Table3 by comparing related attribute. By contrast, Two arrows indicates the probable boundary to approach the optimal objection value of "biologic conservation".

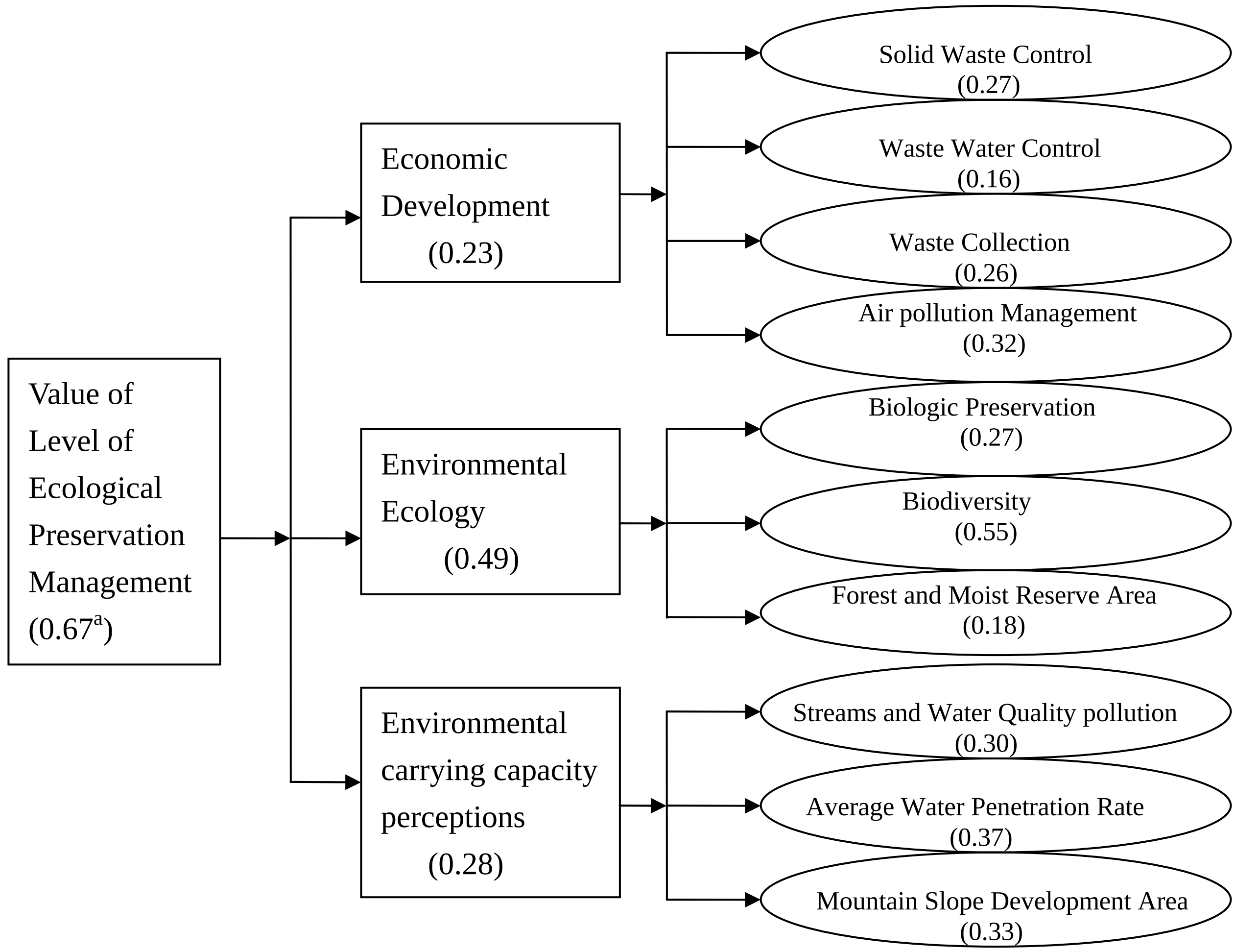

Fig. 3. Level of toward an ecological preservation planning in Tatung community study using multi-stage decision and FAHB method in the Miaoli city of Taiwan. Numbers in parentheses indicates the value in $\omega(x)$ and "a" means calculation value in CUV.

Table1 Weighted object performance value for each program path in Tatung community, Maoli, Taiwan

Year	Node	Decision	Connected Spot	$d_1(x)$	a	b	$\mu(x)/d_1$	$\omega(x)$	Performance Value (PV)	Weighted PV
1st y	A	d_1	$A-B_1$	2.83	2.33	3.67	0.38	0.17	0.76	0.61
	A	d_2	$A-B_2$	2.50	1.83	3.33	0.44	0.49	0.74	0.67^{a1}
	A	d_3	$A-B_3$	3.67	2.50	4.50	0.58	0.30	0.52	0.66
2nd y	B_1	d_1	B_1-C_1	2.83	2.00	3.50	0.56	0.14	0.55	0.58
	B_1	d_2	B_1-C_2	2.83	2.50	3.67	0.29	0.38	0.79	0.63
	B_1	d_3	B_1-C_3	3.17	2.17	3.83	0.60	0.17	0.61	0.59
	B_2	d_1	B_2-C_1	3.50	2.17	4.50	0.57	0.31	0.50	0.54
	B_2	d_2	B_2-C_2	3.33	2.17	4.17	0.58	0.49	0.56	0.57
	B_2	d_3	B_2-C_3	3.17	2.17	4.17	0.50	0.28	0.75	0.75^{a2}
	B_3	d_1	B_3-C_1	3.00	2.00	3.67	0.60	0.36	0.58	0.55
	B_3	d_2	B_3-C_2	3.50	2.33	4.00	0.70	0.49	0.71	0.66
	B_3	d_3	B_3-C_3	4.17	2.67	4.83	0.60	0.66	0.56	0.56
3rd y	C_1	d_1	C_1-D	3.00	2.33	3.83	0.44	0.17	0.57	0.60
	C_2	d_2	C_2-D	3.50	2.50	4.33	0.55	0.49	0.67	0.61
	C_3	d_3	C_3-D	3.33	2.50	4.50	0.42	0.30	0.65	0.63^{a3}

Note: the longest distance= the optimal ecological preservation management in Tatung community, Maoli, Taiwan= $a^3+a^2+a^1=0.63+0.75+0.67=2.05$ (shown in Fig.5)

Table 2 The process of calculation for optimal path in Tatung community, Maoli, Taiwan

State	Node-node	$\tilde{f}_n(s_n, x_n)$	$\max \tilde{f}_n$	x_n^*
1st y	A-B1	1.85		
	A-B2	2.05	2.05	B2
	A-B3	1.93		
2nd y	B1-C2	1.24	1.24	C2
	B1-C3	1.22		
	B2-C1	1.14		
	B2-C2	1.18		
	B2-C3	1.38	1.38	C3
	B3-C1	1.15		
	B3-C2	1.27	1.27	C2
	B3-C3	1.19		
3rd y	C1-D	0.60	0.60	C1
	C2-D	0.61	0.61	C2
	C3-D	0.63	0.63	C3

x_n^* is the best decision making under n stage and s_n status

Table 3. Objection and attributes in A-B2 of optimal path study in Tatung community, Maoli, Taiwan

A-B2	d1(x)	a	c	μ(x)/d1	ω(x)	Performance Value / Attributes	Performance Value / Objectives	Composite Utility Value
Objectives								
Economic Development	3.17	2.50	4.00	0.44	0.23		0.56[a]	0.67[b]
Environmental Ecology	2.50	1.83	3.33	0.44	0.49		0.74	
Carrying capacity perceptions	3.67	2.67	4.67	0.50	0.28		0.64	
Attributes								
Solid Waste Control	3.50	2.33	4.67	0.50	0.27		0.13	
Waste Water Control	3.33	2.50	4.50	0.42	0.16		0.07	
Waste Collection	3.17	2.17	3.67	0.67	0.26		0.17	
Air pollution Management	3.83	2.83	4.50	0.60	0.32		0.19	
Biologic Preservation	3.67	2.17	4.17	0.75	0.27		0.20	
Biodiversity	4.00	2.33	4.33	0.83	0.55		0.46	
Forest and Moist Reserve Area	3.67	2.83	4.83	0.42	0.18		0.08	
Streams and Water Quality Pollution	3.17	2.17	3.83	0.60	0.30		0.18	
Average Water Penetration Rate	3.50	2.00	4.00	0.75	0.37		0.28	
Mountain slope Development Area	3.33	2.17	4.33	0.54	0.33		0.18	

a. 0.56=0.5*0.27+0.42*0.16+0.67*0.26+0.6*0.32; b. 0.67=0.23*0.56+0.49*0.74+0.28*0.64

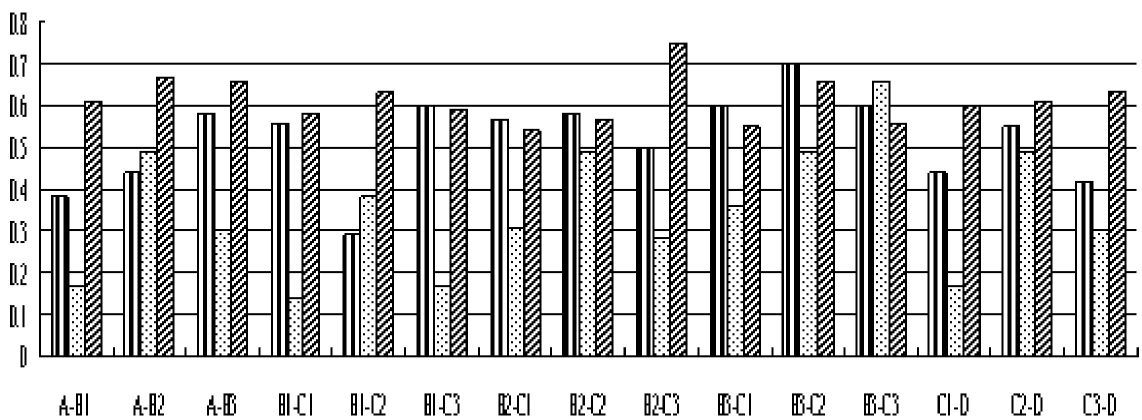

Fig. 4. Decision-makers adopted triangular fuzzy set to evaluate every decision node and benchmark weight in ecological conservation planning by interviewing with manager in Tatung Community in this study. Left, middle and right in A-B1, A-B2,…., C3-D, etc. represent d_1, $\omega(x)$, and weighted performance value, respectively.

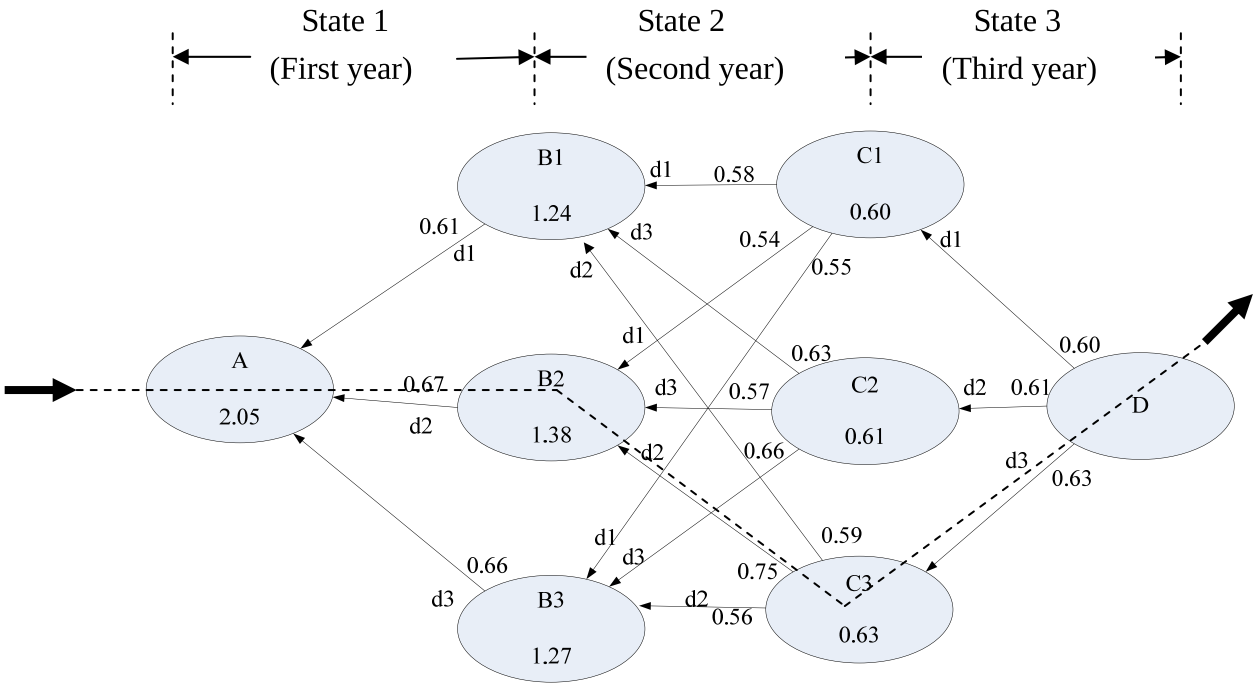

Fig. 5. A network to demonstrate the multi-objective dynamic procedure in Tatung Community study. The best path for ecological conservation programming is A→B2→C1→D in this community. The objective performance values are: object 1 (0.67), object 2(0.75) and object 3 (0.63). Thus the process of community ecological conservation programming should be considered in environmental ecology in first year, then considered in environmental ecology in second year, and considered in environmental carrying capacity perceptions in third year. Dot line indicating the best route (strategy) programming is the longest distance, i.e. the biggest value in sum of DPV is 2.05 in this research.