Invitational Synthesis Paper

Papers published by the *Journal of Range Management* for many years have been almost entirely reports of results from focused studies designed to test specific hypotheses or to fulfill specific objectives. While this is entirely appropriate for a scientific journal, the Editor and Associate Editors realized the genuine need to publish articles that synthesize results from focused studies into a more general fabric of knowledge, providing greater insight than the sum of information reviewed. It was agreed during 1986-87 that distinguished scientists should be invited to prepare synthesis papers, and a goal was set to publish one synthesis paper in each volume of the *Journal*. The Editor and Associate Editors were pleased that Dr. Charles J. Scifres accepted their invitation to write the first such paper.

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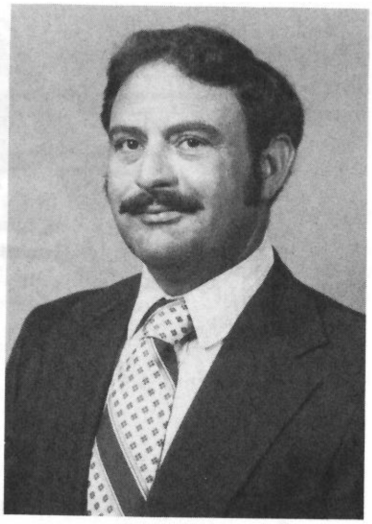

Charles J. Scifres

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Scifres and his wife Julia have two children and a granddaughter.

Decision-Analysis Approach to Brush Management Planning: Ramifications for Integrated Range Resources Management

CHARLES J. SCIFRES

Abstract

Simulation, optimization, and other modeling paradigms for systems ecology and economics have not been broadly applied to development of models for range resource management in real-world settings. The lag in emergence of applicable management models may be attributed to the lack of a conceptual context for their application. Recent appreciation of the decision-analysis approach to natural resource management and the general availability of high-speed computing capabilities have provided viable bases for using increasingly sophisticated analytical tools to solve management problems. Decision models may be used to generate *proforma* contrasts of selected management alternatives for multi-enterprise firms and implementation protocols for the selected management program(s). Such models, operating from a computer-managed information base, become decision-support systems (DSS) for approaching specific management problems; Integrated Brush Management Systems (IBMS) is one example. These DSS are proposed at the first step toward creating comprehensive decision-making models for total resource management (i.e. Integrated Range Resource Management or Integrated Range Resource Analysis). The next generation of models will link qualitative information and rules-of-thumb (heuristics) with hard (experimentally derived) data. These knowledge-based or expert systems, one facet of the growing field of artificial intelligence, hold great promise as vehicles for achieving Integrated Range Resource management. Bringing Integrated Range Resource Management Systems to fruition can be expedited by interdisciplinary research and educational programs for potential user groups.

Key Words: computer decision aids, expert systems, integrated brush management systems, knowledge-based systems

Range resource managers act daily in decision-making environments that require understanding the biological and economic interactions among management practices and habitats of domestic and wild animals. Solutions to such complex ecological-management problems first require adoption of long-term strate-

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Much of the information in this paper represents results of the collective efforts of a research team working on Integrated Range Resources Management at Texas A&M University. I am indebted to Wayne Hamilton, Richard Conner, Steve Archer, Jerry Stuth, and Nick Stone for their subject-matter and editorial suggestions; Julia Scifres for help in manuscript preparation; and Darrell Ueckert for his encouragement and invaluable editorial suggestions.

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gies which provide goals or constraints for tactical decision analysis (Walters and Hillborn 1978). However, traditional research in brush management has emphasized development and improvement of methods and associated technologies for tactical purposes with relatively little consideration for their strategic potential, especially in relation to the economic outcome of brush management practices.

Fundamental to the traditional research approach has been the tacit premise that no 2 firm-level decision-making environments are exactly the same. Ostensibly, the best that could be offered resource managers has been a general assessment of efficacy for individual technologies. As a general and unfortunate rule, it has been left to the manager to adapt technologies and orchestrate their implementation to meet specific strategic goals. Thus arises a major deficiency in technology dissemination: most technologies cannot be directly "transferred" to producers without first being tailored to meet specific needs (Horton 1986). Walker et al. (1978) suggested that the gap between research and management may be bridged by development of simple decision rules which help resource managers choose appropriate strategies and effectively implement them.

As aptly proposed by Norton and Walker (1985), "If research programmes in applied ecology are to have the greatest chance of improving management, they must be designed with the resource manager's problems in mind. It is suggested that the adoption of a decision-analysis approach can achieve this objective and increase the relevance of ecological research." They earlier argued that application of ecological principles has been constrained by lack of a conceptual, problem-oriented (management) framework that outlines specific requirements for ecological information (Norton and Walker 1982). These arguments provided the impetus for directing recent research toward developing the conceptual framework for identifying best management alternatives within the broad context of firm level, decision-making environments. As a result, a new generation of decision models and systems has been created for rangelands (Wight 1987).

The objective of this paper is to propose, from an applied biologist's viewpoint (and one who certainly is not a systems scientist), the potential for broader applications of systems logic, decision analysis, and eventually expert systems to range resource and ranch firm management. Involvement of natural resource scientists and managers in systems research and application is a natural extension of their traditional roles as integrators of resource use. Evolution and potential of a planning model, Integrated Brush Management Systems (IBMS), will be used as the central theme on the premise that the underlying concepts and ideas have application to range resource management in the broader context.

Terms

The word *system* is used in relation to a broad array of phenomena and activities and has various meanings to range scientists and managers depending on context of use. The definition, "...a group of elements, either physical or nonphysical in nature, that exhibit a set of interrelations among themselves and interact together toward one or more goals, objectives, or ends" (Mittra 1986), is adopted for the purposes of this discussion. In this context, *model* is defined as any representation or abstraction of a system or process which helps us (1) define problems, (2) organize thoughts, (3) understand data, (4) communicate and test that understanding, and (5) make predictions (Starfield and Bleloch 1986, Williams 1979). A *decision-analysis aid* is any model that helps the user arrive at a feasible solution to a specific problem given available information. A *decision-support system* (DSS) is a computer-based information system that helps a manager make key decisions, thereby enhancing the effectiveness of the problem-solving process (Mittra 1986). Logically, then, a computerized decision-analysis aid becomes a DSS as it provides information from a data base which enhances the user's ability to arrive at an appropriate solution. An *expert* or *knowledged-based system* can be viewed as a model of the expertise of the best practitioners in the particular field of inquiry (Harmon and King 1985). Knowledge systems interact with a user much the same as a consultant would, and provide advice along with the underlying rationale (a more detailed discussion of knowledge-based systems is given in a later section).

Evolution of the Brush Management Concept

Since the chronology of the changing philosophy concerning brush and its management has been detailed (Scifres 1980; Scifres et al. 1983, 1985), only the salient points will be presented. The changing attitude from brush eradication to brush control implied understanding that there exists a threshold of economic advantage beyond which an incremental increase in cost does not generate a significant increase in benefits from woody plant control. However, eradication still appears in the popular literature, and "brush control" still connotes the desire to kill all woody plants in the targeted stand. "Brush management" first appeared in the literature in 1965 when Box and Powell (1965) espoused the idea that forage values of certain otherwise troublesome woody species could be improved by selected manipulations. The idea was subsequently expanded and utilities of the concept presented in a broader context, "management and manipulation of stands of brush to achieve specific management objectives" (Scifres 1980). This approach embraces the potential values of certain quantitites of woody plants for an array of purposes in range management (Scifres et al. 1983), but wildlife habitat remains as one of the primary foci (Beasom and Scifres 1977, Whitson et al. 1977, Tanner et al. 1978, Beasom et al. 1982, Scifres and Koerth 1986). The view was explicitly stated by Jacob's (1987) objective for sagebrush (*Artemisia* spp.) ecosystems, "Maintaining vegetation to sustain the optimum level of livestock and wildlife consistent with other uses of rangeland."

The idea of Integrated Brush Management Systems (IBMS) was catalyzed by the awareness that no single brush control method normally is sufficient to meet resource goals. The pervasive limitation facing resource managers considering use of available brush control technologies as single treatments was, and still is, lack of positive economic performance. Given cost of treatment, available methods too often do not provide the necessary level of efficacy, and life of effective control is often inadequate to compete with alternative investments of capital. This reality provided the impetus for focusing research on application of methods in a logical sequence. Each method in the sequence initially was chosen to complement other method(s) (e.g., broaden the spectrum of species suppression, increase the effective life of an initial costly method). This research indicated that the potential interactions of treatments in sequence, expressed in terms of efficacy, may produce predictable outcomes. For example, herbicide application and prescribed burning in sequence may be additive (i.e., response to the treatment sequence is as expected based on performance of the treatments applied singly, [see Scifres 1975, Scifres et al. 1983]); synergistic (positive results from treatment sequence greater than expected based on performance of individual treatments, [see Gordon et al. 1982; Ueckert and Whisenant 1980a, 1980b; Mayeux and Hamilton 1983, Dow Chemical U.S.A.]); or antagonistic (results from treatment sequence less than from the most effective treatment in the sequence [see Ueckert et al. 1983]).

The potential interactions among brush control methods and the need to design brush management to best fit multi-enterprise ranch firms gave rise to the development of IBMS: "a rational decision-making process that seeks to optimize sustained yield of all rangeland products" (Scifres 1986). Theoretically, yield optimization should maximize sustainable economic returns over a predetermined planning horizon.

Generalized Decision Models

Decision-analysis models are designed to aid the user in selecting the course of management action which best fits the management environment and addresses his/her specific management goals. Generalized decision models, such as that of Norton and Mumford (1984) for pest management, provide a decision-analysis framework driven by 3 major variables: perceptions of problems, perceptions of options, and management objectives (Fig. 1). "In this model, and in reality, a decision problem only exists where there is a physical problem and a range of control options to deal with" (Norton and Mumford 1984). If the decision-maker's objectives are satisfied by a standard operating procedure (e.g., routine spraying for a given pest), a decision model is of little use. Decision problems arise because of the introduction of new pests which the standard practice will not control or because a new option has emerged (e.g., newly developed pesticide).

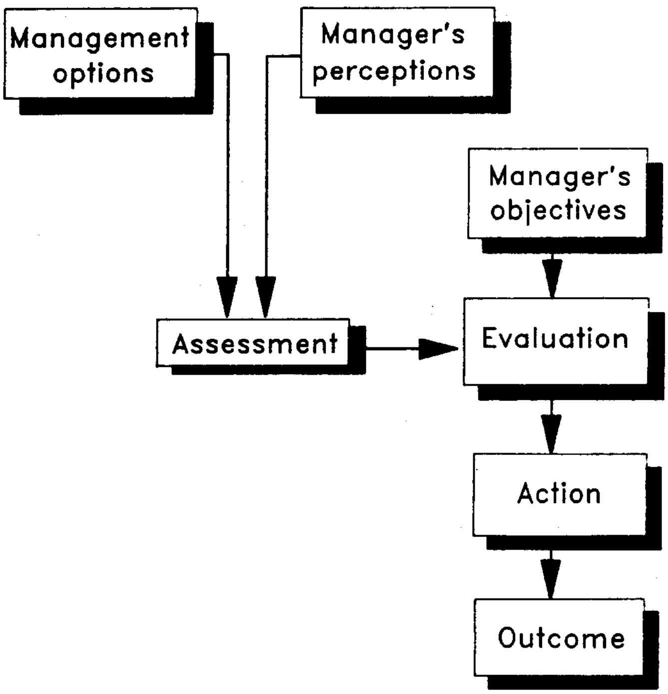

Fig. 1. *Generalized decision model adapted by Norton and Walker (1985) from Norton and Mumford (1984) for pest control.*

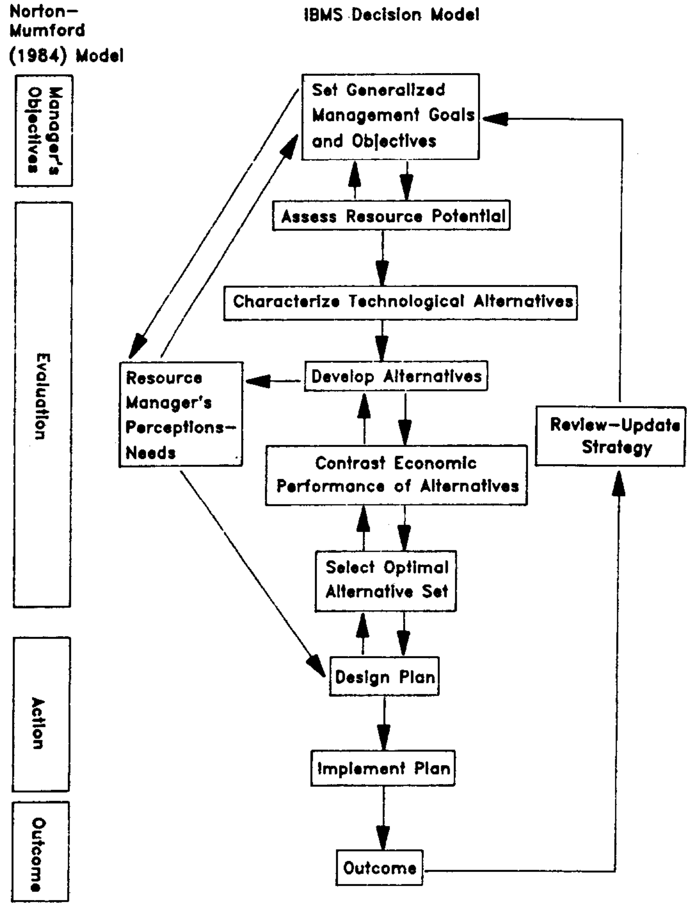

Fig. 2. *Parallels between the generalized Norton and Walker (1985) and IBMS (Scifres et al. 1985) decision models.*

Although the Norton-Mumford model was developed for agronomic settings, its driving logic can be directly applied to range resource management. Standard operating procedure(s) for brush management is(are) normally used by range resource managers until a new option emerges (e.g., new herbicide, prescribed burning) or a new brush problem develops (e.g., increase in species resistant to the herbicide previously used), a commonly used herbicide is withdrawn from the marketplace, herbicide costs increase significantly, and/or livestock prices decline seriously. In any case, the decision environment has generally been informal and the problem-solving mentality largely reactive environments. Greatest benefits from decision-making processes are accrued when the user employs them in a proactive fashion (which invokes, at least to a certain degree, formality). Proactive planning is especially germane to the long-term planning required to effectively manage natural resources.

The IBMS model (Fig. 2) decomposes the generalized decision model of Norton and Mumford (1984) into the series of functions necessary for brush management planning. A major difference in models for natural resource management and those for management of agronomic systems is the longer planning profile dictated by the former. Natural resource management decisions may affect the outcomes of subsequent actions for 5 to 20 years in contrast to decisions for agronomic systems, which may be altered significantly on an annual basis with shorter-term impacts of previous decisions. Because outcome of previous actions forms a new decision-making environment, long-term planning for natural resource management requires dynamic, iterative models which can take advantage of new technologies as they emerge (Fig. 2).

The ultimate effectiveness of any brush management program hinges largely on the effectiveness of other ranch management practices (e.g., grazing management, livestock herd management, wildlife management and merchandising strategies, and recreational uses). Management ability (i.e., managerial intelligence, experience, skill and effort [Walker et al. 1978]) is critical to the outcome of any management plan. The potential unique interactions of these elements in a multi-enterprise firm setting justify a planning process that develops a long-term strategy to meet specific management goals (Scifres et al. 1985), and one that allows adjustments in strategy to meet changes in goals through time. The idea was recently presented by Mendoza et al. (1986) as Multiple Objective Programming. Norton and Walker (1982) referred to this approach as Integrated Resource Analysis and proposed it as an operational framework on a national basis. Certainly, the decision-analysis approach has considerable merit for discerning optimal approaches to policy development (e.g., Bonnicksen 1980, 1981, 1985; Bonnicksen and Becker 1983; Bonnicksen and Lee 1982) as well as to resource allocation and planning at the ranch firm level. Resource allocation can be determined at 3 levels of decision-making: planning (strategic); design (tactical); and management (operational) decisions (Norton and Walker 1982, Mittra 1986).

To effectively work for the user, a decision model must be:

(1) presented in a format understandable and applicable to a given planning environment;
(2) based on systems logic (ideally biases are imposed only by user, and all biases and their sources are identified as such), and
(3) dynamic and iterative to accommodate progressive temporal changes in state of the firm.

For specified land management programs such as brush management, an effective decision-analysis model must meet certain criteria and perform several primary functions:

(1) require statements of working objectives for land (resource) use on a management unit-by-unit basis;
(2) project potential change(s) in production level that can be achieved by management action (i.e., evaluate present state and assess production capabilities) under alternative management schemes;
(3) allow selection of applicable alternative technologies first based on objective performance criteria (projected degree to which production capability can be achieved), then allow screening based on user preferences and/or specific application constraints (the technologies may include primary and/or secondary technologies with information relative to the implementation);
(4) allow periodic incorporation of new knowledge;
(5) allow assessment and restatement of objectives, and restart the technology selection loop if technology is inadequate to meet stated goals;
(6) isolate and quantify key interactions among land uses in a multi-enterprise setting that might result from employing specific technologies;
(7) objectively contrast selected alternatives based on economic criteria, clearly identifying compromises among enterprises (and assigning value lost), then subject output to user scrutiny for final selection;
(8) provide the framework for developing an implementation/-monitoring plan, and,
(9) provide a mechanism for reviewing plan and updating as necessary.

Objective Setting

Decision-analysis protocols such as employed by the IBMS model require setting of goals within the constraints of production potential of the resource (Fig. 2). Setting of goals for brush management must occur at several levels. The first level is vested in those who discern the overall goals for the firm. The pervasive goal may be as simple as "staying in the ranching business," and can be decomposed into a hierarchy:

I. Stay in the ranching business
   A. Optimize returns to the firm from selected enterprises on
   A. management unit basis.
      1. Optimize returns from cow-calf and lease-hunting enterprises in Venado Grande pasture.
      2. Etc....

As straightforward as this management-by-objective approach seems, it too often is not formalized. Lack of such formal guidance may result in brush management becoming the end rather than the means for attaining stated objectives.

Evaluating Resource Potential

Effective decision-analysis requires that management goals be commensurate with production potential of the resource. In this regard, land is viewed as one production input by the IBMS planning process. Projected potential productivity is a function of the specific investment and management inputs that are combined with land capability (Norton and Walker 1982). This stage of the planning process provides information critical to each subsequent step in the analysis. The analysis requires that projected levels of annual production be quantified (e.g., as forage production or carrying capacity) for the management unit. These projections must contrast anticipated change following implementation of brush management and expected production without treatment. Recently published procedures for estimating forage production in relating to anticipated variations in precipitation are extremely useful in this regard (Hamilton et al. 1986).

Evaluation of Alternative Technologies

Decision-analysis models should first present the array of technological alternatives known to be effective, then use management preference as the criterion to select a subset for further consideration (Scifres et al. 1985). The subset of preferred technologies can then be evaluated based on expected levels of performance projected through a planning profile. Planning profiles of 15 to 20 years are appropriate for most range improvement projects (Scifres et al. 1985).

It is critical that all available options be equitably screened. This prevents placing unwarranted emphasis on new methods unless dictated explicitly by the user. Decision-analysis aids, such as *if-then* treatment selection routines (Fig. 3), are useful formats for technology evaluation. Once applicable methods are identified, they are screened for limitations to implementation (e.g., aerial spraying might be omitted from the list of potential alternatives because of the proximity of susceptible crops). Once evaluation of the initial (primary) technology is completed, followup technologies may be evaluated by the same process but in the context of projected alterations resulting from deployment of the primary method (i.e., the analysis must be conducted on each complete treatment set).

A general decision-analysis model, to be functional, must allow partitioning the management problem into a hierarchy of simpler problems [see Walters and Hillborn (1978) for discussion]. Details for the IBMS model are not illustrated in Figure 2; however, the model is structured such that it may be decomposed into a series of functions. Such models may be enlarged to encompass range resource management in the broadest sense (in that case, critical functions become modules in the hierarchy). The economic component serves as an example of such a module.

Economic Analysis

The greatest limitation to development of effective management models has been lack of information adequate to estimate production changes resulting from application of the technology. Often, lack of quantitative data necessitates use of expert opinion (Fig. 4). The Whitson-Scifres (1980) model (Fig. 5) was effectively verified using expert opinion (Scifres et al. 1985). Biologists often initially shy away from the prospect of allowing opinion rather than "hard data" to be used in a model (although their opinions typically flow freely through informal interactions with information users). However, this approach is being progressively accepted as necessary if significant progress in development of management models is to be made. Where information is urgently required, the use of Delphi and other techniques aimed at obtaining quick, best estimates from expert opinion can be usefully employed (Norton and Mumford 1984). "Educated guessing: this approach may be quite formalised...referred to as multidisciplinary judgments...involving a round-table workshop of limited duration with selected experts..." (paraphrased from Norton and Walker 1982). The usefulness of such judgments can be further refined by attaching a confidence level (0 to 1) to each.

Economic analysis in the IBMS process is based on refinement of the generalized response curve of Workman et al. (1965) (Fig. 5). Although still in need of refinement [e.g., inclusion of a function

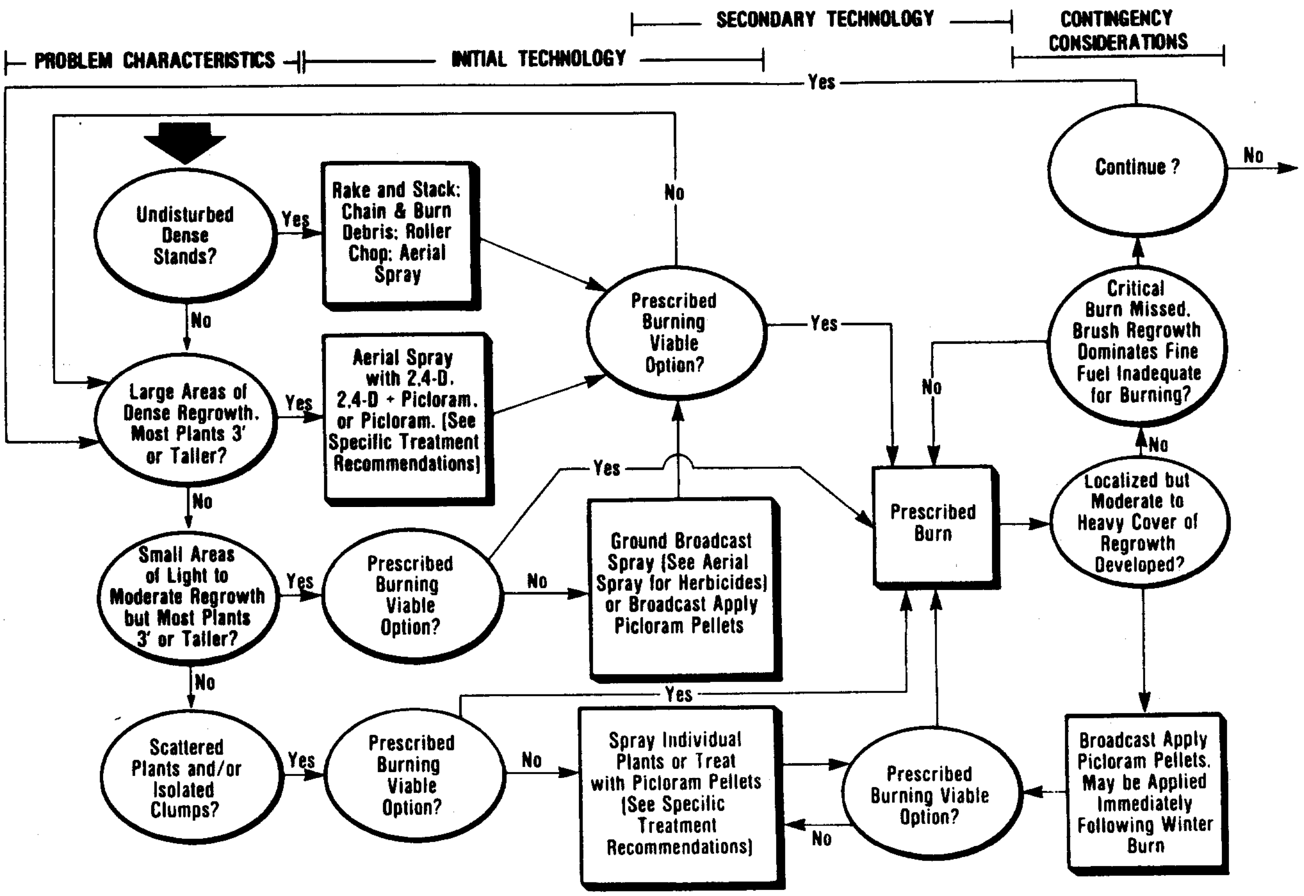

Fig.3. *Decision-analysis aids such as this* if-then *treatment selection routine for Macartney rose* (Rosa bracteata) *management are useful formats for brush management system implementation (taken from Scifres et al. 1985).*

which assesses the change in production over time if brush management is not employed (note static P_0 function, Fig. 5)], the model provides a mechanism for comparison of alternative methods and strategies in pecuniary terms. Utilization of the model for analysis of experimental results (Scifres 1987), empirical data (Garoian et al. 1984), and expert opinion (Whitson and Scifres 1980) clearly establishes the economic superiority of a well-defined brush management strategy and the need to consider that strategy in the overall context of range resource management. The general economic model has also been used for evaluation of projects such as spraying of sagebrush rangelands (Jacobs 1987). It is based on little or no change in forage production the year after treatment of brush, then an increase to the maximum production the year after treatment of brush, then an increase to the maximum production value (P_{max}) which is sustained for a period of years. Thereafter, forage production gradually declines to the original level at which time treatment life (T_L) has expired.

One of the simplest approaches to quantifying the importance of forage released by treatment is to assign it a lease value. However, there are several sources of production change (e.g., increased calving percentages and weaning weights) in addition to increased carrying capacity for cow-calf enterprises (Fig. 6). Also, there are several costs normally associated with a brush control treatment (e.g., additional breeding animals to take advantage of increased forage and associated variable costs, and potential reduced revenues for other enterprises such as lease hunting) in addition to treatment application costs.

The cost/return information may be used to create partial budgets for a series of selected alternatives. Subsequent net present-value analyses facilitate scrutiny of alternatives on financial (magnitude of investment, timing of investments, cash flow), economic (internal rates of return, net-present value) and risk preference criteria (Fig. 7) (Scifres et al. 1985).

Knowledge-based Systems: Toward Comprehensive Decision-Analysis at the Ranch Firm Level

Decision models were intentionally presented herein in the most simplistic form, but they are prototypes for more comprehensive models which effectively encompass all significant management elements for multi-enterprise firms. Such models cannot be completely driven by experimentally derived information (much of which is informative but not easily applied [Norton and Walker 1982]). Development of decision-analysis models and supporting subroutines require 4 categories of input: historical, real-time, forecast and fundamental information (Norton and Walker 1985).

Historical information is most heavily used as input at the resource potential assessment stage with the IBMS process (Fig. 2). Real-time information is generated through the continuum from the point of resource potential assessment to completion of economic assessment of alternatives. Forecast or predictive information is derived from the other 3 types of information, generated as output by each subroutine, and then finally forms the interactive result of the system.

Fundamental data are generated from basic research by traditional experimentation. The impetus for the experiments often is information gaps which invariably emerge during the decision-analysis process. For example, additional research may be required to characterize the interactive nature of selected alternatives (e.g., grazing management × brush management; wildlife habitat × grazing management × brush management), and to develop more

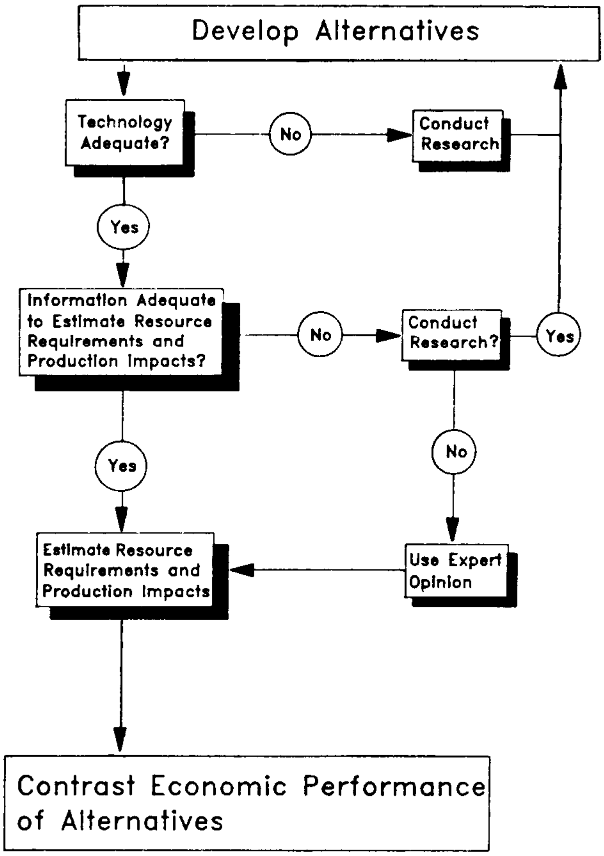

Fig. 4. *Process subroutine for selection of alternative technologies using generalized processes in Figure 2. This stepwise procedure for developing estimates of resource requirements and production impacts is used to satisfy information needed to construct response curves (Figure 5). Where information is inadequate, the option for using expert opinion may be exercised.*

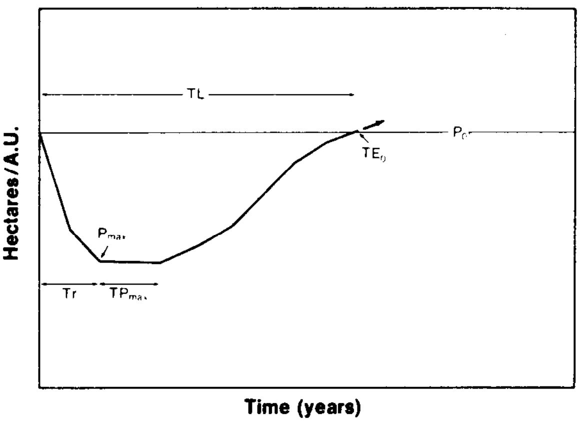

Fig. 5. *Function for estimating livestock production response to brush management. (T_r represents time from treatment application to maximum response; TP_{max} is the time period during which maximum production is realized; P_{max} is maximum expected production level; TE_o is time at which production following treatment is expected to equal P_o, initial production level; TL is estimated treatment life.) (Taken from Scifres et al. 1985).*

effective alternatives and/or refine existing brush management alternatives. However, until such time that experimentally derived data are available, expert opinion will be required for the models to function (see Fig. 4).

The use of opinion and experience (heuristics, rules-of-thumb) is the mainstay of any successful natural resource manager. "Decisions in ecological management are often made in practice on the basis of qualitative data and an individual's accumulated experience" (Starfield and Bleloch 1983). Expert systems or knowledge-based consultation systems offer promise in developing explicit links between hard data and final management decisions. Rule-based diagnostic expert systems have been developed in various fields and there is growing interest in their applications to ecological problem-solving (Loehle 1987). These systems incorporate opinions of practitioners as well as those of scientific experts with source of information determined solely by problem context.

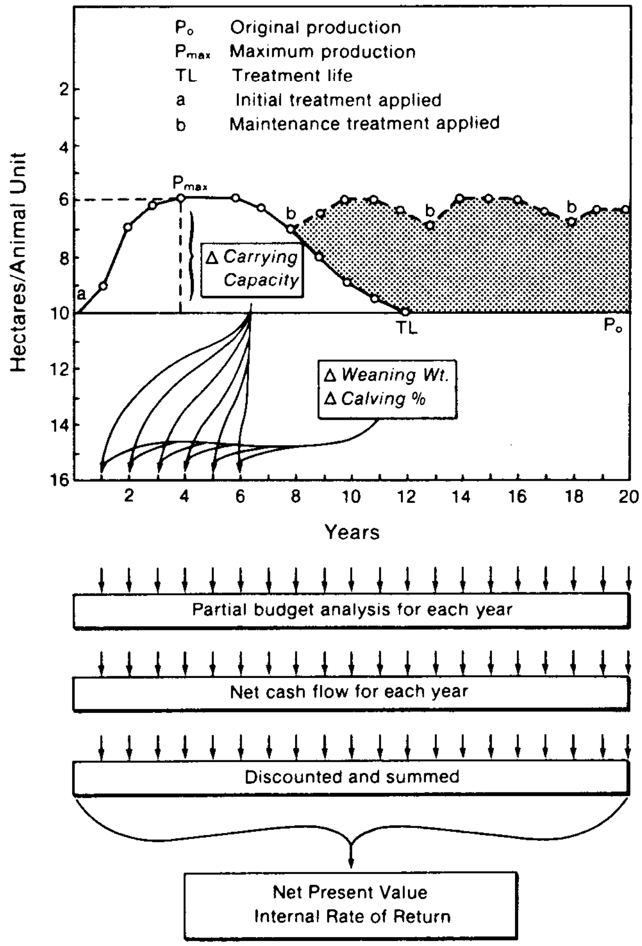

Fig. 6. *Information inputs on cow-calf enterprise (Courtesy W. T. Hamilton).*

Interactive decision-analysis aids can be considered to be one form of expert system within the general field of artificial intelligence (AI). Research in AI has been conducted largely in computer science and cognitive psychology with applications to natural resource management explored only recently (Coulson et al. 1987). The formal definition of expert systems by the British Computer Society (from Naylor 1983) is:

> An expert system is regarded as the embodiment within a computer of knowledge-based component from an expert skill in such a form that the system can offer **INTELLIGENT ADVICE** or make an **INTELLIGENT DECISION** about a processing function. A desirable additional characteristic, which many would consider fundamental, is the capability of the system, on demand, to **JUSTIFY ITS OWN LINE OF REASONING** in a manner directly intelligible to the enquirer. The style adopted to attain these characteristics is **RULE-BASED PROGRAMMING.**

Harmon and King (1985) elaborate on Feigenbaum's (undated) definition of an expert system:

> ...an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to

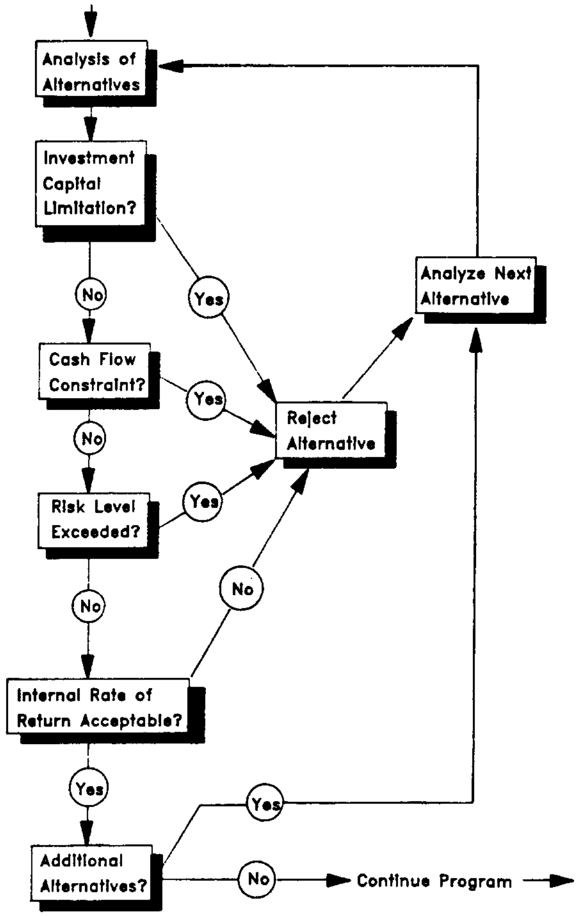

Fig. 7. *Expanded decision-analysis procedure (generalized as "contrast economic performance of alternatives" in Figure 2) for screening alternative brush management technologies and systems based on economic criteria.*

require significant human expertise for their solution. Knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners of the field.

The knowledge of an expert system consists of facts and heuristics. The 'facts' constitute a body of information that is widely shared, publicly available, and generally agreed upon by experts in a field. The 'heuristics' are mostly private, little discussed rules of good judgment (rules of plausible reasoning, rules of good guessing) that characterize expert-level decision making in the field. The performance level of an expert system is primarily a function of the size and quality of a knowledge base it possesses.

Harmon and King (1985) use the term *knowledge systems* in lieu of the more widely used *expert systems*. Knowledge systems interact with the user much as a consultant interacts with a client [i.e. knowledge-based consultation system (Starfield and Bleloch 1983)], so that knowledge engineers (persons who create knowledge-based systems) employ facts and heuristics as employed by an expert in the field. Such systems are composed of a knowledge base, an inference engine and a user interface (Fig. 8).

Some general working properties of rule-based knowledge systems (i.e. diagnostic expert systems are:

1. *Knowledge-based systems may function as consultation systems.* They may be highly interactive with the user, use a computer framework for organizing information (both qualitative and quantitative), and investigate the rationale behind decision-making in the specific domain of inquiry (Starfield and Bleloch 1983). The system holds an apparent intelligent conversation with user by asking questions (the order and nature of which depend on answers to previous questions).
2. *System logic is based on decision rules.* Simple knowledge-based systems may be formed around straightforward *if-then* rule bases. For example, a system could be built around the Macartney rose problem featured in Figure 3 by developing the appropriate decision rules [see Starfield and Bleloch (1986), Harmon and King (1985), Naylor (1983), and Sell (1985) for discussion of rule development].
3. *Knowledge-based systems may vary widely in complexity.* The complexity of the systems should be a direct function of anticipated use; as with most problem-solving tools, the simpler the better [Starfield and Louw (1986); also see the straightforward system presented by Starfield and Bleloch (1983)]. However, knowledge-based systems may not be necessary to solve many problems. When the rule base becomes so small that an inference engine is not needed, branching conditional statements may be adequate to reach a feasible solution (as illustrated in Figure 3). Performance of the system is largely a function of the size of the knowledge base used by the system.

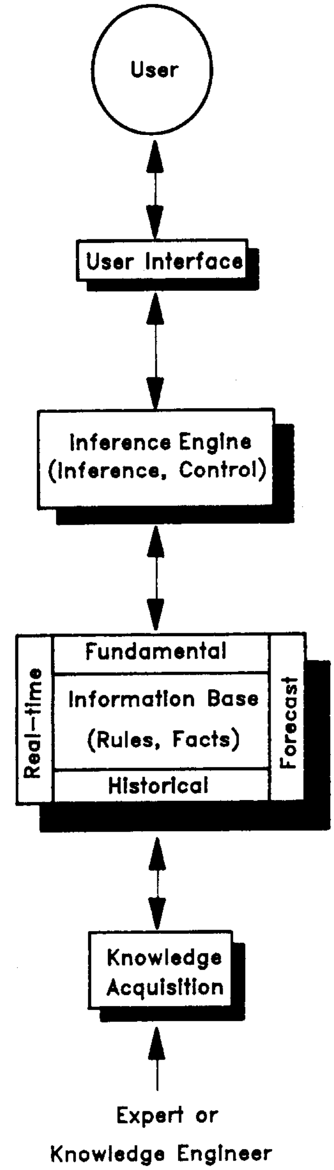

Fig. 8. *Components of generalized knowledge-based system adapted from Harmon and King (1985).*

The rule base for a simple expert system to determine the best approach to managing a Macartney rose stand can be developed from the decision tree in Figure 3 and the following knowledge:

Rule 1. If the Macartney rose is an undisturbed (most plants ≥2 m tall), dense (≥ 60% canopy cover) stand, then broadcast mechanical or chemical methods should be employed.

Rule 2. If the Macartney rose is a stand of dense (≥ 60% canopy cover) regrowth with most plants 1 m or taller, then broadcast chemical methods should be used.

Rule 3. If the Macartney rose stand is regrowth on small areas with light to moderate canopy cover (≥ 10%, <60%) and most plants are 1 m or taller, then prescribed burning should be considered as the initial treatment.

Rule 4. If the Macartney rose stand occurs as scattered plants or as isolated clumps, then prescribed burning should be considered as the initial treatment.

Rule 5. Etc.....

Given this sample set of generalized rules, the system can then be developed to interact with the user by querying for information that will allow step-by-step movement through the decision tree. Such a question/answer session might follow the format:

Selected portion of theoretical knowledge-based system designed to assist in designing Macartney rose management strategy.

1.0	System's question	Users response
1.0	Has the management unit or pasture in question been treated previously to control Macartney rose?	Yes
	1.1	
	.	
	.	
	.	
2.0	Does the Macartney rose cover exceed 60% of the area on the management unit or pasture in question?	No
	2.1	
	.	
	.	
	.	
3.0	Does te Macartney rose cover exceed 10% of the area on the management unit or pasture in question?	Yes
	3.1 Does the Macartney rose occur as scattered patches or more or less uniformly over the management unit?	Uniformly
	3.1a. Is the area small enough to warrant spraying with ground equipment?	No
	System Analysis. The most effective control measure is to aerially spray with 2,4,-D, 2,4-D + picloram or picloram. Would you like to review specific treatment recommendations?	Yes
	{Screen displays recommendations for each alternative herbicide including rate(s) of application, carrier, season of treatment, use precautions, etc.}. Would you like to review current treatment costs?	Yes
	{Screen displays most current costs for herbicide and application listing sources and dates of estimates.}. Would you like to review expected results from application of the alternatives?	Yes
	{Screen displays expected results including canopy reduction, proportion of plants killed, impacts on herbage production (anticipated reduction in forb production, grass response etc.)} Would you like to choose a treatment and conduct *proforma* economic analysis? [N = no, D = 2,4,-D, D+P = 2,4-D + picloram; P = picloram]	D + P
	{System branches to economic analysis program and begins new round of queries to build production response function.}	

The economic subroutine will query the user as to present production level (carrying capacity, calving percentage, bull:cow ratio, weaning weights, etc.); will ask the user to select a selling price, anticipated cost of additional cows and bulls (if needed), variable costs/AU and other information necessary for the analysis. The system will then construct an expected response curve, create a partial budget and display upon request the results of a net present-value analysis. Upon completion of the analysis, the program will query the user:

Do you wish to evaluate another alternative?

Do you wish to evaluate followup (secondary) control practices?

These knowledge-based systems can be updated as new technologies emerge and certainly are not limited to brush control. Rule-based systems can be built for grazing management systems, supplemental feeding, wildlife management strategies, livestock herd management and other elements essential to decision-making in multi-enterprise environments.

Role of Interdisciplinary Research

Natural resources research traditionally has followed strictly defined disciplinary boundaries, often with areas of study further isolated within disciplines. As examples, studies of livestock reproductive efficiency and herd improvement often are not conducted in, and therefore may not be relevant to, the rangeland environment; research on game animals and wildlife habitat have largely been pursued independent of range management in the real-world- context; and, grazing management studies have been isolated from brush management research. This mode of research is being universally questioned [e.g. Tainton's (1986) plea for an interdisciplinary approach to grassland-animal research].

Application of decision models at the firm level depends on successful functioning of 4 processes: information generation, synthesis, dissemination, and reception (Norton and Mumford 1984). Given the complexity of decision-making at the ranch firm level, decision model development and delivery of the technology cannot be accomplished by any given discipline. The overall task requires focusing of the coordinated expertise of representatives from the appropriate plant, animal, and social-economic sciences on the common goal. Organization and function of such an effort within the traditional decentralized educational system pose various problems for sponsoring organizations as well as for disciplines with organizations (see Swanson 1979 for discussion). Thus, critical barriers to interdisciplinary research arise from impairment of communication induced by scientific specialization (Horton 1986) and institutional barriers (Tainton 1986). The systems approach is of interest to many scientists, however, because it also allows synthesis of their individual pieces of research information in the context of the larger production problems. As this interest becomes more pervasive in academic environments, barriers to interdisciplinary research will hopefully be reduced or eliminated.

The IBMS process and recent interest in knowledge-based systems offer potential for taking advantage of the expertise of specialists in a format for problem-solving in the broad contest of range resource management. This "higher order" of range research and education will require the pooling of expertise from various disciplines and orchestrating investigations that meld relevant science with management, social and economic issues. Applications of the systems approach to range education was slighted only for the sake of space for reasonable treatment of the subject. Bawden et al. (1984) argue that a systems approach to investigative problem solving is a more useful paradigm for learning about agriculture (and natural resource management) than reductionist, discipline-based approaches. Thus, the systems approach is robust relative to problem-solving potential in education and research, and holds promise for creating working Integrated Range Resource Management Systems for application in production systems. The time is appropriate for development of these comprehensive management systems.

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