

***APPLICATIONS OF SYSTEMS ANALYSIS
IN WILDLAND MANAGEMENT: AN OVERVIEW**

By

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**Presented at ORSA/TIMS Joint National Meeting, Philadelphia, PA.
March 31 - April 2, 1976**

Applications of Systems Analysis in Wildland

Management: An Overview

Introduction

Managers of the nation's wildlands are being subjected to increased pressure to satisfy the growing desires of the American people from a static or shrinking land base. This pressure manifests itself in several ways. One obvious source of pressure is that which accompanies any major land use decision. For example, certain segments of society advocate massive land withdrawals for wilderness or national parks to promote the preservation of the native flora, fauna and naturally endowed beauty for future generations. Others promote increased utilization and development of our wildlands for commodity resources such as timber, forage and minerals. Both groups act in a manner consistent with their perception of the best use of the resources to meet current and projected demands. With much at stake conflicts are inevitable. This results in pressure being applied to the nation's wildlands managers in an effort to resolve the conflict in the most satisfactory and expeditious manner.

In addition to land use pressures, managers and administrators are also confronted with conflicting demands to: (a) "save the ecology" by promoting sound environmental programs and policies, (b) adopt economically efficient and equitable policies--especially on the public lands, (c) limit use of resources today to maintain future options, (d) increase the output of all goods and services from our wildlands, and (e) modernize administrative procedures through the use of a comprehensive management information system. In addition to these pressures we must acknowledge that wildland management systems are complex aggregations of physical, ecological, cultural and

political sub-systems. Each of these sub-systems is, in turn, composed of a complex set of interrelated components. Therefore, it is apparent that comprehensive and systematic long-range planning and policy analysis are necessary precursors of effective wildland management.

These reasons, and others, suggest that systems analysis - operations research (SA-OR) has a vital role to play by providing a sound structure for policy and decision analysis. While some yearn for "the good ole days" it seems apparent that current demands for increased levels of detailed analysis coupled with more sophisticated computerized systems of planning and control should insure that SA-OR play a role in the future. The paramount, but unanswerable question, is, "How much of a role SA-OR will play in shaping the future policies and strategies which affect our wildlands." It is towards a resolution of this question that this paper is directed.

Before addressing this issue in any depth it seems appropriate to access the current state of the art by reviewing past applications of SA-OR to the management of our wildlands. Following this review the discussion will center on possible reasons which explain why SA-OR has, or has not, been effectively utilized by wildland managers and administrators and suggestions for ways to increase the utilization in the future.

Five years ago Bare (1971), in a comprehensive review article, reported on the state of the art concerning the application of SA-OR techniques to the management of forested lands. At that time a search of the literature produced 336 references containing applications. The majority of uses involved either linear programming or computer simulation. Martin and Sendak (1973) published an annotated bibliography of forestry applications which contained 416 references current through 1971. After reviewing

source materials for the preparation of this paper the number of references has grown to over 925.^{1/} Obviously, with this number of references it is impossible to present a detailed analysis of individual papers. Instead, we will attempt to relate applications of SA-OR to the general classes or types of problems.

Linear Programming

As mentioned above, linear programming(LP) has been the most widely used of the mathematical programming techniques. The reasons for this are probably the same ones previously identified by analysts in other disciplines-- simplicity of model formulation, computational capacity, minimal data requirements and general level of managerial familiarity. As far as known, LP was the first SA-OR technique widely applied by land managers with the first application reported in 1958. In the intervening years LP has been extensively used by: (a) land use planners interested in allocating land resources to their optimal use so as to satisfy budgetary, ecological and physical constraints, (b) timber management specialists to derive optimal silvicultural schedules and cutting budgets, (c) range managers to derive optimal patterns of grazing and ranch management, (d) wood procurement managers to obtain least-cost schedules subject to raw material demands and available wood supplies, (e) mill managers to allocate and/or utilize logs to obtain their maximum contribution to profit, (f) wildlife and fishery managers to optimize the management of animal populations subject to constraints on the reproductive potential of the population, hunter pressure and carrying capacity of the land, (g) transportation planners to

^{1/}This bibliography will be published as a separate document.

design optimal road networks, and (h) fire managers to allocate scarce firefighting resources in the most efficient manner. Today LP is routinely used in both the public and private sectors to solve these types of problems. In addition, the literature abounds with other reported applications which have been applied on a limited scale.

Goal Programming

Many wildland management decisions involve the consideration of multiple goals and objectives. In the case of the national forests, this is required by law; in other instances the character of the land and/or pressures from users of the land create a multiple goal environment. Often times these goals conflict thus necessitating a compromise solution. SA-OR offers considerable promise by providing tools useful for analyzing alternatives under these circumstances. To date the only multiple criteria decision-making tool used by wildland managers has been goal programming. While this tool is currently enjoying considerable popularity, which due to its computational power may continue, it has yet to be extensively utilized in a routine fashion. Further, to be an effective decision aid goal programming requires that managers assign priorities and/or weights to each of their goals. In practice this is extremely difficult to accomplish especially on public lands where Congress has failed to identify the national policies and goals in a manner consistent with a quantitative determination of priorities. However, in some instances, managers and/or interdisciplinary planning teams are able to arrive at an agreeable priority structure. Public input often times results in conflicting recommendations which also must be incorporated into the priority setting process. Of course, without a clearly stated set of objectives it is difficult to

arrive at an agreeable set of priorities to input into the analysis. This suggests that the bottleneck is one of goal specification and quantification rather than one of an analytical nature. This further suggests that until this issue is clarified there is little hope that increased analytic capability--in the form of more sophisticated multiple criteria decision-making tools--will be of much value.

Integer Programming

Papers illustrating the use of integer linear programming (ILP) have appeared in modest numbers. Applications to date have been associated with: (a) transportation planning involving the optimal set of road projects to undertake to minimize construction and road maintenance costs, (b) the derivation of optimal timber management schedules involving harvesting and thinning operations, (c) the allocation of land parcels to their best use to meet certain land use requirements, and (d) the determination of the optimal number and location of manufacturing plants supportable by the wild-land base. The transportation analysis applications are routinely used on some western national forests, but the other uses are still in the experimental stages. Historically, the inability of most ILP computer codes to handle large-scale problems has been a primary cause of low usage by wild-land managers. In addition, most managers feel that LP provides an approximate solution that is adequate considering the lack of control that accompanies actual implementation. Of course, for some applications - such as transportation planning - the nature of the formulation requires the use of ILP.

Non-linear Programming

Actual applications of non-linear programming (NLP) in wildland management are almost nonexistent. In fact, fewer than a dozen references were found in the literature which report any use of NLP. Possible reasons for this are: (a) many wildland managers and/or their technical staff are unfamiliar with NLP, (b) most problems faced by wildland managers can be satisfactorily solved using LP, (c) most NLP computer packages can only handle relatively small problems thus making them unattractive to managers faced with real-life problems, and (d) general purpose computer codes for solving NLP problems are relatively difficult to use - often requiring the manager to furnish partial derivatives. Needless to say, most wildland managers have not been trained to provide such inputs, and feel uncomfortable using such techniques. The few reported uses of NLP have involved resource allocation problems similar to those reported for LP. However, to our knowledge, there are no routine production-oriented uses made of NLP in wildland management.

Dynamic Programming

Dynamic programming (DP) has received considerably more attention in the literature than has NLP. However, there are very few actual applications to real-life problems. Examples of the use of DP are: (a) the determination of optimal timber management programs including the harvest schedule, (b) the optimal allocation of trees and/or logs to various manufacturing facilities to maximize profit, (c) the determination of optimal pest management strategies, (d) the development of optimal fire suppression plans, and (e) the development of rate-of-spread models useful for

studying the behavior of forest fires. Reasons explaining why DP has not been heavily used by wildland managers are similar to those given for NLP. In addition, the lack of a single DP model discourages managers because of the difficulty of model formulation. The level of mathematical maturity required also scares off some potential users. Lastly, the "curse of dimensionality" and enormous computational times further discourage the use of DP for large-scale applications. In short, it is doubtful whether DP will ever enjoy the popularity of LP.

Simulation

Computer simulation is the most popular SA-OR technique being used to study to a variety of wildland problems including: (a) the efficiency of alternative forest sampling designs, (b) the characteristics of alternative timber harvesting and transportation systems, (c) the response of stands and/or individual trees to various growth stimulating treatments and growing conditions, (d) the behavior of whole forests and regional economies as alternative land use policies and treatment programs are tested, (e) the population dynamics of insect, wildlife and fishery populations as influenced by weather, stand conditions and wildland use decisions, (f) the characteristics of wildfires under a variety of burning conditions, fuel arrangements and attack strategies, (g) the mill-yard inventories of forest production manufacturing facilities, under conditions of varying mill consumption rates, labor pools, weather conditions and delays in ordering and acquiring wood, (h) the allocation of logs to various end product users, (i) the behavior of the hydrologic characteristics of watersheds under different land use practices and (j) the training of wildland managers in gaming-simulation experiments.

In terms of real-life applications, computer simulation ranks as the most widely used SA-OR tool in wildland management. The primary reason for this is the versatility of the tool enabling it to be used for a variety of purposes. Secondly, models can be constructed to tailor-fit the situation thus relieving the analyst from imposing large numbers of limiting assumptions. Third, simulation models can be built around the existing data base without requiring a major data-gathering effort prior to implementation and/or analysis. Fourth, "quick and dirty" models can be developed with short lead times to provide timely inputs to the decision-making process. And, lastly, "quick and dirty" solutions obtained through simulation are often times satisfactory when viewed in the context of actual implementation where on-the-ground modification is the rule rather than the exception.

Miscellaneous

Applications of queuing theory, decision theory and network theory to wildland management problems are also very sparse. While three dozen references were observed in the literature, most of these were small scale "demonstration" applications. Network theory, including critical path methods, has shown great promise in dealing with the design and construction of forest transportation networks. Several applications have been reported on the western national forests and by forest industry. Decision theory offers promise if used as a pedagogical tool to provide structure to decision making under uncertainty. In fact, all of the references to decision theory fall into this category. Queuing theory has received some attention with regard to timber harvesting and manufacturing but no known applications pertaining to land management exist.

Assessment of Utilization

With this brief overview of applications the discussion now turns to an assessment of the success of SA-OR in solving - or aiding the solution of - the major problems of wildland managers. Certainly the list of references containing applications is impressive. Further, the above overview has identified certain successful applications which are in routine use. Nevertheless, it is our opinion that only a small percentage of the SA-OR work reported in the literature is ever used to aid the resource manager. We further believe that in order to change this we must alter our modus operandi and steer a new course with renewed enthusiasm. Before turning to this, let's briefly assess where we stand today.

Bare (1971) summarized his review of the forestry SA-OR literature by identifying six hurdles or problems which inhibited greater managerial use of SA-OR. Among these were: (a) minimal use of multiple criteria decision-making tools inspite of the fact that many wildland management problems involve multiple goals, (b) difficulties associated with incorporating non-quantifiable and/or non-marketable benefits into the analysis, (c) sub-optimization introduced by incorrectly specifying system boundaries in an effort to deal with a more manageable problem formulation, and (d) the under-utilization or mis-management of the SA-OR group within an organization. Many times such groups are used after the fact to justify decisions already reached rather than as an integral part of the decision-making process.

One might classify these as "technical" barriers to effective utilization as they primarily relate to matters of technical origin. In retrospect we feel that while these were - and still are - significant barriers to the utilization of SA-OR they pale in significance when compared to what we may

call the "institutional" barriers. These are hurdles associated with the practice of SA-OR which for the most part have been erected by practitioners of SA-OR themselves. Grayson (1973, 1975) discusses these in the context of explaining why managers refuse to use SA-OR. His conclusions are that managers refuse to use SA-OR because: (a) of excessive time taken by SA-OR groups to respond to managerial requests, (b) of the inaccessibility of data needed by many SA-OR models once they are constructed, (c) many managers aren't familiar with SA-OR models and are resistant to change, and (d) many SA-OR groups produce models which barely resemble the real-world because the messy, hard-to-handle people problems, power structures and political pressures are assumed away. Certainly it is hard to find fault with Grayson's conclusions and yet it leaves the systems analyst in a quandry as to how to resolve the dilemma. For instance, isn't SA-OR taught in universities as an orderly, systematic approach to operational problems which utilizes the scientific method? And, further, doesn't science operate slowly and methodically by critically examining all available evidence before making an informed judgement? [If you read any contemporary introductory OR text, this is the mental picture that is conveyed.] It is no great surprise then that analysts are slow to respond to managerial requests.

This, as Grayson (1975) and others suggest, implies that the root of the problem of ineffective analyst - manager interaction may lie squarely in the lap of the educational system. However, Grayson is quick to acknowledge that the sword has two edges, and for managers he suggests the following for increasing the use of SA-OR: (a) dismantle SA-OR groups by placing personnel out in the organization, (b) hold the SA-OR staff accountable for results and not just for recommendations, and (c) maintain managerial expectations

within reasonable bounds and appreciate small gains. We should point out that these same Institutional barriers apply just as well within the context of wildland management as they do to managerial situations in other environments.

Another tendency of analysts, which inhibits utilization, is to produce "packages" of models to solve the every need of the manager. Except for the highly structured - time invariant decision situation - these packages of models tend to discourage managers rather than encourage them. Further, due to their necessary generality, they can rarely be used without modification, and this further lessens their utility. A recent review of several large scale RANN-NSF environmentally-oriented models supports the same conclusion (Mar, 1974). Other agencies seem to be reaching this same conclusion with a resultant slow-down in the development of new "packages" of models.

Those practicing SA-OR in the public lands sector are faced with another set of potential hurdles. These are associated with what Rittel and Webber (1973) refer to as "wicked" problems. Liebmann (1975) in discussing the application of SA-OR to public sector systems also discusses these problems or barriers. He identifies the following properties of wicked systems:

- (a) technological uncertainty - for example in wildland management we do not have a sufficient understanding of the basic behavior of wildland ecosystems to be able to predict with certainty the response of the system to a natural or man-induced disturbance. Thus, with this imperfect understanding it is difficult to identify the set of actions to undertake to attain some desired outcome, (b) no common agreement on public goals, and (c) the large number of "clients" who have a legitimate voice in the decisions. Certainly, practitioners of SA-OR in the public sector - and even to some degree in the

private sector - view these as significant barriers because of their perceived role in the decision-making process. That is, analysts often assume away the "messy problems" so that they can proceed with their analysis. However, as stated by Liebmann (1975), these analysts may be erring by failing to recognize that "...to a large degree, the role of optimization and modelling, is the formulation of alternatives rather than the selection of one of them. And their new role, in turn, requires a qualitatively different approach on the part of the analyst." Quade (1975) in speaking to the lack of success of SA-OR in solving the major problems of society suggests that explicit recognition be made of the non-quantifiable, political and sociological characteristics of the systems being studied. Obviously, consideration of these factors will greatly complicate the analysis but may be needed if SA-OR is to be used effectively, or at all, to address future problems.

Summary

In summary, "What is the future role of SA-OR in wildland management?" We think that the forgoing overview and assessment provides ample justification for the following conclusions:

- 1) Wildland managers and administrators will continue to feel the pressure to provide increased levels of outputs and services from a shrinking land base. This will necessitate comprehensive and systematic analysis of alternative programs and policies in order to pursue the most effective and efficient course of action. This all points to an increased role for SA-OR in the future. However, practitioners of SA-OR must be responsive to the criticisms identified earlier in this paper if maximum usage of SA-OR is to become a reality.

- 2) We should accelerate the evaluation and use of multiple criteria decision-making models. This will sharpen the distinction between the trade-offs involved under differing priority sets, and it will provide an analytical framework compatible with the multiple goals for which most wildlands are managed.
- 3) Where possible, pursue the use of "quick and dirty" models in lieu of large-scale, expensive, time-consuming, data intensive models. Where not appropriate we must recognize that large-scale models may only be cost effective in situations where a repetitive usage is anticipated.
- 4) De-emphasize the development of "packages" of models unless they are composed of modules which can be dis-assembled and re-assembled quickly and cheaply.
- 5) Recognize that SA-OR analysts should be spread throughout a firm or agency along with other managers to encourage increased communication and utilization of SA-OR results.
- 6) We should strive to incorporate non-quantitative political, cultural and sociological factors into our analyses if they are relevant. While the resulting "messy" problems will be difficult to analyze using conventional techniques, this should stimulate the development of new concepts and procedures more useful to managers and administrators.
- 7) Fully recognize the difference between public and private sector problems. As suggested earlier in this paper, this may involve the use of SA-OR to help identify alternatives and not just to

select from a previously given set. This will unquestionably require the development of new concepts of analysis but should result in a more useful set of analytical procedures.

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