New Issues in Forest Land Management from an Operations Research Perspective

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Over the last two decades, forest land management practices have changed in response to ecological issues and the need to improve efficiency to remain competitive in emerging global markets. Decision processes have become more open and complex as information and communication technologies change. The OR/MS community is meeting these challenges by developing new modeling strategies, algorithms, and solution procedures that address spatial requirements, multiresource planning, hierarchical systems, multiple objectives, and uncertainty as they pertain to both industrial timberlands and public forests.

Over the past two decades, several factors have altered the practice of forest land management around the world. As population and resource development increase, many forest-based outputs are approaching or exceeding sustainable levels of use. People are increasingly aware of the need to preserve forest ecosystems, to sustain a wide spectrum of resources, and to protect threatened and endangered species, wildlife habitat, scenic beauty, and biodiversity. As a result, forest land managers—especially on public lands—are shifting their emphasis from the production of goods and services (the agricultural model) toward maintaining forest health, biodiversity, and productivity (the ecosystem model). On private timberlands this trend is tempered by the concurrent need to remain competitive in a global marketplace. With increased public participation in the management of all forest resources, it is not

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surprising that the decision-making process has become more open, political, and complex.

Ecological objectives play a major role on public lands where most of the native forests are found, while objectives for industrial timberlands, where most of the intensively managed plantations are found, focus on the efficient production of commercial crops of timber products. Both classes of ownership have created new challenges for the OR/MS community. On the public lands, the shift toward an ecosystem model has stimulated the development of a new set of OR/MS models that incorporate spatial relationships, ecological processes, resource protection issues, and consideration of a wide spectrum of natural resources beyond timber. In the private sector, the increase in open, global markets has encouraged forest products companies to improve productivity and managerial efficiency while being cognizant of environmental and ecological values. This has stimulated the use of OR/MS tools in planning and programming operations and has lead to new modeling strategies, solution procedures, and algorithms.

The OR/MS community is responding to these new concerns by developing (1) forest land management models sensitive to spatial issues arising at both the forest and subforest levels, (2) landscape-level models that address concerns over the cumulative effects of road building, patch cutting, habitat fragmentation, and riparian and wetlands protection, (3) models that reflect the consequences of several independent land owners (decision makers) taking action in the same local geographic area, (4) new modeling strategies to deal with the concerns of ecosystem management, (5) resource models to reflect the multiple objectives of many forest planning environments, (6) models that explicitly incorporate the uncertainty of natural resource systems, (7) models for industrial plantations that promote greater managerial efficiency and simultaneously satisfy environmental constraints, and (8) hierarchical planning approaches that link decisions at the operational, tactical, and strategic levels.

In this paper, we focus on forest land management issues. We omit discussion of some related areas, such as pest management, forest fire management and control, trade models, and forest products manufacturing. We also limit our discussion to forest-wide models and hence do not cover the many OR/MS efforts directed at the stand level.

Multiple Use Planning

While privately owned plantations largely serve to produce commercial crops of timber products, native publicly owned forests traditionally have been managed for multiple purposes. In the last two decades, attention to nonconsumptive uses of native forests has increased. In the United States, the Multiple Use Sustained Yield Act of 1960 mandated that USDA Forest Service lands be managed for a multiplicity of uses on a sustainable basis. Yet it wasn't until 1976, with passage of the National Forest Management Act (NFMA), that specific legislative guidance required integrated and systematic planning for all resources for each forest within the national forest system. A similar history is associated with the development of multiple use planning on the USDI Bureau of Land Management lands, progressing from the 1964 Classification and Multiple Use Act to the 1976 Federal Land Policy and Management Act.

In the 1960s, researchers developed the first linear programming (LP) forest-planning models. One, widely used by the USDA Forest Service, was the timber resources allocation model (RAM) [Navon 1971]. It concentrated mainly on timber production, treating such other aspects as recreation, wildlife habitat preservation, and water quality only through limiting constraints. It did not explicitly include spatial considerations involving roads and the proximity of different habitat types and cutting units within an area.

With passage of the NFMA, USDA Forest Service land managers began to pay more attention to multiple use concerns. To help develop forest plans, Johnson, Stuart, and Crimm [1986] developed FORPLAN. This model—an outgrowth of Timber RAM—considered timber as just one more output and explicitly included all other resources of concern. This more complex model required more resource data—some of it difficult to generate or quantify. Although FORPLAN included land allocation dimensions that were missing from previous models, it did not initially include the forest roading problem, nor did it adequately address site-specific spatial concerns. Weintraub and Navon [1976] and Kirby, Hager, and Wong [1986] proposed models integrating road building and forest management activities years ago, but they were not implemented into actual decision making until recently. A current version of FORPLAN includes roading as an option. FORPLAN has been widely adopted by the USDA Forest Service [Field 1984; Kent and Bevers 1992; and Kent et al. 1991].

Many forest-management problems are resolved in an adversarial environment.

In the 1980s, it became apparent that existing models did not address some of the concerns of forest managers and the public. Because FORPLAN and its predecessors operated at the forest level of planning, spatial factors could not be easily treated. Efforts to include them at this level led to models too large to be useful in long-term planning. However, if forest-level models produced solutions that could not be implemented because of spatial conflicts, they had little utility. As a consequence, forest researchers developed many OR/MS tools to look at implementing forest-wide plans at the subforest level [Schuster, Leefers, and Thompson 1993]. Given the difficult combinatorial aspects of these problems, researchers based most solution approaches on heuristic schemes in order to obtain acceptable solutions.

In the 1990s, public concern for resource sustainability, biodiversity, and habitat and endangered species protection caused a shift toward ecosystem management—largely on public lands. Instead of focusing on a desired mix of multiresource outputs, managers now seek to achieve desired future states of the ecosystem. Because this focus is new, few OR/MS models have been reported in the literature. Systems under development by the USDA Forest Service include Spectrum [USDA Forest Service 1994] and RELMdss [Church, Murray, and Barber 1995; Church, Murray, and

Figueroa 1995]. Both are optimization-based software tools intended to facilitate ecosystem management at several levels in the decision hierarchy. They are designed as flexible tools to be used for trade-off analysis within a what-if environment. Both models interface with geographic information systems (GIS) to enhance the analysis of spatial relationships in the land management planning process.

Spatial Issues

Spatial concerns arise when considering the adjacency of land units, the placement of forest roads, the management of stream-side riparian zones or scenic road corridors, and the management of vegetative corridors through which migrating wildlife pass. Incorporating adjacency constraints, which preclude harvesting adjacent units in the same time period, into forest-planning models is fairly new. Several states in the Pacific Northwest have enacted forest practice laws that require private and state-owned forest organizations to adhere to such adjacency constraints. Western Canadian forests are also likely to face similar requirements.

In order to satisfy one objective, conflicts with another may arise. For example, satisfying adjacency requirements may cause excessive forest fragmentation and the loss of the interior area some wildlife species need. A way to solve this is to block up harvests into larger areas, but this may lead to unacceptable scenic costs.

The best known OR/MS solution procedures for addressing the spatial problem follow two basic lines: (1) adding the adjacency constraints explicitly to an original LP model or (2) using a random search procedure. Accounting for adjacency constraints explicitly in linear, integer, and mixed-integer programming models has typically meant adding a large number of pair-wise constraints. Jones, Meneghin, and Kirby [1991], Torres-Rojo and Brodie [1990], and Yoshimoto and Brodie [1994] developed heuristic algorithms to reduce the number of such constraints by aggregation. Guignard, Ryu, and Spielberg [1994] and Murray and Church [1994] show that adding lifting constraints to tighten the integer formulation greatly reduces the computer time required to solve mixed zero-one integer-programming planning problems. Murray and Church [1995] report on a series of test problems showing that constraint-reduction in the absence of a tighter formulation increases the computational effort. They also show that the Type I method of Jones, Meneghin, and Kirby [1991] performs best in most test cases. At the moment, practitioners wanting to explicitly introduce adjacency constraints into forest planning models should consider this approach.

Barahona, Weintraub, and Epstein [1992] and Weintraub, Barahona, and Epstein [1994] also address the adjacency problem. They add constraints to the original LP model but use a column-generation technique coupled with either a greedy heuristic or a cutting plane approach in the subproblem to create valid harvesting patterns. Computational results with medium-sized problems are satisfactory.

Random search techniques for handling the spatial aspects of forest planning were first introduced by O'Hara, Faaland, and Bare [1989] and Nelson and Brodie [1990]. They select harvest units—randomly or in a biased manner—to determine feasible solutions to harvest-planning problems with adjacency constraints. They choose the best of many such solutions as the preferred solution. Clements, Dallain, and Jamnick [1990], Daust and Nelson [1993], Nelson, Brodie, and Sessions [1991], and Yoshimoto, Brodie, and Sessions [1994] introduce other random search methods. Lockwood and Moore [1993] report the results of a simulated annealing approach that they successfully applied to a large spatial harvest-scheduling problem in Canada concerning more than 27,000 harvest units.

Sessions and Sessions [1991] developed a heuristic short-term algorithm for solving the combined harvest-scheduling and road-location problem with spatial constraints. Their system schedules up to four periods and accepts capacity limitations on the branches of the road network. Other factors it considers include (1) the size of opening allowed, (2) habitat connections, and (3) seral stage distribution. Habitat connections are pathways for migratory animals to use in moving from one area of forest to another. Seral stage requirements concern the structural condition of vegetation (for example, seedling, sapling, pole-sized, small sawtimber, large sawtimber, and meadow) needed for wildlife feeding, reproduction, shelter, or other purposes. The model is based on a sequential application of a random search for treating adjacency concerns, a Steiner problem for the habitat-connection problem, and a shortest path algorithm to support road-building decisions. USDA Forest Service planners in the Pacific Northwest use the model as a planning tool.

Weintraub et al. [1994] and Weintraub et al. [1995] developed a mixed-integer LP model to deal jointly with land-management and road-building activities. They solve the problem by relaxing the integrality constraints and then use a heuristic to iteratively round fractional values to their required integer equivalents. USDA Forest Service planners in the Rocky Mountain region have used this model and obtained solutions close to the bound given by the LP relaxation in moderate CPU time. Tests showed that models dealing jointly with land management and road building led to better solutions than the traditional method of solving the two problems separately.

Multiple Objectives

Native, publicly owned forests have multiple uses and are subject to many concerns. Some forest outputs have direct economic value: timber, forage, recreation, and water. Others have less measurable value: scenic beauty, undisturbed wilderness landscapes, biodiversity, and preservation of endangered species. Also important are the social and economic issues of forest-dependent communities, intergenerational equity, efficiency, and fairness.

The last decade has seen the growing involvement of ecologically minded groups, supported by a public increasingly concerned with environmental issues. This has changed decision making; traditionally public land owners (such as the USDA Forest Service) and private timber firms have managed lands with a high degree of autonomy. Now decision making is much more politicized with the public involved in both global and local issues. Explicit recognition of multiple objectives in forest-planning models is becoming increasingly important.

The use of geographic information systems has helped resolve some of these issues (for example, critical habitats for the northern spotted owl). However, concern for such resources as wildlife and scenic beauty have led to severe spatial restrictions on harvesting patterns, stimulating the development of new algorithmic procedures. To date, most real-life multiple-objective situations have been handled in an ad hoc negotiated way, but methodological contributions have been reported in the OR/MS and forestry literature (for example, Davis and Liu [1991]) and will likely increase in the coming years.

The two multiple-objective models most widely used in forest management are based on goal programming (GP) and multiple-objective linear programming (MOLP) [Bare and Mendoza 1988; Liu and Davis 1995; Mendoza, Bare, and Campbell 1987; Rustagi and Bare 1987]. Generally, these models optimize a given set of forest-management decisions in light of multiple objectives. A different approach is to design the optimal system while simultaneously satisfying multiple objectives. Known as de novo programming, this method treats the constraint levels as soft instead of hard and determines optimal levels of each constraining resource while simultaneously determining the optimal allocation of resources [Bare and Mendoza 1990]. Any of the standard MOLP algorithms may be used under a de novo environment. With the exception of GP, which has been used on occasion by the USDA Forest Service, none of the MOLP methods have been adopted by forest managers. Given the political complexities of making the trade-offs necessary under a multiple objective environment, analysts will likely continue to use these OR/MS tools sparingly and only for measuring the magnitude of trade-offs.

Such factors as scenic beauty and spiritual value are extremely difficult to capture.

Uncertainty

Forest managers and OR/MS analysts are increasingly concerned with treating risk and uncertainty explicitly in forest management models. Traditionally, they have focused on the uncertainties of future timber markets, timber growth and yield projections, and the possible occurrence of catastrophic events, such as forest fires, wind storms, and insect infestations. More recently, concerns over the possible extinction of species and catastrophic changes in the global biosphere have been raised. Forest managers have adopted two approaches to modeling these concerns: probability-based models and fuzzy models. Probabilistic models are based on the assumption that the uncertainty inherent in a system can be captured by defining the probability distribution that the random variables of interest follow. Fuzzy models are based on the assumption that the uncertainties can be represented by treating certain model parameters as fuzzy numbers or relationships—implying vagueness or ambiguity. Fuzzy coefficients are usually represented as an interval instead of a single number and constraints are referred to as fuzzy or soft if they do not have to be strictly satisfied. Mendoza and Sprouse [1989] give an overview of fuzzy approaches to forest management. Bare and Mendoza [1992], Bevers, Meneghin, and Hof [1993], Hof, Pickens, and Bartlett [1986], Mendoza, Bare, and Zhou [1993], and Pickens and Hof [1991] describe applications to a variety of forestry problems. Most involve fuzzy linear-programming formulations including both fuzzy goals and constraints. The FORPLAN LP model has also been formulated as a fuzzy model, but with few reported applications.

Researchers have proposed a wide variety of forest planning models that explicitly incorporate uncertainty using probabilistic-based methods. Techniques applied to forestry include probabilistic dynamic programming [Dempster and Stevens 1987; Lohmander 1990], stochastic programming [Boychuk and Martell 1996], portfolio theory [Thomson and Baumgartner 1988], chance-constrained linear programming [Hof, Kent, and Pickens 1992; Thompson and Haynes 1971; Weintraub and Abramovich 1995], scenario analysis [Hof, Bevers, and Pickens 1995; Hoganson and Rose 1987; Manley and Wakelin 1989], nonlinear programming [Weintraub and Vera 1991], Markov decision models [Kaya and Buongiorno 1987; Lembersky and Johnson 1975], and optimal control theory [Dixon and Howitt 1980; Haight 1990].

Parametric programming has also been used to analyze the uncertainty involved in predicting future timber yields. As is intuitive, in the presence of uncertainly in future yields, it is not known if proposed solutions will satisfy demand constraints. Experiments carried out by solving LP models with expected yield values in the LP constraint matrix and then simulating real yields through random generation of values show that most solutions are infeasible [Hof, Robinson, and Betters 1988; Hof and Pickens 1991; Pickens and Dress 1988]. Adaptive decision-making approaches have been developed to deal with price uncertainties [Gassmann 1989; Gong 1994; Lohmander 1987; Lohmander 1994]. These studies confirm that higher expected present values can be attained relative to those achieved assuming certainty and these gains increase as timber price uncertainty increases. However, adaptive management also implies a higher cost of decision analysis [Gong 1994].

Most efforts to incorporate uncertainty explicitly in forest management models are at a developmental stage. Yet, it is important that forest managers recognize the effects of uncertainty when they evaluate and report on planning alternatives. Difficulties in developing reliable probability functions and algorithmic complexities should not deter researchers and analysts from striving to improve on available methods. Fuzzy models and scenario analysis, on the other hand, are much easier approaches for dealing with uncertainty in an explicit fashion. In the near term, they are more likely to be implemented.

Managing Timber Operations

For over 30 years, forest managers have applied OR/MS techniques to the production of industrial wood crops. Most of the early applications used either LP, simulation, or both. Such models were developed first in Canada, Chile, New Zealand, Scandinavia, and the USA [Bare et al. 1984; Garcia 1990; Gunn and Rai 1987].

Jamnick [1990] compared FORMAN—a timber-management simulation model—with an LP approach and discussed when each is preferable. Unlike LP which searches for an optimal solution, FORMAN is a simple sequential inventory-projection model that examines the effects of particular management scenarios on harvest flow. In addition to scheduling harvests, FORMAN keeps track of only two silvicultural activities: planting and spacing. The model operates with prespecified harvest and spacing priorities and continues to harvest in a given time period until it reaches the desired harvest level. FORMAN cannot make trade-offs between planning periods, handle other types of constraints beyond the timber harvest, or incorporate economic concerns. In tests of the model, LP always produced a superior solution.

Johnson and Tedder [1983] compared LP and binary search models for scheduling timber harvests. A binary search model is structured like a simulation model but incorporates some features of an optimization model. Binary search models operate with prespecified harvest priorities but seek the maximum harvest volume or net present value subject to constraints on area harvested or ending inventory volumes. Johnson and Tedder found that while both can address issues of forest-wide sustainability they cannot address site-specific spatial issues. Further, they report that it is easier to modify the size and character of the forest land base over the planning horizon, introduce random events, and carry detailed information about each forest unit using binary search models. However, analysts generally prefer optimization approaches, because generalized models are available and can be tailored for individual use much easier and faster than can binary search (or simulation) models, and because they produce optimal solutions and not just consequences of proposed solutions.

McGuigan and Scott [1992] developed an LP model used in New Zealand on some private plantations for planning timber harvests. Garcia [1990] and Manley and Threadgill [1991] developed an LP-based forest estate model widely used in New Zealand for planning and evaluation purposes. Morales and Weintraub [1991] present a strategic LP model used to schedule timber harvests in Chile, and Jacobsson [1986] discusses a forest-management optimization model used in Sweden. Generally, LP models have been widely accepted by forest planners engaged in long-term strategic planning and they are being used increasingly in private sector forestry. Recent improvements in such models have been driven by developments in computer hardware and software with modest improvements due to algorithmic enhancements.

In the last two decades, researchers have developed a large number of OR/MS tools to aid decision making at the subforest level. These operational models have shorter time horizons, more important spatial components, and more disaggregated data sets compared to the strategic models. For example, decisions made at this level concern short-term harvesting (selecting harvest units, bucking stems, and allocating logs to manufacturing facilities), scheduling harvesting equipment (cable yarders, ground skidders, loaders, and trucks), and planning transportation.

Short-Term Harvesting

Typical harvesting decisions at the operations level concern which harvest units to cut, how much to cut, which stem-bucking pattern to use, and how to allocate logs to end-markets to fill standing orders. Managers typically decide on what to cut, how much to cut, and how to allocate logs with the aid of models incorporating either LP or random search procedures. Researchers have developed systems to assist with these decisions in Canada, Chile, New Zealand, and the USA [Burger and Jamnick 1991; Jamnick and Walters 1991; Morales and Weintraub 1991; Papps and Manley 1992].

The problem becomes more difficult to solve if stem-bucking decisions are modeled simultaneously with the harvest-planning process. In solving the stem-bucking problem, the manager must decide how to cut each stem most efficiently to satisfy demand for specific products while achieving maximum value. Because there are many possible stem-bucking patterns, solution approaches for realistic problems incorporate some means of generating a reasonable set of patterns either external to the optimization [McGuigan 1984] or internally using Dantzig-Wolfe decomposition [Eng, Daellenbach, and Whyte 1986] or column-generation schemes [Mendoza and Bare 1986]. Usually, managers generate optimal stem-bucking patterns using dynamic programming [Briggs 1989] or a heuristic [Sessions, Olsen, and Garland 1989]. Few harvest-planning models that incorporate stem-bucking decisions have been applied. In most cases, stem-bucking is done at a wood-processing facility after the harvest-planning decisions have been made and executed.

Scheduling of Harvesting Equipment

While other possibilities exist (for example, helicopters and balloons), most timber harvesting is carried out using ground skidders or cable logging systems. The system used depends mainly on the steepness of the terrain, the density and value of the timber, the location of roads, and the availability of labor and capital resources. The main developments in computerized models have been in cable logging to support decisions about locating supporting cable towers. These systems interact with digital terrain models or geographic information systems to obtain the topographic information required to perform the analysis.

Systems in use include PLANS in the USDA Forest Service [Twito et al. 1987] and PLANZ [Cossens 1992] in New Zealand. These models operate mainly as simulation tools. The user proposes installation of towers, and the system, in a visual interactive form, produces information on the access roads needed, the area to be harvested, the volumes to be obtained, and profiles of skylines and payloads. Another system, PLANEX, used by several Chilean forest firms, incorporates heuristic decision rules to operate as an optimization tool [Epstein et al. 1995]. Newnham [1991] describes a version of LOGPLAN II used in Canada. This LP-based model develops an annual operating plan, scheduling timber-harvesting and regeneration activities given available equipment, wood resources, planting stock, and mill demands to minimize cost. The model was first developed in the 1970s and has been refined over time.

LoggerPC [Jarmer and Sessions 1992] is a program extensively used in the Pacific Northwest to provide physical feasibility analyses for harvesting by cable systems. The planner provides equipment specifications, a description of the ground profile, log geometry, and the type of cable configuration to be used. LoggerPC generates the allowable log load that can be carried, a profile of the clearance of the log above the ground, and the line tensions.

Transportation

Transporting timber products from their origin in the forest to their intermediate or final destination (mills, stocking yards, or port for export) plays an important role in overall wood costs and constitutes a complex scheduling problem. To improve on these decisions, Weintraub et al. [1996] developed an administrative and computational system for the Chilean timber industry. The system is based on a central transportation unit that schedules and controls operations. The schedules given to truck drivers each day are developed using a deterministic simulation model that assigns trips according to heuristic decision rules. The implementation of this system has led to improvements in efficiency of 15 to 25 percent.

Hierarchical Approaches to Forest Planning

Forest management problems range in geographic scale from individual areas of 20 to 40 acres to entire forests of more than 2,000,000 acres; run from short-term time horizons of one year or less to long-term horizons of 150 to 200 years; involve decision makers at high managerial levels and on the ground; and include concerns over biodiversity, species preservation, sustainability, and ecosystem management. Road construction, transportation, and marketing requirements add additional complexities.

Two trends have emerged in modeling these problems. One is large monolithic LP models, such as FORPLAN, with sophisticated formulations including many land types and decision variables [Kent and Bevers 1992]. As Kent et al. [1991] comment, these models require large amounts of data and resources but still do not allow one to include particular structures, such as spatial elements, risk and uncertainty, and nonlinearities. Results of such models are also difficult to analyze. While FORPLAN recognizes the hierarchical nature of forest-land-management planning by identifying allocation and scheduling as two separate but linked activities, the resulting LP model does not retain this hierarchical structure in its solution procedure. These drawbacks have apparently limited the usefulness of monolithic approaches. As an alternative, Mitchell, Anderson, and Mealy [1987] and Kent et al. [1991] advocate a multistage approach to forest-management planning recognizing distinct levels of planning.

The second way of addressing contemporary forest-management problems is to adopt some form of hierarchical approach. Models based on this paradigm promise to cope with the increasingly complex and varied problems forest managers face. Analysts split the problems according to natural divisions and solve each separately. Nelson, Brodie, and Sessions [1991] illustrate how a hierarchical approach can be used to link the different levels of planning. Their model uses LP to produce a long-term timber harvest schedule, which is subsequently integrated with spatially feasible solutions at the subforest level. The subforest solutions are found using a random

Many managers rely on their own instincts when making judgments.

search procedure and need only be within plus or minus 10 percent of the output targets previously determined by the long-term model. This approach takes advantage of the ability of LP to optimize large forest-level problems to ensure sustainability while still taking spatial relationships into account at the subforest level.

Weintraub and Cholaky [1991] and Bare and Liermann [1994] take a slightly different approach. They recognize three levels of decision making—strategic, tactical, and operational. At the highest level of decision making, managers analyze a given forest globally with aggregate temporal and spatial data over a long time horizon and produce schedules for geographic subdivisions called zones. At the tactical level, they further subdivide each zone into areas and allocate the zonal-level strategic plan for the first period in the planning horizon to each area within the zone. Also, the planning horizon is shortened. In the last step, they further allocate area-level decisions to individual treatment units within each area. As the spatial and temporal dimensions become more refined, outputs of the higher levels become input targets for the lower-level models. Coordination and feedback among the different levels of analysis is critical in the hierarchical approach. In practice, practitioners handle feedback in ad hoc ways; this is still an area for research at this time.

The increasing importance of approaching forestry problems in a hierarchical way and of developing sound general methodology approaches prompted the organization of a workshop on hierarchical approaches to forest management in public and private organizations [Martell, Davis, and Weintraub 1996]. It seems clear that as problems increase in complexity, hierarchical approaches to decision making will become more important.

Conclusions

The growth in world population and increased development of natural resources are two important forces affecting the management of forest resources today. The conflict between those wishing to use forests to satisfy demands for timber, forage, and recreation and those primarily concerned with environmental quality, protection of endangered species and habitats, enhancement of biodiversity, and sustainability of ecosystems is a consequence of these two forces. While conflict over the appropriate use of forests is not new, the current debate differs in that it is worldwide and encompasses a growing list of issues.

As a consequence of the conflict between exploitation and preservation, new concepts of forest management are being introduced. Forest ecosystem advocates take a holistic view of the forest by designing management strategies that preserve the health and ecological integrity of the forest at the landscape level while permitting resource use to continue—albeit at a reduced level. Ecosystem management favors management strategies that achieve some future desired state over strategies that produce some desired mix of resource outputs over time. Because of the ongoing paradigm shift between management for utilitarian purposes versus management for ecological purposes, forest managers must now explicitly consider a large array of factors that were previously considered only implicitly—at best.

To help forest managers make decisions

in this complicated and evolving environment, researchers are developing many new OR/MS models. Particularly impressive is the capability to couple geographic information systems with spatially oriented tactical and operational forest-planning models. Advances in this area over the past two decades allow analysts to treat roading, silvicultural, critical habitat, riparian zone, and other spatially sensitive aspects of forest management simultaneously. Managers are using these models to analyze ongoing problems. Linking these models with strategic models has proved elusive.

While our ability to incorporate multiple objectives in models has grown over the past two decades, forest managers have not adopted these models widely. We suspect that making trade-offs among multiple objectives is a difficult task that often takes place during the final stages of negotiation. Thus most managers would rather postpone consideration of painful trade-offs and not objectively analyze them within the confines of an OR/MS decision model. Equally important is the fact that many multiple-objective forest-management problems are resolved in an adversarial environment in which regulatory constraints are proposed in an effort to achieve satisfactory levels of hard-to-value common property resources, such as water, fish, and wildlife. Compromise solutions, therefore, are developed around the bargaining table and not in the office of the OR/MS analyst. While multiple objective computer models help frame these discussions, they are not seen as the most valuable tool in the final deliberative stages of negotiation. Last, many of the political and social objectives of forest management cannot be incorporated into existing multiple objective models. Such factors as scenic beauty and spiritual value are extremely difficult to capture in formalized models. While surrogate measures may be used to represent such factors, many managers have difficulty accepting such measures and rely on their own instincts when making judgments.

Research on probabilistic models has also grown over the past two decades. However, we do not see much use of these models in forest management. This is due partly to the lack of empirical information needed to construct the probability distributions and partly to a lack of understanding on the part of decision makers. Attempts to use fuzzy programming are in their infancy but have seen limited use in forest management. The FORPLAN model includes a MAXMIN option for those applications in which the objective is to raise the lowest level of some critical resource to its maximum potential.

Hierarchical decision models offer the advantage of relatively small size per module; they are tailored to the needs of decision makers at various levels within the organization; they can handle forestwide concerns at the strategic level and specific spatial concerns at the subforest level; and they do not have the black box quality that large decision support models do. On the down side is the obvious need to design clever feedback linkages between models at the various levels in the hierarchy. Last, hierarchical decision models are a fairly new approach in forest management and are not yet widely used.

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