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Multiple-Use Management Planning of Forest Resources Using Fuzzy Multiobjective Linear Programming[1]

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퍼지 多目標 線型計劃法에 의한 山林資源의 多目的 經營計劃[1]

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ABSTRACT

This paper described the application of fuzzy multiobjective linear programming to solving a multiple-use problem of forest resources management. At first the concepts of linear programming, fuzzy linear programming and fuzzy multiobjective linear programming were introduced briefly. In order to illustrate a role of fuzzy multiobjective linear programming in the process of multiple-use forest planning, the natural recreation forest in Mt. Yoomyung was selected for this study. A fuzzy multiobjective linear programming model is formulated with data obtained from this Mt. Yoomyung natural recreation forest to solve the multiple-use management planning problem of forest resources. Finally, the results, which were obtained from the calculation of this model, were discussed. The maximal value of the membership function(λ) was 0.29, when the timber production and the forest recreation function were optimized at the same time through the fuzzy multiobjective linear programming. The cutting area in each period was 102.7ha, while total cutting area was 410.8ha for 4 periods. During 4 periods 57,904m^3 will be harvested from this natural recreation forest and at the same time total visitors were estimated to be about 8.6 millions persons.

Key Words : Multiple-use, natural recreation forest, linear programming, fuzzy linear programming, fuzzy multiobjective linear programming.

要 約

본 연구는 山林資源의 多目的 利用 문제에 합리적으로 접근하기 위하여 퍼지 多目標 線型計劃法을 삼림경영계획에 응용하고자 시도되었다. 산림이 가지고 있는 두 가지 기능 즉, 木材生産機能과 公益機能이 지역별로 적절히 발휘되면서 조화를 이룰때 산림자원의 다목적 이용문제가 해결될 수 있다. 여기에서는 공익기능 중에서 休養機能이 발휘되고 있는 自然休養林을 대상으로 목재생산기능과 휴양기능이 合目的的으로 조합을 이룰 수 있는 모델을 개발하였다. 우리나라에서 최초로 조성된 유명산 자연휴양림 지역을 대상으로 자료를 수집하여 퍼지 多目標 線型計劃모델을 구성하였다. 그리고 이 모델의 계산을 통해 얻어진 결과가 기존의 휴양림 경영계획서상의 자료와 비교 검토되었다. 이때 유명산 자연휴양림 면적 829ha를 대상으로 퍼지 多目標 線型計劃모델을 적용한 결과 4分期 동안 收穫更新가능한 면적이 410.8ha로 나타났고 이 때의 수확재적은 57,904m^3 였으며, 이 休養林을 찾는 방문객

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수는 약 860만명 정도로 추정되었다. 퍼지 多目標 線型計劃모델에 의해서 木材生産計劃과 休養計劃이 동시에 最適化 될때의 最大構成函數값 λ는 0.29로 나타났다.

INTRODUCTION

The forest has not only the function of timber production as the direct function, but also the social benefits of the forest as the indirect function, such as environmental protection, soil and water conservation, forest recreation and so on. In the past, the function of timber production was the most important above all things. According to modernizing or industrialization of the society, however, the indirect function of forest has been needed more and more. From the middle of 1980's, therefore, the concepts of multiple-use of the forest was appeared in Korea and the policy for forest management was changed centering with this concept of multiple-use. As a line in the chain of this forest policy the recreation forests have been constructed from the year 1988 in Korea. 62 recreation forests were constructed until the last year 1994 and about 100 recreation forests are going to be constructed until 1998 in Korea[6]. Therefore, in this changing point a new approach is needed to integrate both the function of timber production and the function of the social benefits of forest.

Now, usually mathematical programming models are used to help forest managers plan and to help them better understand the effects of any proposed forest management activity. Mathematical programming models are widely used because of their capability to optimize management objectives and simultaneously meet any set of constraints. Linear programming models are especially much more applied than any others to solve the problem of the complex forest management planning[3].

To gain the satisfactory results the accurate data are needed. However, forest data that we can obtain from the forest, are fuzzy data sets, and the forest planning is under the fuzzy environment. Therefore, to find the best solution to complex forest management problems the fuzzy linear programming is introduced and to solve the multiple-use forest management problem the fuzzy multiobjective linear programming model is explained[1,4,5]

This method is applied for the first time to forest management planning problem in Korea. In this paper, the applicability of this method is examined with multiple-use planning problem adopted from Mt. Yoomyung natural recreation forest of Chunchon national forest area in Korea and the results will be discussed.

LINEAR PROGRAMMING

Standard LP model to be generally used is formulated as follows:

$$\text{Max.}Z = \sum_{j=1}^{n} C_j X_j$$

subject to

$$\sum_{j=1}^{n} a_{ij} X_{ij} \leq b_i \ (i=1,2,3, \cdots\cdots, m)$$

$$X_{ij} \geq 0 \ (j=1,2,3, \cdots\cdots, n) \qquad (1)$$

FUZZY LINEAR PROGRAMMING

Under a fuzzy environment, standard LP model can be formulated as follows[7,8,9] :

$$\begin{aligned} C^t x &\lesssim Z_o \\ Ax &\lesssim b_o \\ x &\geq 0 \end{aligned} \qquad (2)$$

Here the symbol "$\lesssim$" is a fuzzy inequality which means "essentially smaller than or equal to". Z_o represents an aspiration level for the objective function and b_o represents tolerance value for the constraints. Because the objective function and the constraints are expressed by inequalities, Fuzzy linear programming model(2) is integrated and can be reformulated as follows:

$$\begin{aligned} Bx &\lesssim b \\ x &\geq 0 \end{aligned} \qquad (3)$$

If the constraints are linear, the ith inequality with value less than or equal to b_i

for the problem(3) is defined by the following membership functions.

$$\mu_i([Bx]_i) = \begin{cases} 1 & \text{for } [Bx]_i \le b_i \\ 1-([Bx]_i-b_i)/d_i & \text{for } b_i \le [Bx]_i \le b_i+d_i \\ 0 & \text{for } [Bx]_i \ge b_i+d_i \end{cases} \quad (4)$$

Here $[Bx]_i$ is the ith element of the vector, μ_i the membership function of the ith inequality, and d_i the maximum tolerance level for the right-hand side of the inequality. The problem of decision for maximizing a fuzzy intersection set by the problem(4) is to find x such that

$$\max_{x \ge 0} \min_i \{\mu_i([Bx]_i)\} \quad (5)$$

If b_i and $[Bx]_i$ are respectively normalized with $b'_i = b_i/d_i$ and $[B'x]_i = [Bx]_i/d_i$ and the constraints are linear, problem(5) can be formulated as follows:

$$\max_{x \ge 0} \min_i \{b'_i - [B'x]_i\} \quad (6)$$

We can represent problem(6) as the following standard LP problem :

$$\begin{aligned} &\text{maximize} \quad \lambda \\ &\text{subject to} \quad \lambda \le b'_i - [B'x]_i \\ &\qquad\qquad x,\ \lambda \ge 0 \end{aligned} \quad (7)$$

With this information, We can obtain the solutions for fuzzy LP problems using standard LP.

FUZZY MULTIOBJECTIVE LINEAR PROGRAMMING

If objective function or constraints in a problem contain a clear and accurate values, these can be directly added to crisp model(7) with their original form.

For example, Mendoza et al.[5] have developed Fuzzy multiple objevctive linear programming (FMOLP) that consider a multiple objective problem for forest planning where imprecise objective function coefficients exist. Standard multiple objective linear programming model is formulated as follows:

$$\begin{aligned} &\text{maximize} \quad Z_i = C_i x \\ &\text{subject to} \quad Ax \le b_o \\ &\qquad\qquad x \ge 0 \end{aligned} \quad (8)$$

If the objective functions are more indeterminately defined and have inaccurate coefficients, the coefficients can be represented by interval values instead of precise values and then, the objectives can be defined by the membership functions as follows:

$$\mu_i(x) = \begin{cases} 0 & \text{if } Z_i(x) \le f_{li} \\ (Z_i(x)-f_{li})/(f_{oi}-f_{li}) & \text{if } f_{li} \le Z_i(x) \le f_{oi} \\ 1 & \text{if } f_{oi} \le Z_i(x) \end{cases} \quad (9)$$

Here f_{oi} is the hightest aspiration level for objective i, and f_{li} is the lowest tolerance value for objective i. Now, an important fact for the problem is that all objective functions represented by the membership funtions have to be simultaneously satisfied.

By this fact, the multiple objective linear programming model(8) can be formulated as follows:

$$\begin{aligned} &\text{maximize} \quad \lambda \\ &\text{subject to} \quad \lambda \le (Z_i(x)-f_{li})/(f_{oi}-f_{li}) \\ &\qquad\qquad Ax \le b_o \\ &\qquad\qquad x,\ \lambda \ge 0 \end{aligned} \quad (10)$$

This formulation(10) is called "Fuzzy Multiple Objective Linear Programming Model(FMOLP)". It follows the MAXMIN approach, the objective of which is to find a solution that computes the maximum membership function value, λ. λ means the value that the constraints described in formulation(10) are simultaneously satisfied. That is, λ is the highest minimum degree of satisfaction considering all objectives and their respective aspiration levels denoted by f_{oi} and f_{li}.

STUDY AREA

In order to illustrate a role of fuzzy multiobjective linear programming in the process of multiple-use forest planning, a recreation forest in Yoomyung mountain was selected for this study. Yoomyung mountain is located at Kyunggi-Do, Kapyung-Kun and close to Seoul, the capital city of Korea.

This recreation forest is built up along the

Table 1. Area and volume distribution for each age class of each species in Mt. Yoomyung recreation forest (unit : ha, m^3)

Species Area & Volume Ageclass	*Pinus koraiensis*		*Larix leptolepis*		*Quercus spp.*		Sum	
	Area	Volume	Area	Volume	Area	Volume	Area	Volume
1 (1-10)	14	0	28	0	1	0	43	0
2 (11-20)	146	13,563	17	680	67	1,394	230	15,637
3 (21-30)	96	7,406	86	7,128	187	6,744	369	21,278
4 (31-40)	31	2,393	64	3,779	92	3,370	187	9,542
Sum	287	23,362	195	11,587	347	11,508	829	46,457

ridge of Mt. Yoomyung(864.0m), Mt. Sokuni (799.9m) and Mt. Jungmi(838.9m). There are the recreation facilities area of 13ha and timber production area of 829ha in this recreation forest. In this area, the natural forest and the afforestation forest are respectively distributed with similar areas. Natural forest is composed of the mixed stands with conifers and broadleaf trees, and plantation by planting is a pure forest with *Larix leptolepis* or *Pinus koraiensis*. Table 1 shows area and volume distribution for each age class of each species in Mt. Yoomyung recreation forest[2].

MULTIOBJECTIVE LINEAR PROGRAMMING MODEL

The following articles are assumed for this model formulation(11).

(1) The interval of each age class for each species is 10 years.

(2) Cutting age ranges from 30 to 40 years.

(3) There are 4 planning periods(a 40-year planning horizon)

(4) Any action taken is done at the beginning of a planning period.

(5) No thinning is done during the planning horizon and after harvesting the regeneration is immediately taken by planting.

(6) As the visitors gradually increase, the recreation area must be extended every period.

Objective Functions :

$$\text{Max.}Z_1=\sum_{i=1}^{4}\sum_{s=1}^{3}\sum_{j=1}^{4} V_{isj}(X_{isj}+R_{isj})$$

$$\text{Max.}Z_2=\sum_{i=1}^{4}\sum_{k=1}^{4} P_i\, Y_{ik}$$

Constraints :

(a) Area constraints

$$\sum_{s=1}^{3}(X_{3s1}+R_{3s1})+\sum_{s=1}^{3}(X_{4s1}+R_{4s1})\leq 43$$

$$\sum_{s=1}^{3}(X_{2s2}+R_{2s2})+\sum_{s=1}^{3}(X_{3s2}+R_{3s2})\leq 230 \qquad (11)$$

$$\sum_{s=1}^{3}(X_{1s3}+R_{1s3})+\sum_{s=1}^{3}(X_{2s3}+R_{2s3})\leq 369$$

$$\sum_{s=1}^{3}(X_{1s4}+R_{1s4})\leq 187$$

(b) Cutting area flow constraints

$$\sum_{s=1}^{3}\sum_{j=1}^{4}(X_{1sj}+R_{1sj})=\sum_{s=1}^{3}\sum_{j=1}^{4}(X_{2sj}+R_{2sj})$$

$$\sum_{s=1}^{3}\sum_{j=1}^{4}(X_{2sj}+R_{2sj})=\sum_{s=1}^{3}\sum_{j=1}^{4}(X_{3sj}+R_{3sj})$$

$$\sum_{s=1}^{3}\sum_{j=1}^{4}(X_{3sj}+R_{3sj})=\sum_{s=1}^{3}\sum_{j=1}^{4}(X_{4sj}+R_{4sj})$$

(C) Harvest flow constraints

$$\sum_{s=1}^{3}\sum_{j=1}^{4} V_{1sj}(X_{1sj}+R_{1sj})=15489$$

$$\sum_{s=1}^{3}\sum_{j=1}^{4} V_{2sj}(X_{2sj}+R_{2sj})=15489$$

$$\sum_{s=1}^{3}\sum_{j=1}^{4} V_{3sj}(X_{3sj}+R_{3sj})=15489$$

$$\sum_{s=1}^{3}\sum_{j=1}^{4} V_{4sj}(X_{4sj}+R_{4sj})=15489$$

(d) Cutting area and recreation area constraints

$$\sum_{s=1}^{3}\sum_{j=1}^{4} X_{1sj} \leq \sum_{s=1}^{3}\sum_{j=1}^{4} R_{1sj}$$

$$\sum_{s=1}^{3}\sum_{j=1}^{4} X_{2sj} \leq \sum_{s=1}^{3}\sum_{j=1}^{4} R_{2sj}$$

$$\sum_{s=1}^{3}\sum_{j=1}^{4} X_{3sj} \leq \sum_{s=1}^{3}\sum_{j=1}^{4} R_{3sj}$$

$$\sum_{s=1}^{3}\sum_{j=1}^{4} X_{4sj} \leq \sum_{s=1}^{3}\sum_{j=1}^{4} R_{4sj}$$

(e) Cutting area constraint for each species

$$\sum_{i=1}^{4}\sum_{j=1}^{4}(X_{i1j}+R_{i1j}) \leq 150$$

$$\sum_{i=1}^{4}\sum_{j=1}^{4}(X_{i2j}+R_{i2j}) \leq 150$$

$$\sum_{i=1}^{4}\sum_{j=1}^{4}(X_{i3j}+R_{i3j}) \leq 150$$

(f) Recreation area constraints for each period

$$\sum_{k=1}^{4} Y_{4k} \leq 200$$

$$\sum_{k=1}^{4} Y_{3k} \leq 150$$

$$\sum_{k=1}^{4} Y_{2k} \leq 100$$

(g) Recreation area constraints for each compartment during the planning horizon

$$\sum_{i=1}^{4} Y_{i2} \leq 100$$

$$\sum_{i=1}^{4} Y_{i3} \leq 120$$

$$\sum_{i=1}^{4} Y_{i4} \leq 150$$

(h) constraints for integrating two model

$$\sum_{s=1}^{3}\sum_{j=1}^{4} R_{1sj} = \sum_{i=1}^{4} Y_{i2}$$

$$\sum_{s=1}^{3}\sum_{j=1}^{4} R_{2sj} = \sum_{i=1}^{4} Y_{i3}$$

$$\sum_{s=1}^{3}\sum_{j=1}^{4} R_{1sj} + \sum_{s=1}^{3}\sum_{j=1}^{4} R_{1sj} = \sum_{i=1}^{4} Y_{i2}$$

(i) non-negativity contraints

V_{isj}, X_{isj}, $R_{isj} \geq 0$

Where,

Z_1, Z_2=objective functions respectively, representing timber volume and recreation visitors-hectare per year.

i=The number of periods in planning horizon (i=1,2,3,4,).

s=The number of tree species(s=1,2,3,).

j=The number of age classes(j=1,2,3,4).

k=the number of compartments(k=1,2,3,4).

V_{isj}=Volume per hectare harvested in period i and in age class j for s tree species.

X_{isj}=hectare of land harvested and planted in period i and in age class j for S tree species.

R_{isj}=hectare of land harvested in period i and in age class j for S tree species, then this area is transferred for a recreation area.

P_i=The number of visitors-hectare per year.

Y_{ik}=recreation area in period i and in compartment k.

The equality funtions(a) mean the actual area for each age class. An area of each age class for three species should be identical with area investigated(Table 1). The equality functions(b) are constraints concerning even cutting area. Although the period changes, the cutting area should be the same. The equality funtcions(c) are harvest flow constraints. Harvest flow in each period should be smaller than or equal to harvest flow estimated. The estimation of harvest flow, 15,489m^3 was computed by Gehrhardt method. The inequality functions(d) are cutting area and recreation area constraints. The area transferred to recreation area in each period should be the larger than regeneration area in each period. The inequality functions(e) are constraints concerning cutting area for each species. Each species should be evenly harvested during planning horizon. The constraints(f) are recreation area constraints.

The recreation area for each compartment managed in each period should be smaller than or equal to an recreation area assigned. The right-hand side level of this constraint was subjectively allocated, considering that the visitors gradually increase. The constraint(g) means that a recreation area for each compartment managed during the planning horizon should be smaller than or equal to an area designated. It is assumed that this area should be smaller than 370ha in total. The equality funstions (h)are the contraints that combine two model, the model about timber production and the model about a recreation area. Finally, the constraint (i)is non-negativity contraint.

FUZZY MULTIOBJECTIVE LINEAR PROGRAMMING MODEL(FMLP)

As mentioned above,there are two objective funtions. That is, one is to maximize the volume from timber production area and another is to maximize the number of visitors to visit the recreation forest. Two objective functions could be respectively optimized by the LP model. LP model could be reformulated with two objective funtions as equation(12). This is called a multi-objective linear programming model,and can be formulated as follows :

$$\begin{aligned} &\text{Maximize } Z_1 = C_1X \cdots \text{(maximize the volume)} \\ &\text{Maximize } Z_2 = C_2X \cdots \text{(maximize the number of visitors)} \\ &\text{subject to} \\ &\quad Ax \leq b_o \\ &\quad x \geq 0 \end{aligned} \tag{12}$$

Using the membership funtion(9) and FMLP model(10), the FMLP model for this multiple-use forest planning problem is formulated by MAXMIN approach as follows :

$$\begin{aligned} &\text{Maximize} \quad \lambda \\ &\text{subject to} \quad C_1X - \lambda(f_{o1} - f_{11}) \geq f_{11} \\ &\qquad\qquad C_2X - \lambda(f_{o2} - f_{12}) \geq f_{12} \\ &\qquad\qquad Ax \leq b_o \\ &\qquad\qquad x,\ \lambda \leq 0 \end{aligned} \tag{13}$$

To find a solution using this FMLP formulation (13), the values of f_{oi} and f_{li} must be presented, where these values are decided by the experience of a decision maker. In this example, it was subjectively presented that the lowest and highest aspiration level for the timber production were 55,000m^3, 65,000m^3, respectively. As the visitors gradually increase, the lowest visitors of 8 millions and the hightest visitors of 10 millions were subjectively chosen for the number of visitors. This could be estimated with the real data, which were obtained from the office of Mt. Yoomyung natural recreation forest, to be about 82,000 visitors per one year from May 1993 to April 1994.

RESULTS AND DISCUSSION

To demonstrate the role of fuzzy multiobjective linear programming in multiple-use forest management planning process, first of all, one LP model was developed and using this LP model, two objective functions were formulated. That is, one was formulated in terms of maximizing the volume from the timber production area under uncertainty of the volume production and another was formulated for the purpose of maximizing the visitors to the recreation forest. Secondly, to reduce the imprecision and uncertainty caused by the volume production and the number of visitors, a fuzzy multiobjective linear programming model was applied. This model was developed to attain an optimal compromise solution considering two objectives simultaneously.

In this example, the degree of the satisfaction for objective Z_1, $\lambda=0.69$ was obtained and for Z_2, $\lambda=0.29$ was gained. But, the problem is to find the optimal compromise solution that all membership function values of two objectives are simultaneously satisfied. Because of that, the formulation(13) was formulated to obtain the optimal compromise solution for this problem and for the optimal compromise solution, $\lambda=0.29$ was gained using the formulation(13). Table 2 shows the harvest area and recreation area in 4 forest planning periods. The cutting area in each period is 102.7ha respectively, total cutting area are 410.8ha for 4 periods. During 4 periods 57,904m^3 volume will be harvested from this natural recreation forest and at the same time total visitors could be estimated to be 8,590,493 persons for 4 periods with this fuzzy model. The recreation facilities area is now 13ha, this becomes the first compartment. And, the area(RA), which is harvested and transferred to recreation area in the first period, are 33.3ha. This area becomes the second compartment in this recreation forest. RA in the second period are 60ha, becoming the third compartment. RA in the third and fourth period are 106.7ha, becoming the fourth comparment.

Table 3 shows cutting area and recreation area by harvesting in each species. *Pinus Koraiensis*

Table 2. Harvest and recreation area in 4 forest planning periods (unit : ha, m^3)

	Age class / Area & Volume / Species Period	10 A˙	10 RA¨	20 A˙	20 RA¨	30 A˙	30 RA¨	40 A˙	40 RA¨	Harvest area	Recreation area in compartment 1	2	3	4
	Pinus koraiensis													
I	*Larix leptolepis*							42.5	33.3	102.7	13			
	Quercus spp					26.9								
	Pinus koraiensis								57.3					
II	*Larix leptolepis*							30.3		102.7	13	33.3		
	Quercus spp					12.4	2.7							
	Pinus koraiensis							30.5	51.2					
III	*Larix leptolepis*							10.9		102.7	13	33.3	60	
	Quercus spp					10.1								
	Pinus koraiensis													
IV	*Larix leptolepis*							32.8		102.7	13	33.3	60	106.7
	Quercus spp					14.4	55.5							
	Sum	0	0	0	0	63.8	58.2	147.0	141.8	410.8				

Volume harvested : 57,904 Visitor : 8,590,493
$\lambda = 0.29$

A˙ = Cutting area
RA¨ = Recreation area by cutting

Table 3. Cutting area and recreation area transferred by harvesting in each species (unit : ha)

Species	Harvest area: Cutting area	Harvest area: Recreation area by cutting	Sum
Pinus koraiensis	30.5	108.5	139.0
Larix leptolepis	116.5	33.3	149.8
Quercus spp.	63.8	58.2	122.0
Sum	210.8	200.0	410.8

stands are used the most area of all for recreation, i.e. 108.5ha among total cutting area 139.0ha. *Larix leptolepis* stands are used 33.3ha for the recreation forest among 149.8ha, *Quercus spp.* stands are used 58.2ha for the recreation forest among 122.0ha. According to this result, total recreation area transferred by harvesting in each species are 200.0ha(49% of total cutting area).

To formulate the fuzzy multiobjective linear programming in multiple-use management planning process, only two forest functions, timber production and forest recreation function, were considered. If another functions or another elements could be considered, another results could be obtained and more detailed analysis could be performed.

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