The 7th Balkan Conference on Operational Research
"BACOR 05"
Constanta, May 2005, Romania

OVERCOMING SPATIAL CONSTRAINTS IN FOREST MANAGEMENT USING INTEGER PROGRAMMING: A CASE STUDY

MEHMET MISIR
UZAY KARAHALIL

Karadeniz Technical University, Faculty of Forestry, Trabzon, Turkey

---

Abstract

Forest management modeling has recently addressed concerns with resources other than timber. Considerable attention has been given to the spatial and temporal arrangement of wildlife habitat and forest management activities. Some forest regulations, for instance, place limits on the size and spatial relationships of harvest. Adjacency or "green up", requirements are becoming increasingly common policies in many countries. Forest practices green-up rules, which act as adjacency constraints, are designed to restrict both the size of the forest openings and the length of time before adjacent harvest units can be harvested.

In this study, we present an integer programming model for a five-period harvest problem. Integer programming techniques have been used to produce management plans that recognize green-up (adjacency) requirements. Different planning alternatives were developed that maximizing timber volume with constraints on the harvesting adjacent units until regenerated trees reach a certain size. This spatial forest planning process allows forest managers to examine a number of management options, from ecological perspectives, prior to selecting a preferred alternative. In addition, different outcomes could be composed according to the spatial layout of the stand treatments, and the results would be alternative spatial forest structures.

***Keywords**: Forest Planning, Harvest Scheduling, Adjacency Constraints, Integer Programming*

1. INTRODUCTION

Modeling plays a significant role in decision making today as the spatial and temporal arrangement of wildlife habitat and forest management activities is becoming increasingly important. Some forest regulations, for instance, place limits on the size and spatial relationships of harvest units. In addition, many forest management goals are now being specified by decision makers in the form of desired landscape conditions. As a result of a need to manage forest land within regulatory and organizational frameworks, forest management planning efforts now often attempt to achieve multiple resource goals, and increasingly use spatial and temporal constraints on the selection of management activities [1].

A forest management plan is often constructed by selecting the optimal combination of stand treatments among various simulated stand-level alternatives in the light of the desired objectives. Several different outcomes with respect to timing and the degree of utilization of forest resources could be composed on the basis of the simulated alternatives. In addition, different outcomes could be composed according to the spatial layout of the stand treatments, and the results would be alternative spatial forest structures. The spatial structure of forests refers to the relative spatial arrangement of patches and interconnections between them. It represents both the spatial characteristics (e.g., size, shape and relative arrangement) and the non-spatial characteristics (or composition) of patches. The spatial structure of a forest landscape, as well as its attributes at the level of the stand, affects the ecological processes and the abundance of forest species. Since ecological considerations and biodiversity management are important for both society and individual forest-owners, there is an increasing need to analyze the development of the spatial structure of forests and to develop the means by which spatial objectives can be explicitly included in forest planning.

The forestry literature discusses integer programming approaches that consider constraints on the maximum clearcut. In general, constraints on the maximum clearcut size preclude the clearcutting of adjacent stands (adjacency constraints). Adjacency constraints ensure that the predetermined maximum size of the clear-cut is not exceeded. In addition, an exclusion period determines the temporal constraint on adjacent harvests. Forest practices green-up rules, which act as adjacency constraints in forest planning, are designed to restrict both the size of the forest openings and the length of time before adjacent harvest units can be harvested. They are becoming a common component of forest practices rules worldwide.

Murray (1999) identifies two types of adjacency constraint models: unit restriction models (URM) and area restriction models (ARM). Unit restriction models assume that the average size of management unit is near the maximum clearcut size being considered. Therefore, if one management unit is scheduled for harvest, the adjacent units are restricted from being harvested until the regenerated trees reach a certain size. Area restriction models assume that management units have not been aggregated to form larger harvest units and are therefore much smaller than the maximum clearcut size. Here, activities can be scheduled for multiple adjacent management units in the same time period, as long as their aggregate contiguous area is less than or equal to the maximum allowable size, and similar activities can not be scheduled for any management unit adjacent to the units comprising the aggregated area for some period of time [2].

For example, the maximum opening size in the sub-boreal region in Sweden, approximately 10% to 20% of their forested area, is limited to 20 ha with the restriction in place until forest regeneration in the cutover patch reaches a height of 1.5 m for spruce stands and 2.5 m for pine stands. Regeneration must reach a height of 2 m before the felling of adjacent management units in the United Kingdom. In Australia, the green-up constraints vary by state, for example, there is a 100-ha maximum opening size rule in Tasmania, and the green-up constraint is in place until regeneration with acceptable stocking has reached a height of 5 m. By contrast, in Victoria, harvest units are limited to 40 ha per year, but can be combined during a 5-year period into openings as large as 120 ha. [3, 4, 5]

The purpose for green-up and adjacency rules varies, some were put into effect due to concerns about the effects of clearcutting on forest fragmentation and other ecological processes. The Swedish rule, for example, was meant to reduce the formation of frost pockets that hinder reforestation. Forest practices laws may also include these constraints either as a response to public pressure regarding the aesthetic quality of large harvest areas, or in an effort to disperse the potential impact on water quality from timber harvesting. Green-up rules are also often a requirement of forest certification schemes. The Sustainable Forestry Initiative (SFI), for example, requires the maximum average opening size be less than 48 ha (120 ac). This green-up constraint is in place for 3 years or until the regeneration reaches an average height of 1.2 m (4 ft). The three western United States that border the Pacific Ocean (Washington, Oregon, and California), all have state forest practices laws that contain adjacency and green-up provisions [6, 5].

Nelson and Brodie (1990) compared a random search heuristic and branchand-bound to solve a mixed integer programming model. Murray and Church (1995) developed heuristics to aggregate adjacency constraints in order to reduce the computational effort of model solving by either random search or branch-and-bound. Yet computational effort still limited the applicability of these approaches. Sydner and Revelle (1996a,b) presented results of research aiming at describing adjacency constraints in a form that favours 0–1 solutions. In order to reduce the computational effort of model solving, other methodologies have been proposed. They include, for example, tabu search and simulated annealing. Borges et al. (1999) developed and tested a dynamic programming based approach and reported results that compared favorably to alternative heuristics. The interior space of a patch is the area where ecological functioning is not impacted by characteristics of surrounding patches. Wildlife habitat requirements may encompass minimum old growth interior space. Ohman and Eriksson (1998) proposed simulated annealing to address constraints on the interior space of old growth patches, but constraints on the maximum clearcut size were not considered [7, 8, 9, 10, 11, 12, 13].

In this paper, we present an integer programming model for a five-period harvest problem. A unit restriction model was assumed that the average size of management unit is near the maximum clearcut size being considered. In this case, if one management unit is scheduled for harvest, the adjacent units are restricted from being harvested until the regenerated trees reach a certain size. Thus, spatial considerations were taken into consideration in the ecological component of the model for species populations depend upon the spatial pattern of habitat as well as the extent of habitat.

2. MATERIAL AND NETHOD

This study is performed for a part of Düzlerçamı forests in Antalya. The total area of the research area is 509.1 ha (Table 2.1).

Land Use	Area (ha)
Productive Forests	432.5
Degraded Forests	44.1
Bare Land	32.5
Total Forested Land	509.1

Table 2.1 Forested land of the study area

Forest stands in the study area are grouped according to the dominant tree species, development stage and crown closure into 16 stand types. 29 individual stands are available in the planning unit consists of Calabrian pine (*Pinus brutia*). The initial state age class distribution with 10 year internal of productive forests in the study area is given in figure 2.1.

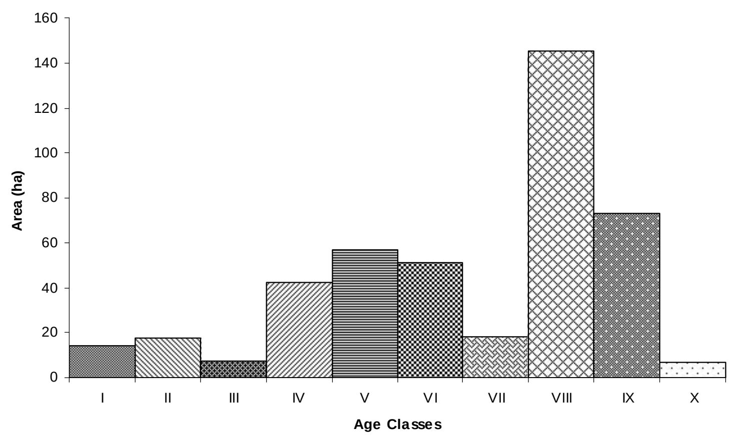

Figure 2.1 The initial state of productive forests in the study area

2.1 THE MODEL

A harvest regeneration schedule covers a 50 year planning horizon with 10 year-periods. The set of feasible management options for stand types are identified based on the following assumptions and regulations.

Harvesting takes place at the middle of each period and each stand will be regenerated immediately after harvesting and that the same tree species will be planted. Thinning is taken into consideration using the normal yield tables of Alemdağ (1962) for Calabrian pine (*Pinus brutia*) [14].

Actual stand parameters like volume, increment and etc. are taken from Düzlerçamı Planning Unit forest management plan (2004-2013) [15]. These data were used to build wood production matrixes. Timber yields are estimated using the normal yield tables of Alemdağ (1962) for Calabrian pine (*Pinus brutia*).

The minimum ages of final harvest for Calabrian pine stands are 60 years. This age limit is taken from the Turkish Forest Management and Planning Act (1991). All stands must be regenerated following the five periods [16].

A URM was taken into consideration during the creating of alternatives. An integer programming model is formulated to represent the forest planning problem. Three different alternatives were generated including:

1. Objecting only maximization of timber production,
2. Objecting maximization of timber production under constraint of %10 harvets flow
3. Objecting maximization of timber production under constraint of %10 harvets flow and %10 age class distribution flow.

2.2 MODEL FORMULATION

1. Objective Function:

$$Z_{\max} = \sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij} x_{ij} \tag{2.1}$$

2. Constraints:

$$\sum_{j=1}^{n} x_{ij} - A_i = 0 \tag{2.2}$$

$$\sum_{i=1}^{m} x_i = 1 \tag{2.3}$$

$$\sum_{i=1}^{m} y_{ij} = 1 \tag{2.4}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij} x_{ij} - H = 0 \tag{2.5}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} <= T_i \tag{2.6}$$

$$T_j - T_{j+1} = 0 \tag{2.7}$$

$$H_j - H_{j+1} = 0 \tag{2.8}$$

$$x_{ij} \geq 0 \tag{2.9}$$

Here,

x_{ij} : Stand i to be regenerated in period j (0, 1).

y_{ij} : Adjacent stands to be regenerated in period j period j.

a_{ij} : Harvest yield of stand i to be regenerated in period j (m^3).

b_{ij} : Yield of stand i to be regenerated in period j (m^3).

H : Total yield or harvest at the end of the planning horizon (m^3).
m : Number of stands (i=1,...29).
n : Alternative treatments assigned to stand i during the planning horizon (n=1,...5). (regeneration in period 1, 2, ….5)
T_i : Total area (ha).
A_j : Area of stand i (ha).

3. RESULTS AND DISCUSSION

The total, regeneration and thinning harvest volumes and age structure of the forest at the end of the planning horizon are presented below considering three different planning alternatives.

3.1 TIMBER HARVEST VOLUME

Chart 3.1 shows the periodic total, regeneration and thinning timber harvest volumes associated with each of the three alternatives. The maximum total harvest volume is obtained from alternative 1 and 2, 3 respectively. The same case can be seen for regeneration and thinning harvest volumes. All alternatives generated the highest total harvest volume in period 5, like regeneration harvests. Alternative 2 and 3 obtained the highest thinning harvest in period 5 while alternative 1 gained in period 4.

Alternative 2 and 3 generated more or the less same amount of harvest yields because of even harvest flow constraints but alternative 1 generated irregular harvest flow.

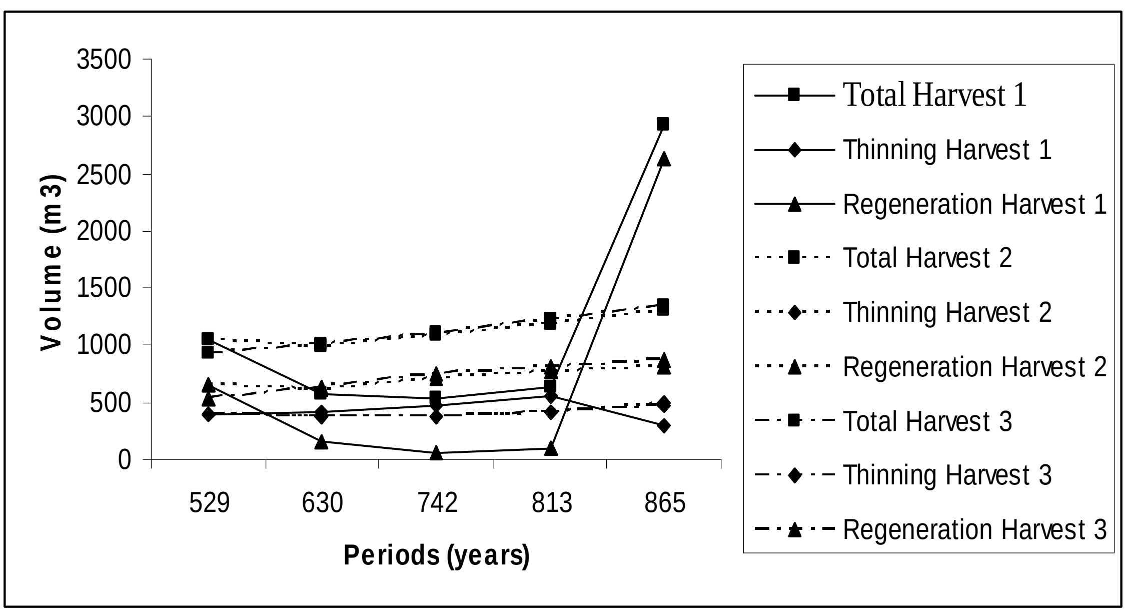

Chart 3.1 Harvest of alternatives according to periods

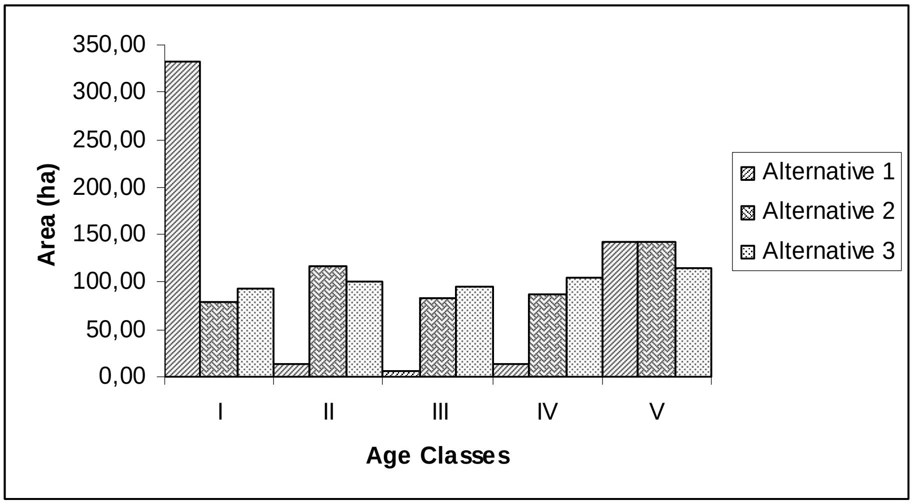

Chart 3.2 Age classes and OGF generated from alternatives

3.2 AGE STRUCTURE OF THE FOREST AT THE END OF THE PLANNING HORIZON

Chart 3.2 shows the age structure of the forest at the end of the planning horizon associated with different alternatives. Alternative 3 generated more or less equal age class distribution. Alternative 1 and 2 generated irregular age class distribution. The most regeneration was made in period 1 in alternative 1 while allocated areas for regeneration was the most in period 5 for alternatives 2 and 3.

4. CONCLUSIONS

Standard LP approaches are rather unsuitable for dealing with spatial variables, since decision variables can be split into fractions.

The spatial objectives can be included in Integer Programming models by defining the areas that are under restriction. This can be achieved including one objective that is to be maximized or minimized and spatial other objectives can be expressed as constraints.

Thus;

- minimizing the effects of clearcutting on forest fragmentation and other ecological processes,
- reducing the formation of frost pockets that hinder reforestation,
- achieving forest practices laws that public pressure regarding the aesthetic quality of large harvest areas,
- dispersing the potential impact on water quality from timber harvesting.
- fulfilling of forest certification schemes can be achieved.

Forest manager can choice one of three alternatives generated. Economic situations, workers, laws and other factors effects decision making. But a forest manager can choice alternative 3 because of its advantages like % 10 harvest flow and % 10 age class flow. Other alternatives give irregular outcomes according to periods.

BIBLIOGRAPHY

[1] Jørgensen, S.E., (2000), "Editorial: 25 years of ecological modelling by Ecological Modelling", Ecological Modelling, 126, 95–99;

[2] Murray, A.T., (1999), "Spatial restrictions in harvest scheduling", Forest Science, 45, 45-52;

[3] Anonyms, (2001), "Oregon revised statutes", Oregon state legislature, chapter 527, http://www.leg.state.or.us/ors/527.html (accessed 7/16/04);

[4] Anonyms, (1992), "Oregon State University Research Forests", McDonald-Dunn research forest plan, College of Forestry, Oregon State University, Corvallis, OR;

[5] Anonyms, (2002), "Title 222 WAC (Washington Administrative Code)", Forest practices board. http://www.leg.wa.gov/wac/index.cfm?fuseaction=title&title=222 (accessed 7/26/05);

[6] Dahlin, B., Sallnas, O., (1993), "Harvest scheduling under adjacency constraints: a case study from the Swedish sub-alpine region" Scand. J. For. Res, 8, 281-290;

[7] Nelson, J.D., Brodie, J.D., (1990), "Comparison of a random search algorithm and mixed integer programming for solving areabased forest plans", Can. J. For. Res, 20, 934-942;

[8] Murray, A.T., Church, R.L., (1995), "Measuring the efficacy of adjacency constraint structure in forest planning models. Can.J. For. Res. 25, 1416-1424;

[9] Snyder, S., ReVelle, C., (1996a). "The grid packing problem: selecting a harvesting pattern in an area with forbidden regions", For. Sci. 42 (1), 27-34;

[10] Snyder, S., ReVelle, C., (1996b), "Temporal and spatial harvesting of irregular systems of parcels", Can. J. For. Res, 26, 1079-1088;

[11] Lockwood, C., Moore, T., (1993), "Harvest scheduling with spatial constraints, a simulated annealing approach", Can. J. For. Res, 23, 468-478;

[12] Borges, J.G., Hoganson, H.M., (1999), "Structuring a landscape by forestland classification and harvest scheduling spatial constraints", For. Ecol. Manage., in press;

[13] Ohman, K., Eriksson, L.O., (1998), "The core area concept in forming contiguous areas for long-term forest planning", Can. J. For. Res. 28, 1032-1039;

[14] Alemdağ, Ş. (1962), Türkiye'deki kızılçam ormanlarının gelişimi, hasılatı ve amenajman esasları, Ormancılık Araştırma Enstitüsü yayını,Ankara;

[15] Anonyms (2004), "Forest management plan of Düzlerçamı planning unit", General Directorate of Forests.;

[16] Anonyms (1991), Forest management and planning act, General Directorate of Forestry, Ankara.