29 Decision Support for Sustainable Forestry: Enhancing the Basic Rational Model

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Abstract

Decision-support systems (DSS) have been extensively used in the management of natural resources for nearly two decades. However, practical difficulties with the application of DSS in real-world situations have become increasingly apparent. Complexities of decision making, encountered in the context of ecosystem management, are equally present in sustainable forestry. Various writers have criticized the classical rational/technical solutions commonly employed in DSS and have proposed new approaches based on consensus building, collaborative learning and social DSS, for example. We propose that rational models provide necessary, but not sufficient, tools for effective decision support of sustainable forestry. On this basis, we hypothesize that rational models are not intrinsically limiting, as some have suggested. Rather, perceived limitations of rational models in contemporary DSS might be more a consequence of our methods or of how we have chosen to employ them. Using the Ecosystem Management Decision Support system as an example, we describe how solutions based on rational methods can be integrated with new approaches, such as collaborative learning, to better cope with the practical difficulties of decision support for sustainable forestry. The chapter also discusses eco-phenomenology as an outlook that offers a more integrative view of humans and nature and that avoids some of the basic issues facing the rational model.

Introduction

Decision-support systems (DSS) have evolved significantly during the last four decades. However, their capabilities are still very limited. Elgarah *et al.* (2002), for instance, writing on a project to develop a DSS for decision making on urban infrastructure for the city of Houston, report that they 'know of no DSS design methodology suitable for use in such a complex, conflict-filled situation as this'. This sort of observation is somewhat disturbing in the face of decades of research and practice on DSS. This chapter proposes some remedies for this situation.

The major reason for the current shortcomings of DSS, we argue, has to do with the techno-centric nature of the development of these systems. The history of DSS suggests that development has been largely driven by changes and innovations in computer technologies such as data and knowledge bases, expert systems, software agents and, more recently, web-based tools, and reveals the dominance of a techno-centric view in DSS development, which has sought purely technical solutions to problems of various natures. We argue that most DSS fall into the category of rational models. By rational models, we mean any DSS system or system component that uses a framework or procedure to implement a form of formal reasoning such as decision or logic modelling. We call these basic rational models because they provide the decision maker with basic necessary tools for dealing with situations such as those in sustainable forestry, but they may not be sufficient to account for the full complexity of such situations. Similarly, ecosystem management, since its inception more than a decade ago, has been dominated by a view that characterizes ecosystem management as a 'wicked problem'. Examining these views might provide fresh insights and may be a first step towards alternative ways of thinking about decision making in ecosystem management in general and forest sustainability in particular.

The chapter continues in the next section with a brief overview of ecosystem management and its relation to sustainable forestry, and introduces possible alternative formulations of ecosystem management, such as the socio-ecological approach of the Resilience Alliance. The third section provides an overview of DSS development in the last few decades, and the fourth reviews current proposals for improving decision making in ecosystem and natural resource management that might be used to enhance rational models. The fifth briefly introduces the Ecosystem Management Decision Support (EMDS) system, a relatively successful DSS model in ecosystem management, and discusses specific examples of how enhancements can be implemented. The final section discusses some implications of the alternative approaches for models such as EMDS, and draws some conclusions in terms of future directions of DSS development, especially from the perspective of eco-phenomenology.

Ecosystem Management and Sustainable Forestry

Ecosystem management is a relatively new and popular conceptual framework for land and forest management (Grumbine, 1994). Although a shared understanding of this framework is far from attainable, there is a consensus that the goal of ecosystem management is to create a balance between the long-term protection of the natural environment and the current use of its resources for improving the quality of life of a growing human population (Rauscher, 1999). This formulation of the goal also reveals an inherent tension within the notion of ecosystem management, which manifests itself both in the formulation of the 'ecosystem management problem' and in the characterization of the relation between its two major components – namely, 'ecosystem' and 'management'.

Rauscher (1999, p. 175), for instance, characterizes the ecosystem management problem (particularly in the US context) as one that is riddled with ambiguity

In the first approach, scientists focus on the dynamics of the resource, while managers focus on sustained exploitation; in the latter, scientists focus on maximization of resource usage, assuming the same decision model for all actors. Recently, there has been a trend towards an integrated and interactive approach, which substitutes interactions among all actors for the traditional dynamics under constraints (Bousquet and Le Page, 2004). This trend is best captured in the notion of resilience, which integrates the social and natural environments. The Resilience Alliance, a research organization of scientists and practitioners from various disciplines who have adopted resilience as a central concept in ecosystem management, defines resilience as follows (http://resalliance.org):

> Ecosystem resilience is the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes. A resilient ecosystem can withstand shocks and rebuild itself when necessary . . . Resilience in social systems has the added capacity of humans to anticipate and plan for the future. Resilience is a property of these linked social-ecological systems (SES).

According to the above characterization, resilience as applied to ecosystems, or to integrated systems of people and the natural environment, provides these systems with stability as well as a capability for self-organization, learning and adaptation. We consider these to be crucial features of sustainable forestry as well, and suggest that DSS for sustainable forestry should be of such a character as to support and enhance resilience. Current DSS used in forestry often apply rational models of decision making, such as multi-criteria evaluation (Carver, 1991; Malczewski, 1999). As mentioned earlier, basic rational models may not be sufficient to account for the full complexity of situations faced in forestry. To be sufficient, they need certain enhancement. Various alternatives have been proposed to the rational models, and we shalll draw upon some of these alternatives to suggest enhancements to the basic model. We specifically discuss those that support an integrated approach to the social and ecological aspects of ecosystem management, which is also the key insight behind the notion of resilience.

Decision-support Systems

Decision making, as an area of study, originates in organization science (Simon, 1960). According to Simon, organizational issues that cannot be solved by the optimization models of classical operations research can be successfully handled by modern computer technologies. DSS are, therefore, broadly understood as computer technologies used to support complex decision making in organizations (Keen and Scott Morton, 1978). This characterization applies to various types of DSS – data-driven, model-driven, group support system, intelligent DSS, and so on.

There has been a close parallel between the evolution of the concept of DSS and the development of computer technologies and tools (Shim *et al.*, 2002). In the era of data processing and management information systems, for example, the emphasis in DSS was on databases and data models. Later, with the advent of expert systems and executive information systems, the scope of DSS extended and conflict in terms of social goals and values, complex and unclear in terms of legal mandates, variable in terms of stakeholder participation, permeated with missing and uncertain data, subject to political pressure and lacking in agreed-upon processes of decision making. He concludes that 'The ecosystem management debate is a competitive, conflict-laden social process that determines how power flows in resource management' (Rauscher, 1999, p. 175; see also Grumbine, 1994). This might be a fair assessment of the ecosystem management problem in many respects – for instance, in pointing out the interrelationship between power and knowledge (Foucault, 1980) – but it fails to provide a positive characterization of the problem – that is, one that would tell us the essential constitution of ecosystem management. On the basis of the above description, for example, the ecosystem management problem is usually thought of as an instance of unstructured or wicked problems, which are believed to have (Rauscher 1999, p. 175):

- No definite correct formulation – anyone can define it in their own terms
- No stopping rule to identify when they are solved
- No true or false solutions, rather good and bad ones
- No enumerable or exhaustively describable set of solutions
- No (or limited) susceptibility to rational-based methods

This characterization largely stems from the complexity of ecosystem management as an integration of natural and human systems at different levels. The third point about the evaluation criteria (good or bad rather than true or false), for example, derives from the fact that ecosystem management problems are far too complex, blurry, and contestable to warrant abstract logical distinctions based on truth and falsity. The above list, however, provides a negative characterization of wicked problems and, for that matter, of the ecosystem management problem itself. A careful consideration of these characteristics would reveal that, by this definition, most interesting real-life problems are, in fact, 'wicked'. This suggests that the negative characterization of the ecosystem problem (and the negative label 'wicked' attached to it) might derive from a particular world view. A more positive perspective on ecosystem management emerges if it is considered in the context of adaptive management and sustainable forestry. In this view, ecosystem management provides principles that help define the basic goals of management, adaptive management provides a general methodology to support the goals (Walters, 1986) and sustainable forestry provides specific objectives with which to evaluate progress towards goals (Maser, 1994). Yet another alternative world view might understand the ecosystem management situation differently and welcome, rather than lament, decisions based, for instance, on 'local, pragmatic inventions of necessity' or on 'missing and uncertain data'. Such is the world view presented by the phenomenological school of thought (Thomson, 2004). It is beyond the scope of this chapter to go into a discussion of the tenets of phenomenology in all its variations, but we discuss some insights derived from this view in the concluding section.

Traditionally, approaches to ecosystem management fall into one of two categories (Bousquet and Le Page, 2004):

- Ecological: an ecological system subject to anthropogenic disturbance.
- Economic: a social system subject to natural constraints.

Table 29.1. The development of DSS in relation to technology.

Stage	Approximate period	Dominant concept of DSS	Technologies
I	1960s–1970s	Data modelling	Databases, Management Information Systems
II	1980s	Collaborative and group decision support (GSS)	Knowledge bases, expert systems, Enterprise Information Systems
III	1990s	Knowledge management	Online analytical processing, data warehouse, data mining
IV	2000s	Web-based and active DSS	Internet, client-server tools, software agents

to group and corporate levels. Then the growing interest in intelligent systems and knowledge bases brought about the notion of organizational knowledge management. Most recently, the expansion of the world-wide web and wireless technologies is giving rise to web-based DSS and to new concepts of decision making from multiple perspectives (Courtney, 2001).

Table 29.1 summarizes DSS development as it relates to the supporting technologies (Shim *et al.*, 2002). As Table 29.1 illustrates, development has been dominantly bottom-up and technology-driven, with the available technical tools supporting the traditional concept of decision making as a basically rational process (Simon, 1960). We believe that many of the shortcomings of current DSS, as pointed out, for instance, by Elgarah *et al.* (2002), are due to this techno-centric view. This view considers technology as the panacea for all issues that emerge in human contexts (organizations, communities, societies, etc.), and, as such, underplays the integration of human and technical aspects that is proved to be crucial in socio-technical systems (Kling, 1980). The emphasis in DSS history on emerging new technologies is a clear manifestation of this view.

Approaches to Enhancing the Basic Rational Model

Various new approaches to decision support have recently emerged within and outside ecosystem management. This section reviews three approaches – namely, agent-based, learning and dialectic models. For each, we briefly describe the underlying principles that motivate the approach, give an overview of how each is implemented and in the section 'Application to the EMDS System' provide brief examples of how these approaches could be employed in the EMDS context to better address some of the difficulties surrounding decision support for sustainable forestry noted earlier.

Multi-agent-based simulation

Multi-agent-based simulation is an approach that is gaining a lot of momentum in ecosystem management, especially in Europe. As its name implies, it involves two major components: multi-agent systems and simulations. The notion of agent used in this approach originates in artificial intelligence (AI) and computer science, where an agent is viewed as anything that can perceive its environment through sensors and act upon the environment through actuators (Bousquet and Le Page, 2004). Thus, a human being, a robot and a software process are each examples of agents. Multi-agent systems typically involve several to many heterogeneous agents that share a common environment, resources and knowledge, communicate with each other and are controlled in a distributed manner. This means that there is no central process that collects information from all agents and then decides what action to take. Rather, each agent is an autonomous decision maker that is brought in contact with other agents through a coordination mechanism. Decision making is, therefore, a key component of agent-based modelling, which links it to DSS as well.

Multi-agent systems have found applications in social sciences (e.g. in Agent-based Computational Economics (ACE, 2005), ecosystem management (Bousquet and Le Page, 2004), common resource management (Bousquet *et al.*, 1998)) and elsewhere. In each area, various empirical methods of modelling have been employed. In resource management, for instance, in which the challenge is to model the interaction between groups of agents and resource dynamics, there are two methods. In one method, the emphasis is on the relationship between people who affect resources, and the model represents exchanges of information, services, contracts and agreements among agents. In another method, the emphasis is on representations that determine how agents and resources interact. Each agent develops and acts on its own representation of a resource, and in doing so transforms the resource for other agents. The model is used to study these representations of actions and attempts to generate coordination among agents through the environment.

The idea of simulation is also used in diverse areas such as computer science, artificial life, experimental economics and, more recently, ecosystem management (Becu *et al.*, 2003b). Ecosystems are typically complex systems characterized by: (i) slow dynamics (relative to other similar complex systems such as physical or even socio-economic systems); and (ii) involving people and livelihoods. It is therefore very difficult to conduct experiments on real ecosystems. This makes simulation an attractive tool for modelling ecosystems. Simulations are useful not only because they provide the opportunity for controlled, simulated experimentation – i.e. playing around with and observing the impact of parameters without affecting the real world – but they are also useful because they 'enable the observation and recording of the background of planning, decision-making, and evaluation processes that are usually hidden' (Dörner, 1996, pp. 9–10). In short, simulations can be conceived as social laboratories that provide an effective way of learning, which is different from the known alternative of learning by doing (Bousquet *et al.*, 1999).

Computer simulations can take different forms. In the context of multi-agent systems, agents are computer processes with distinct roles, capabilities and goals. Bousquet *et al.* (1999) introduce an approach called companion modelling, which uses multi-agent systems and simulations, not as prediction tools, but as learning environments. They also emphasize the importance of scenarios in the following way:

> Because the very long term is beyond the scope of prediction, and we wish to take it into account in the analysis of environmental problems, we must give ourselves very long-term reference points or objectives to guide the possible or impossible pathways of development. The long-term approach must inevitably be based on a scenario.
>
> (Bousquet *et al.*, 1999, p. 119)

Becu *et al.* (2003a) have proposed a methodology for eliciting and modelling stakeholders' representations with agent-based modelling. In this method, each agent is defined with specific abilities, goals and strategies – i.e. with a specific representation of the environment. Unlike traditional views that take individual representations as permanent and stable, this approach considers them 'temporary constructs elaborated through social interactions and communication' (Becu *et al.*, 2003a, p. 132). As such, 'any elicited representations should be used as a basis for discussion rather than decision' (p. 133). Such discussion may take different forms. If there are fundamental conflicts of opinion because people refer to the same process with different labels or indicators – e.g. if one person assesses soil moisture according to its colour while another looks at the aspect of the crop being cultivated – in that case differences are kept and the different indicators will be modelled in the same model using specific viewpoints. If, on the other hand, there is minor disagreement about the value of a threshold or a quantitative result, further discussion is encouraged for resolving the differences. Finally, if individual representations are found to be explicitly and unambiguously contradictory, each view is modelled separately and the overall model is split into two separate models (Becu *et al.*, 2003a).

Learning models

Another class of models of decision making adopts a framework centred on human skills and capabilities such as observation, learning, negotiation, and so on. These models come in different flavours and have distinct labels – e.g. consensus building, collaborative learning, social DSS, participatory DSS, etc. – but they are based on similar insights and premises.

Consensus building

Consensus-building models try to provide a structured environment to explore the intensity and source of conflict and to generate compromise alternatives among multiple decision makers. Like basic rational models, consensus building is based upon the evaluation of a set of alternatives according to a number of relevant criteria. In distinction from those models, however, consensus building recommends a flexible, interactive and transparent mode of decision making, and supports methods that expose the preferences and objectives of multiple decision makers. One group of such methods, which belongs to multi-criteria analysis (Vincke, 1992), is discrete compensatory methods that focus on problems with a finite number of alternatives and allow trade-offs to be made among criteria. Therefore, an alternative with a low score on some criteria can compensate by high scores on other criteria, subject to the priorities of a decision maker (Feick and Hall, 1999, p. 18).

Feick and Hall (1999) describe a spatial DSS, TourPlan, which implements a consensus-building model through a tight coupling of geographic information systems and multiple-criteria analysis. This model uses the concept of developing scenarios to present decision makers with alternative views of the future. The spatial component of the model makes it possible for each participant to develop their preferred solutions within a scenario, and for other participants to visualize and evaluate those solutions according to their own criteria (Feick and Hall, 1999, p. 22).

Collaborative learning

Another approach within this group, called collaborative learning (Daniels and Walker, 1996), tries to respond to both scientific and political realities by putting emphasis on mutual learning. Because 'no single party, agency, organization or discipline holds the key to understanding a particular resource management situation', these authors argue, it is crucial that the various participants learn from one another. That is why negotiation, as 'joint decision-making among parties with interdependent yet incompatible interests', is a central component of this approach. To foster collaborative learning, this approach 'emphasizes activities that encourage systems thinking, joint learning, open communication, and focuses on appropriate change' (Daniels and Walker, 1996). In so doing, it combines features of soft systems approach – e.g. the creation of 'a temporarily shared culture in which conflicts can be accommodated so that action can be taken' (p. 81) – with techniques of alternative dispute resolution, such as bargaining strategies. In other words, collaborative learning tries to seamlessly integrate the human and technical components in the decision-making process. In short, collaborative learning adopts a pragmatic approach, and emphasizes improving the situation rather than problem solving, communication and negotiation over concerns and interests rather than bargaining over positions, making progress towards desirable and feasible change rather than achieving a particular set of future conditions.

Social DSS

A third approach, called social DSS, tries to 'facilitate the integration of diverse views into a growing knowledge base' (Turoff *et al.*, 2002). This approach is mostly suited for situations that involve numerous participants – for example, citizens in a public discussion of the costs and benefits of EZ-Pass systems, an electronic toll collection system that allows drivers to pay toll-road fees in the form of a subscription fee. There are a number of features of social DSS that might be useful. First is the dynamic character of the voting process and the relevant knowledge base in the sense that there is no predetermination of what can be represented in the process. Secondly, in the system design, there is an emphasis on ease of learning over time rather than immediate ease of use. Finally, it introduces a new kind of uncertainty or measure of confidence that has to do with the percentage of individuals who have not voted.

Some social DSS use a scaling method called Thurstone's law of comparative judgement, which provides a formal technique for dealing with this kind of uncertainty (Li *et al.*, 2001). Scaling methods provide techniques of measuring human subjective judgements, and might therefore be as important as data collection techniques. In a voting system, for instance, people vote on a set of alternatives based on their preferences (for example, by rank-ordering them), and the system produces a group result on the basis of individual rankings. The question is how to best represent this result to the group so as to facilitate their understanding and decision making. The Thurstone method creates this facility by transforming individual preference data into a composite interval scale that allows individuals to more clearly observe differences among alternative objectives (Li *et al.*, 2001). A group of researchers at New Jersey Institute of Technology have created a web-based voting system that uses this method (Li *et al.*, 2001).

The dialectical approach

The dialectical approach attempts to accommodate conflicting views into the design process itself (Elgarah *et al.*, 2002). This is done through a dialectical process, in which a thesis that is initially formed on the basis of some mental model of the situation is later negated to form an antithesis. The synthesis then emerges as a result of debate and dialogue between the two opposing views. Ideally, the synthesis resolves the conflict, but practically the dialectical process continues on an iterative basis.

Elgarah *et al.* (2002) have proposed a methodology called the multiple perspective and dialectical approach, which incorporates different perspectives (personal, organizational, technical, ethical, aesthetic and enlightenment) into a dialectical process. The multiple perspective and dialectical approach is a conflict-driven approach that promotes heterogeneous views of decision making, and involves seven major steps: stakeholder identification, multiple perspective identification, decision factor determination, world-view formulation, conflict identification, resolution generation and resolution evaluation. It encourages decision makers to examine their own assumptions and to justify their choices of decision factors. To achieve this, Elgarah *et al.* have developed a model with multiple perspectives such as aesthetic, ethical, etc. The main advantage of the multiple perspective and dialectical approach is that, by producing multiple designs in an iterative process, it increases the likelihood of arriving at the most effective design. Its disadvantage is its inefficiency in dealing with well-structured problems. 'For clear-cut problems, conflict may be a time-consuming nuisance' (Elgarah *et al.*, 2002).

Application to the EMDS System

EMDS is a decision-support system for integrated landscape evaluation and planning (Reynolds *et al.*, 2003). It has been used in various applications for ecosystem management, including decision support for sustainable forestry

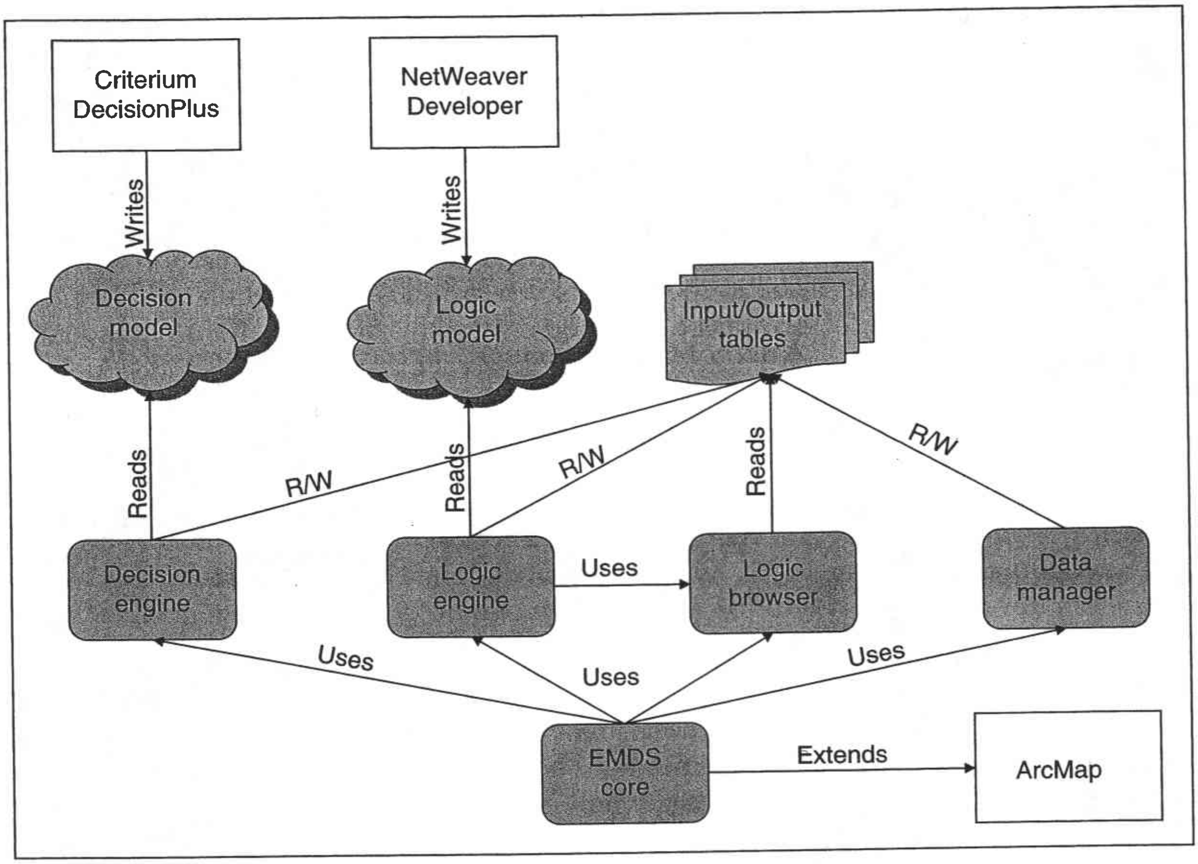

Fig. 29.1. Component diagram for the EMDS extension to ArcMap. Shaded components are internal to the EMDS extension. Relations between components are described by directed arrows. For example, the EMDS core extends ArcMap, and the logic engine reads a logic model written with NetWeaver Developer. The relation R/W indicates reads/writes.

(Reynolds, 2001, 2005). The system (Fig. 29.1) provides decision support for landscape-level analyses through logic and decision engines integrated with ArcMap® (a component of the ArcGIS geographic information system, Environmental Systems Research Institute, Redlands, California.[1] The logic engine evaluates landscape data with a logic model written with the NetWeaver Developer® system (Rules of Thumb, Inc., North East, Pennsylvania) to interpret ecosystem conditions such as sustainability. The decision engine evaluates NetWeaver outcomes and data related to additional logistic considerations, such as feasibility and efficacy of land management actions, with a decision model, written with Criterium DecisionPlus® (InfoHarvest, Seattle, Washington State), which prioritizes landscape elements for management. Criterium DecisionPlus models implement the analytical hierarchy process (Saaty, 1992), the simple multi-attribute rating technique (Kamenetzky, 1982) or a combination of the analytical hierarchy process and simple multi-attribute rating technique methods. Detailed descriptions of how knowledge is represented in the logic and decision models used by EMDS are not pertinent to the present discussion, but can be found in Reynolds *et al.* (2003). For our immediate purposes, it is sufficient to note that knowledge representation in both of these EMDS components clearly conforms to the concept of a rational model. For subsequent discussion, it is also useful to note that both the NetWeaver and Criterium DecisionPlus development systems use graphical design for model construction and that model design can be performed by individuals or groups.

In what follows, we discuss possible ways to enhance the modelling components of EMDS, based on what we presented in the section 'Approaches to Enhancing the Basic Rational Model', concerning alternative approaches to the basic rational model.

Working with logic models

Each alternative discussed in 'Approaches to Enhancing the Basic Rational Model' includes aspects that could be used to enhance the use of logic models as they are implemented by EMDS. In collaborative learning, for instance, people come together on the basis of common objectives and interests. Collaborative learning as such is not a confrontational context; rather, it is more like a planning environment, in which the core participants are motivated by a need to cooperate to accomplish their mission. There is no reason why the methods and principles of collaborative problem solving could not be applied to the design of logic models. Indeed, use of logic models can actually facilitate collaboration by providing a common framework within which people can more easily develop a shared representation of a complex problem.

Similarly, there is no reason why methods and principles of the dialectical approach could not be implemented. For example, a single logic model can contain multiple representations that would support a dialectical approach to decision making. In developing the logic model, a group of individuals might generate two or more variants of model components with a common core. Evaluating such variants side by side within a single logic model, participants, acting as agents in the sense of multi-agent-based systems, can go through a reasoned decision-making process that might eventually lead to a shared logic model. However, even in contexts in which views and opinions are so divergent that realizing a shared representation may be beyond reasonable expectations, logic models can still serve a useful role by helping participants gain a better understanding of the basis for contrasting perspectives, thus helping to clarify the points of agreement and disagreement and better focus discussions.

Finally, in terms of social DSS, logic models can be implemented as Internet-based applications, designed for broad public access and represented in a format that is easily understandable for the public. The issue, in the latter case, would be one of interface design for ease of communication and comprehension of concepts, not one of basic model structure. Table 29.2 lays out the different approaches and indicates how logic models can be designed using the ideas in each of them.

Working with decision models

Comments in the previous section pertaining to use of alternative decision methodologies with logic models are equally applicable in the context of

Table 29.2. Different approaches to enhancing logic models.

Approach	Main idea	Contribution to logic model
Collaborative learning	Joint learning and open communication	Provide a common framework for creating a shared representation
Dialectical approach	Accommodate conflicting views into the design process	Provide a reasoned decision process among variants or a better understanding of differences
Social DSS	Dynamic integration of diverse views	Provide a suitably understandable interface for public participation

decision-modelling components such as the decision engine in EMDS. In fact, if anything, the case for enhancing the utility of rational decision models with the alternative methodologies can be made more convincingly because there is a substantial body of literature documenting the methods for and experiences with collaboration and application of social DSS (Pereira and Corral Quintana, 2002) in the context of decision models.

Working with scenarios

Multi-agent-based systems have sometimes been implemented with people performing the role of agents, as discussed in 'Approaches to Enhancing the Basic Rational Model'. We have already noted one possible application of the multi-agent-based systems concept in the context of alternative logic representations. Similarly, people can also operate as agents in the context of exploring alternative logic scenarios in which either the logic or the data are modified within a running EMDS application to test the outcomes of alternative scenarios on a much more ad hoc basis.

Discussion

As mentioned earlier, DSS evolution has been largely bottom-up and technology driven, in the sense that DSS have evolved in such a way as to be able to accommodate the latest computer and information technologies of the time. Although this evolution has brought about beneficial changes in the way DSS are used and understood, the technical orientation has also tended to preclude the possibility of a deep reconceptualization of decision making as originally formulated by Simon (1960). Simon's view has had a lasting impact on the development of DSS in at least two ways. One is through the idea of bounded rationality, which basically portrays decision making as a weighing of alternatives according to a set of predetermined criteria. Indeed, it can be safely asserted that many subsequent models of decision making – e.g. optimization-based DSS (which involve three stages – formulation, solution and analysis), multi-criteria decision analysis or the analytical hierarchy process – are variants of the original Simon model, although they have become increasingly sophisticated in terms of the number and classification of criteria, in terms of mathematical formalisms, etc.

The second major impact of Simon's work is manifested through the idea of 'cognition as problem solving', which is mostly elaborated in his joint work with Allen Newell in artificial intelligence (AI; Newell and Simon, 1972), but its influence goes far beyond AI to areas such as organization and management science. A key tenet of the problem-solving paradigm is its emphasis on mental representations of external situations. According to this view, people deal with external situations by building more or less faithful models of the problem in their heads. Therefore, decision making consists mainly of the manipulation of these internal models and symbols. In other words, problems are in our heads, as are solutions to problems. A close look at the list of properties of so-called wicked problems in the section 'Ecosystem Management and Sustainable Forestry' precisely illustrates this point. There is almost nothing in that list that is external to people's minds – everything is in the decision maker's head.

The above view of cognition, thinking and decision making has dominated DSS as well as ecosystem management until recently. However, alternative views are on the rise, some of which we examined in 'Application to the EMDS System'. A common tenet of most of these approaches is that rationality is not the modus operandi of decision making. The point is not that rationality is ill conceived, but that the conditions under which it is sufficient by itself are relatively rare (Weick, 2001, p. 34). Rationality prevails if the environment changes slowly, if there are few social groups and if the situation is reasonably well controlled by agents with central authority (Kling, 1980, pp. 90, 100) – all of which are rare in real situations. Another common tenet of the new approaches is the idea, put simply, that problems are not so much in the head as they are in external situations. In other words, what we often have to deal with are problematic situations, not problems as mental models of those situations. This means that problems do not present themselves as given; rather, 'they must be constructed from the materials of problematic situations, which are puzzling, troubling, and uncertain' (Weick 1995, p. 9).

These shifting views have important implications for DSS design and implementation. Subsequently, we explore the possibility of accommodating these views in a system such as EMDS. In what follows, therefore, we shall examine some major ideas in these proposals, and possible methods of enhancing EMDS in particular and DSS in general in the light of those ideas.

Sense making

Recent models focus attention on the process of sense making rather than the product of decision making. A key feature of human sense making has been described as retrospective justification (Weick, 1995). Studies of decision making in juries have indicated that they are largely outcome-driven – 'The outcome comes before the decision' (Garfinkel, 1967, p. 114). That is, jurors do not seem to first evaluate the harm, then allocate blame and finally choose a remedy. Rather, they first decide a remedy and then decide the 'facts' from among alternatives that justify the remedy. In short, they retrospectively justify a decision that is being made on grounds other than (or beyond) facts. Garfinkel concludes from this study that:

> decision making in daily life would thereby have, as a critical feature, the decision maker's task of justifying a course of action. The rules of decision making in daily life . . . may be much more preoccupied with the problem of assigning outcomes to their legitimate history than with questions of deciding before the actual occasion of choice the conditions under which one, among a set of alternative possible courses of action, will be elected.
>
> (Garfinkel, 1967, p. 114)

The inattention of decision makers to this phenomenon might have an impact on their decisions in an undesired manner, and methods should be devised to counter that possibility. A system such as EMDS, for instance, should allow the participants to iteratively relive and review the process by, for instance, explaining it to others. This would reduce the possibility of retrospective justification biasing the evidence and jeopardizing the decision-making process.

Enacting situations

Retrospection also highlights the interleaving of thoughts and actions. People do not face a situation as a given; rather, they enact and produce the situations of which they are a part. As Garfinkel describes them:

> in the course of a career of actions, [people] discover the nature of the situations in which they are acting . . . [T]he actor's own actions are first order determinants of the sense that situations have, in which, literally speaking, actors find themselves.
>
> (Garfinkel, 1967, p. 115)

The active role of participants in enacting and constructing situations also highlights the difference between sense making and interpretation, as it is commonly understood (Weick, 1995, p. 13). Here, the emphasis shifts from the question of what people know to the issue of how people go about knowing what they know. In other words, it shifts towards people enacting situations, rather than taking alternatives as given.

The use of scenarios in EMDS is a good simulacrum for enactment, and the inclusion of role playing, where possible, can enhance this capability. This would allow the participants to observe the consequences of their decisions in a simulated environment, to take note of critical parameters and hence to lower costs and risks to some extent.

Transparency

Finally, the emerging views also suggest that the governing norms of decision-making processes should shift from accuracy and certainty of data towards transparency and plausibility of process. Traditionally, the emphasis in DSS has been on capturing, encoding and providing as much knowledge as possible for decision makers in order to support informed, documentable and responsible decisions (Pereira and Corral Quintana, 2002, p. 97). Responsible in this context has often meant the use of best (expert) scientific knowledge in decision making, not necessarily socially responsible, 'because the social context would not explicitly be taken into account' (Pereira and Corral Quintana, 2002, p. 97). Similarly, documenting the decision has been considered a preamble for the legitimizing and quality assurance of the decision process. While these are important criteria, it is suggested that the emphasis be shifted towards the plausibility, reasonableness and coherence of decisions as well as the transparency of the decision-making process. This shift would highlight the importance of meaningful (as opposed to informed) decisions and of reassuring and legitimate (rather than ensured and authoritative) processes.

Weick (1995, pp. 55–61) provides some reasons why accuracy is nice but not necessary in the sense-making process – e.g. that people need to filter signal from noise in order not to be overwhelmed with data, that there is often a tradeoff between speed and accuracy, that there is always a subjective, interpersonal component present in any decision-making situation, that accuracy is pragmatic and project-specific, that it is impossible to guarantee accuracy prior to action, and so on. Weick concludes from this that what people need is not more information, but 'values, priorities, and clarity about preferences to help them be clear about which projects matter' (p. 27). In a similar vein, those involved in management and policymaking have increasingly emphasized that, in matters of public or group concern, the quality and transparency of the process is no less important than the certainty and validity of the outcome (Pereira and Corral Quintana, 2002).

From its inception, design criteria for the current EMDS system placed strong emphasis on the reasonableness and transparency of results generated by the system. Both the logic and the decision engines in EMDS were selected with these considerations in mind first and foremost. However, among the array of DSS used in contemporary natural resource management, not all systems are equal in this respect, and there remain substantial opportunities to enhance contemporary systems along these lines.

Further on

> Full of merit, yet poetically, man Dwells on this earth.
>
> (Hölderlin, cited in Heidegger, 1975)

> we tend to reduce every entity we encounter to the status of an intrinsically meaningless 'resource' (Bestand) merely to be optimized as efficiently as possible, leveling all attempts to say what matters to us down to empty optimization imperatives (such as the ubiquitous: 'Get the most out of your potential!'). Thus we come to treat even ourselves (modernity's vaunted 'subject') in the terms underlying our technological refashioning of the world, as just another resource to be optimized, ordered, and enhanced with maximal efficiency.
>
> (Thomson, 2004, p. 397)

In this chapter, we have explored the possibility of enhancing a system such as EMDS for the purposes of sustainable forestry by drawing upon recent findings and developments in DSS and ecosystem management. Having examined some of the major views in these areas, we illustrated some of the ways in which these enhancements could be realized in EMDS and other systems. We showed how the logic and decision models of EMDS can be enhanced by incorporating ideas and methods borrowed from multi-agent simulation, as well as learning and dialectical approaches. Furthermore, we discussed a number of shifts based on recent findings and ideas from the sense-making framework – most importantly, a shift of focus towards iterative decision-making processes, enacted scenarios and transparency. We believe that these shifts can significantly contribute to the applicability and improved utility of DSS in ecosystem management and forestry.

But there is always room for improvement, and, as one possible direction, we would like to conclude this chapter by exploring the phenomenological approach, originally based on the views of Martin Heidegger. Heidegger is not unknown to ecologists, environmentalists and conservationists, many of whom have looked upon his writings as sources of insight and inspiration, or have alternatively sought in those writings a philosophical articulation of their own views. Heidegger's ideas have, therefore, been linked to 'deep ecology' (Zimmerman, 1983), environmental ethics (Beckman, 2000; Thomson, 2004) and sustainability (Peters and Irwin, 2002), but they have remained largely foreign to ecosystem management. This strangeness, we believe, has partly to do with the rather incongruous premises of the two approaches. Whereas ecosystem management commonly views the natural environment as a source of resources or services to society, Heideggerian phenomenology questions this attitude and offers a more integrative view of humans and nature. Consequently, ecosystem management seeks to optimize the utilization of natural resources by human beings, while phenomenology recommends a notion of dwelling (*wohenen*) that invites us to be at home with the environment and with 'being as such' (Thomson, 2004, p. 400). Through this shift of perspective, entities acquire a richer meaning far beyond intrinsically meaningless resources awaiting optimization (Thomson, 2004, p. 400).

The phenomenological view of the environment is based on a number of principles, most notably and recently articulated in the book *Eco-phenomenology: Back to the Earth Itself* (Brown and Toadvine, 2003) and discussed at length in Thomson (2004). Postulating a close link between our modern world view and the environmental crisis, eco-phenomenologists challenge the principles that underlie this world view. Thomson singles out two such principles as metaphysical and ethical. These principles have to do with, respectively, the mind/world dualism and the fact–value divide (Thomson, 2004, p. 382). Metaphysically, eco-phenomenology seeks to reunite the mind with the world by returning us to the experience of a pre-differentiated mind–world unity. In so doing, it also proffers an ethical principle that makes it possible for us 'to recognize the reality of environmental "values," the alleged "fact" that certain environmental values are "always already in the world"', and so on (Thomson 2004, p. 383). In short, eco-phenomenology challenges two major rationalist principles of the modern world view that are built into the scientific aspirations of ecosystem management. We believe that the formulation of the ecosystem management problem as wicked (see the earlier section on this topic) derives from these rationalist principles, which, as we discussed, also lie at the foundation of most DSS. By assigning inherent values to certain environmental entities, the phenomenological world view would characterize the issues of the ecosystem as things to be accommodated and organically dealt with, rather than as wicked problems to be avoided and overcome. This shift of perspective would have a deep impact not only on ecosystem management and forestry, but on the design of computer-based systems (DSS or otherwise) built for this purpose.

Note

1. The use of trade or firm names in this publication is for reader information and does not imply endorsement by the US Department of Agriculture of any product or service.

References

ACE (2005) Agent-based Computational Economics website. Retrieved on 8 June 2005 from http://www.econ.iastate.edu/tesfatsi/ace.htm

Beckman, T. (2000) *Martin Heidegger and Environmental Ethics*. Retrieved on 1 January 2005 from: http://www2.hmc.edu/~tbeckman/personal/Heidart.html

Becu, N., Bousquet, F., Barreteau, O., Perez, P. and Walker, A. (2003a) A methodology for eliciting and modelling stakeholders' representations with agent-based modelling. *Lecture Notes in Artificial Intelligence* 2927, 131–148.

Becu, N., Perez, P., Walker, B., Barreteau, O. and Le Page, C. (2003b) Agent-based simulation of a small catchment water management in northern Thailand: description of the CATCHSCAPE model. *Ecological Modelling* 170, 319–331.

Bousquet, F. and Le Page, C. (2004) Multi-agent simulations and ecosystem management: a review. *Ecological Modelling* 176, 313–332.

Bousquet, F., Bakam, I., Proton, H. and Le Page, C. (1998) Cormas: Common-pool Resources and Multi-agent Systems. *Lecture Notes in Artificial Intelligence* 1416, 826–838.

Bousquet, F., Barreteau, O., Le Page, C., Mullon, C. and Weber, J. (1999) An environmental modelling approach: the use of multi-agent simulations. In: Weill, F.B.A. (ed.) *Advances in Environmental Modelling*. Elsevier, London, pp. 113–122.

Brown, C. and Toadvine, T. (2003) *Eco-phenomenology: Back to the Earth Itself*. Syracuse University, Albany, New York.

Carver, S. (1991) Integrating multicriteria evaluation with GIS. *International Journal of Geographical Information Systems* 5, 321–339.

Courtney, J.F. (2001) Decision making and knowledge management in inquiring organizations: toward a new decision-making paradigm for DSS. *Decision Support Systems* 31, 17–38.

Daniels, S.E. and Walker, G.B. (1996) Collaborative learning: improving public deliberation in ecosystem-based management. *Environmental Impact Assessment Review* 16, 71–102.

Dörner, D. (1996) The *Logic of Failure: Recognizing and Avoiding Error in Complex Situations*. Perseus Books, Cambridge, Massachussetts.

Elgarah, W., Courtney, J.F. and Haynes, J.D. (2002) A dialectical methodology for decision support systems design. Paper presented at the 35th Annual Hawaii International Conference on System Sciences, Big Island, Hawaii.

Feick, R.D. and Hall, G.B. (1999) Consensus-building in a multi-participant spatial decision support system. *URISA Journal* 11, 17–23.

Garfinkel, H. (1967) *Studies in Ethnomethodology*. Prentice-Hall, Englewood Cliffs, New Jersey.
Grumbine, E. (1994) What is ecosystem management? *Conservation Biology* 8, 27–38.
Heidegger, M. (1975) *Poetry, Language, Thought*. Trans by Albert Hofstadter. Harper & Row, New York.
Kamenetzky, R. (1982) The relationship between the analytical hierarchy process and the additive value function. *Decision Sciences* 13, 702–716.
Keen, P.G.W. and Scott Morton, M.S. (1978) *Decision Support Systems: an Organizational Perspective*. Addison-Wesley Publishing, Reading, Massachussets.
Kling, R. (1980) Social analyses of computing: theoretical perspectives in recent empirical research. *Computing Surveys* 12, 61–110.
Li, Z., Cheng, K., Wang, Y., Hiltz, S. and Turoff, M. (2001) Thurstone's law of comparative judgment for group support. In: *Proceedings of the Seventh Americas Conference on Information Systems*. Boston, Massachusetts, pp. 241–244.
Malczewski, J. (1999) *GIS and Multicriteria Decision Analysis*. John Wiley and Sons, New York.
Maser, C. (1994) *Sustainable Forestry: Philosophy, Science, and Economics*. St Lucie Press, Delray Beach, Florida.
Newell, A. and Simon, H.A. (1972) *Human Problem Solving*. Prentice-Hall, Englewood Cliffs, New Jersey.
Pereira, G.A. and Corral Quintana, S. (2002) From technocratic to participatory decision support systems: responding to new governance initiatives. *Journal of Geographic Information and Decision Analysis* 6, 95–107.
Peters, M. and Irwin, R. (2001) Earthsongs: ecopoetics, Heidegger and dwelling. *Trumpeter: Journal of Ecosophy* 18(1), http://trumpeter.athabascau.ca/content/v18.1/
Rauscher, M.H. (1999) Ecosystem management decision support for federal forests in the United States: a review. *Forest Ecology and Management* 114, 173–197.
Reynolds, K.M. (2001) Using a logic framework to assess forest ecosystem sustainability. *Journal of Forestry* 99, 26–30.
Reynolds, K.M. (2005) Decision support for evaluating the US national criteria and indicators for forest ecosystem sustainability. In: Aguirre-Bravo, Celedonio, *et al.* (eds) *Monitoring Science and Technology Symposium: Unifying Knowledge for Sustainability in the Western Hemisphere, 20–24 September 2004, Denver, Colorado*. Proceedings RMRS-P-37CD, US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, Utah.
Reynolds, K.M., Rodriguez, S. and Bevans, K. (2003) *EMDS 3.0 User Guide*. Environmental Systems Research Institute, Redlands, California.
Saaty, T.L. (1992) *Multicriteria Decision Making: The Analytical Hierarchy Process*. RWS Publications, Pittsburgh, Pennsylvania.
Shim, J.P., Warkentin, M., Courtney, J.F., Power, D.J., Sharda, R. and Carlsson, C. (2002) Past, present and future of decision support technology. *Decision Support Systems* 33, 111–126.
Simon, H.A. (1960) *The New Science of Management Decision*, Vol. 3. Harper, New York.
Thomson, I. (2004) Ontology and ethics at the intersection of phenomenology and environmental philosophy. *Inquiry* 47, 380–412.
Turoff, M., Hiltz, S.R., Cho, H.-K., Li, Z. and Wang, Y. (2002) Social decision support systems. Paper presented at the 35th Annual Hawaii International Conference on System Sciences, Big Island, Hawaii.
Vincke, P. (1992) *Multicriteria Decision Aid*. John Wiley and Sons, Rexdale, Ontario.
Walters, C.J. 1986. *Adaptive Management of Renewable Resources*. Macmillan, New York.
Weick, K.E. (1995) *Sensemaking in Organizations*. Sage Publications, Thousand Oaks, California.
Weick, K.E. (2001) *Making Sense of the Organization*. Blackwell Publishers, Oxford, UK.
Zimmerman, M.E. (1983) Toward a Heideggerean ethos for radical environmentalism. *Environmental Ethics* 5, 99–131.