Rethinking DSS:

The Case of Ecosystem Management Decision Support

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ABSTRACT. Decision Support Systems (DSS) are extensively used in ecosystem and land management projects. This paper seeks to derive and generalize the lessons drawn from one such project in the western Mojave Desert in the U.S. We introduce the Ecosystem Management Decision Support system (EMDS) and articulate the lessons that we have learned from a real-world application of this system to a large relocation project of a threatened species. Despite the broad capabilities of EMDS in terms of knowledgebase, GIS, and decision support components, we faced many issues in its practical application. A retrospective analysis of these issues indicated to us that, rather than seeking more sophisticated methods and techniques, we need to rethink DSS at a conceptual level. Therefore, in an effort to reconceptualize decision-making and to align DSS with recent developments in AI , we follow a top-down approach in this paper, starting with a new conceptual framework and then exploring the technologies and tools that can support it. To this end, the paper proposes four major conceptual shifts: a pragmatic shift from problems in the mind to problematic situations in the world, a constructive shift from passive decision making to active sense making, a normative shift from accuracy and certainty to plausibility and transparency, and a technical shift in our understanding of technology as enabler to technology as transformer of human activity. These shifts are in harmony with current theoretical trends in DSS and related disciplines such as AI, cognitive psychology, and organization science.

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1. Introduction

The development of technical systems usually follows a nonlinear path leading to a closure that aims to *blackbox* the underlying technology. More often than not, closure tends to be temporary for different technical, economic, socio-cultural, or political reasons (McKenzie and Wajcman 1999: Introduction). Under such circumstances, the black box is opened, a new technology is incorporated into the system, another closure is accomplished, a new black box is created, until an even newer technology arrives and the whole cycle gets repeated. However, it is sometimes useful to open the black box not so much for the purpose of renewing the technology, but to examine the concepts and methods underlying them. This has happened to DSS before and, we believe, is what needs to be done again at this point in time. DSS have extensively developed in the last four decades, during which different computer technologies have replaced the old ones, giving rise to new implementations of these systems. However, this development has been dominantly techno-centric (Ekbia 2005). It might be time to revisit some of the concepts that underlie many DSS, and to align it with the conceptual developments in neighboring disciplines such as AI and organization science. This is our goal in this paper.

In our experience with the Desert Tortoise project, a threatened species management project in the western Mojave Desert using the Ecosystem Management Decision Support system (EMDS™), we encountered serious limits in the rational implementation of supporting the decision-making process. Our attempts to overcome these limits pushed us more and more toward a reexamination of the concepts and methods that underlie the system. This paper is partly the review of those attempts and partly a retrospective analysis of the lessons that we derived from them. We generalize these lessons by proposing four major conceptual shifts: a pragmatic shift from problems in the mind to problematic situations in the world, a constructive shift from passive decision making to active sense making, a normative shift from accuracy and certainty to plausibility and transparency, and a technical shift in our understanding of technology as enabler to technology as transformer of human activity. We argue that these shifts are in harmony with current theoretical trends in DSS and related disciplines — e.g., the growing emphasis on multiple perspectives in DSS (Courtney 2001), on situated cognition in AI and in cognitive science (Hutchins 1995), and on sense making in organization science (Weick 1995, 2001). By focusing our attention on the collective, distributed, and constructive character of cognition, the framework that results from these shifts provides a useful way of thinking about DSS. Furthermore, ideas from science and technology studies portray a tightly interwoven picture of technologies and their social and organizational context, which is very different from the traditional view of technologies as mere tools. Brought to the realm of DSS, this calls for a fresh look at the relationship between information technologies and decision-making processes, which we articulate as a technical shift in this paper.

The paper continues in the next section with a brief historical overview of the development of DSS, which will demonstrate the techno-centric character of this development. Section 3 provides the background information on the Desert Tortoise Project (DTP), introduces the EMDS, and articulates some of the lessons learned in this project. Based on the analysis of DTP, section 4 discusses the conceptual underpinnings of many DSS such as EMDS, and proposes a new conceptual framework based on recent trends in AI and organization science. Section 5 outlines a methodology for DSS to support the proposed framework, and section 6 discusses our findings and illustrates the application of this methodology to DTP. Section 7 derives general conclusions about intelligent DSS (iDMS) based on our case study and the theoretical discussions of the preceding sections. We should emphasize that we do not intend to build new theory here. Far from novel, the framework proposed here is meant to contribute to iDMS by integrating and articulating a new way of thinking about decision making from the individual, organizational, and technical perspectives, similar in spirit to what others have suggested earlier (Mitroff and Linstone 1993, Weick 1995, Elgarah et al. 2002).

2. Decision Support Systems: An Overview

Decision making, as an area of study, originates in organization science (Simon 1960). Decision Support Systems are computer technologies used to support complex decision making in organizations (Keen & Scott Morton 1978). Turban (1990) defined DSS as "an interactive system, flexible and adaptable, which uses decision rules, models, databases and suitable formal representations of the decision maker(s)' requests to indicate specific and applicable actions to solve problems which cannot be solved by the optimization models of classical Operational Research (OR). It thus assists complex decision processes and increases their efficiency." This definition applies to various types of DSS — data-driven, model-driven, group support system (GSS), etc. In the 1990's, there was a trend toward "intelligent DSS" (IDSS) and the incorporation of tools and techniques of Artificial Intelligence (AI). Shim et al. (2002) have discerned a recent trend toward the personalization of DSS user interface, the use of Web-based technologies, and ubiquitous computing.

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 (MIS), for example, the emphasis in DSS was on databases and data models. Later on, with the advent of expert systems and executive information systems (EIS), the scope of DSS extended to group and corporate levels. Then, the growing interest in 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 conceptualizations of decision making from multiple perspectives (Courtney 2001). In parallel with these, there have also been developments in the data component of DSS from data warehousing and data mining to the notion of data marts. Table 1 summarizes the development of DSS as it relates to the supporting technologies (Shim et al. 2002). As the table illustrates, this 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). The techno-centric character of DSS thinking is best illustrated in its relationship with the reference discipline of AI (Ekbia 2005).

Stage	*Approximate Period*	*Dominant Concept of DSS*	*Technologies*
I	1960's–1970's	Data modeling and problem solving	Databases, MIS
II	1980's	Collaborative and Group Decision Support (GSS)	Knowledge bases, expert systems, EIS
III	1990's	Organizational learning and Knowledge Management	OLAP, data warehouse, data mining
IV	2000's	Web-based and active DSS	Internet, client-server tools, software agents

Table 1: *The development of DSS in relationship to computer technology*

3. Case Study: The Desert Tortoise Project

As stated earlier, the empirical part of this paper is based on a case study of the Desert Tortoise Project (DTP), in which two of the authors participated as research analysts in an institute (henceforth RI, for *Research Institute*) that was charged with the task of implementing a DSS that would help land managers arrive at a plan of action regarding the threatened species. The DSS that was selected for this purpose was EMDS, developed by USDA Forest Service Pacific Northwest Research Station. In this section, we briefly describe DTP and EMDS and discuss the initial plan adopted by RI.

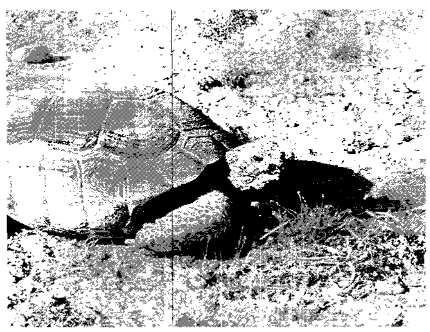

Figure 1. *The desert tortoise*

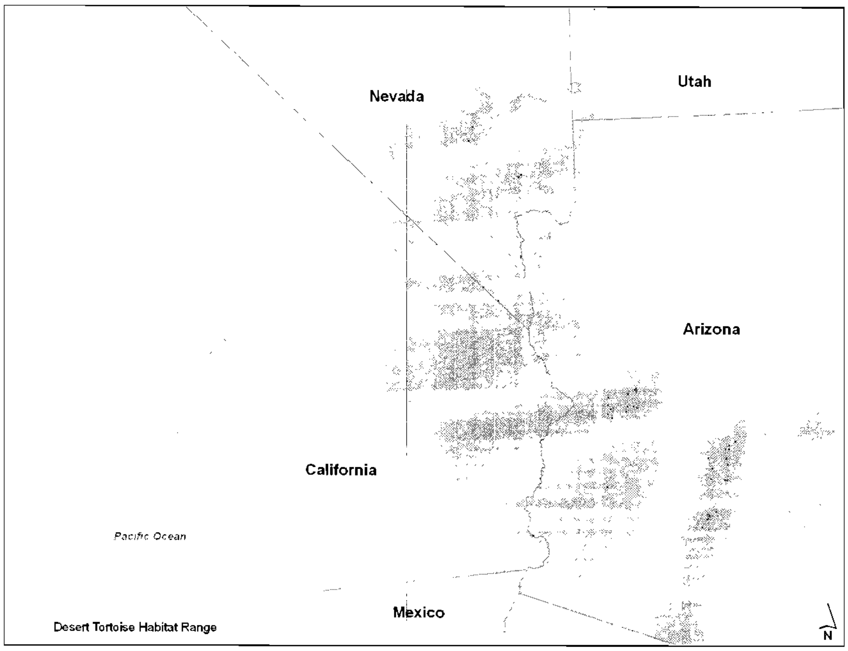

Figure 2. *The tortoise habitat in the Mojave Desert*

3.1. The Desert Tortoise: A Threatened Species

The desert tortoise is a species that is considered to be an indicator of the health of the desert environment (see Figure 1). This species was listed as an endangered species in 1980 and, due to concerns by biologists about apparent declines in its populations in the Mojave Desert, its Mojave Population (an administrative designation for tortoises living north and west of the Colorado River; see Figure 2) was listed as federally threatened in April 1990. The decline in population is attributed to deterioration and loss of habitat, collection for pets and other purposes, elevated levels of predation, loss of individuals from disease, and the inadequacy of existing regulatory mechanisms to protect tortoises and their habitat (USFWS, 1990). Activities attributed to the deterioration or loss of habitat include urbanization, livestock grazing, motorized vehicle recreational activities, mining, agricultural development, and roads. Upper respiratory tract disease (URTD) is also recognized as a potential cause of desert tortoise mortality and population declines. More recently discovered diseases such as herpes virus and cutaneous dyskeratosis have also been implicated.

The goal of the Endangered Species Act (ESA) is to restore species that are at risk of extinction so that they can live in self-sustaining populations (GAO 2002). The Act requires that listing decisions and critical habitat designations be based on the best available scientific and commercial data, and that recovery plans be developed and implemented if doing so would conserve the species (ibid). In 2001, the Fish and Wildlife Service began a monitoring effort to develop a baseline estimate of desert tortoise populations, the development of which will require a total of 5 years to complete at an estimated cost of approximately $7.5 million, with similar figures for determining and monitoring population trends. Expenditures on desert tortoise recovery exceed $100 million since its first listing, but the exact investment to date is not known. What is known is that this is a very large undertaking involving different stakeholders (land managers, biologists, environmentalists, residents, developers, etc.), various agencies and institutions, a significant amount of data, a corresponding degree of uncertainty, and a huge amount of cost and funding. The cumulative effect of these facts is to bestow a significant impact to decisions made in the context of DTP and, by implication, to any technical system in this process.

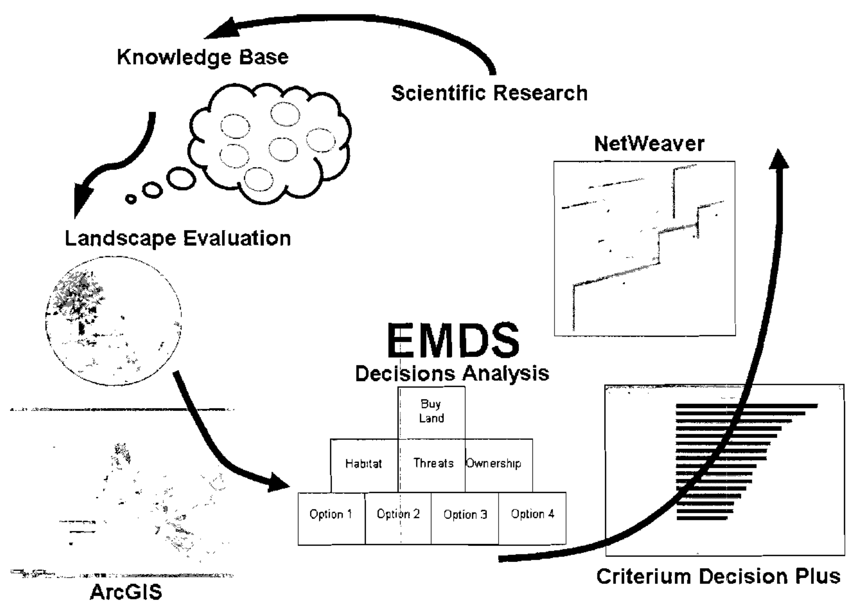

Figure 3. *The overall organization of EMDS*

3.2. Knowledge-based Decision Support for Ecosystem Management

Ecosystem Management Decision Support System (EMDS™) is an extension for ArcGIS™ geographic information system developed by ESRI (Environmental Systems Research Institute, Redlands, California) that provides a framework for knowledge-based decision support for ecological investigations at multiple geographic scales (Reynolds et al 1996, Reynolds et al 2003). The EMDS extension also uses NetWeaver™, (Saunders et al 2005) the logic engine, which allows criteria to be organized in a hierarchy of logical relationships that most appropriately represent true ecological systems (see Figure 3). For example, a simple representation of desert tortoise habitat in the form of a knowledgebase might represent habitat suitability as a function of elevation and geomorphology. Each of these criteria can then be expanded further to define complex topics and multiple influencing relationships.

The EMDS system supports a fuzzy logic framework that may accommodate gray areas in ecological modeling that are commonly lost in traditional mathematical models (Openshaw 1996,Reynolds 2001). The combination of the fuzzy logic framework and the GIS allows users to ask questions in the form of scenarios to provide a truth value response for each landscape analysis unit in the study area. Final outcomes can be interactively interrogated to trace the rationale followed to derive the particular truth value (see Figure 4). In the next section, we briefly describe how the RI team initially went about the implementation of EMDS in DTP.

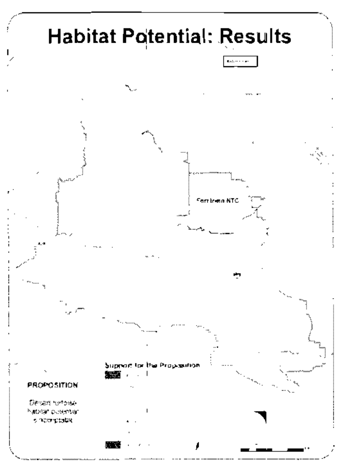

Figure 4. *The results of a habitat analysis using EMDS*

3.3. Initial Plan: Facing the Conceptual Barrier

Following the mandates of ESA and the structure of EMDS, the project team embarked on the implementation of the different components of the system. The first step was to build a knowledge base through a series of knowledge elicitation workshops with domain experts. Based in the outcome of these workshops, we compiled the data necessary to evaluate the parameters provided by the domain experts in a spatial context using GIS. We intended to conduct a similar series of decision framing workshops with the key decision makers. The goal of these workshops would be to identify a decision goal (e.g., find a suitable location to translocate desert tortoises), to establish criteria for evaluating that goal (cost of land, habitat quality,) and to assign weights to those criteria using the analytical hierarchy process. The decision process would culminate in a decision scenario meeting wherein decision makers, domain experts, and stakeholders would explore different outcomes in an interactive environment by modifying the parameters applied to the knowledge base and weights assigned to the decision criteria. Through this process we would identify translocation sites that remained optimal despite disagreements regarding uncertain scientific knowledge and especially sensitive decision criteria.

Several political, logistical, and technological factors prevented us from proceeding as planned. Logistically, it was difficult to convene domain experts in the same place at the same time. More importantly, however, it often proved challenging to get buy-in from the domain experts regarding the knowledge elicitation process. A combination of geographical distance, busy schedules, and skepticism regarding the technology inhibited the series of decision framing workshops planned for the decision makers. The volume of data required to process the model combined with the number of landscape units needed for analysis, inhibited any real time exploration. Running a scenario would take almost 20 minutes at a time. Some of the more advanced scenarios, involving complex manipulations of spatial relationships, were too time-consuming to perform in a live workshop setting. Despite these challenges and constraints, the issue remained that we were charged with supporting a decision, within a fixed duration, that would obtain the backing of the major stakeholders. It was in facing this issue that we discovered that what we are facing might indeed be a conceptual barrier, not a logistical or technological one. For instance, it became clear to us that, previous to solutions, people often have different perceptions of what constitutes the "problem" in a given situation, based on their constraints, priorities, and frames of mind; that they hesitate to espouse a solution often because they cannot put the pieces together; that providing more information to them is not always the best approach; and that the technology often fails to perform the function required of it. In other words, we were pushed more and more toward a conceptual exploration of the underlying premises of our approach. What follows is the outcome of this exploration, which we would like to present by examining the basic conceptual underpinnings of many current DSS, of which EMDS is an example.

4. In Search of a Framework

As mentioned earlier, the development of DSS has been largely bottom-up and technology-driven, in the sense that DSS systems have evolved in such a way as to be able to accommodate the latest computer and information technologies of the time. Although this development has brought about certain changes in the way DSS is used and understood, by and large the technical orientation has undermined the possibility for deep reconceptualization of decision-making. Alternatively, the following presents a top-down, concept-driven approach — that is, an approach that begins with an overarching conceptual framework and then finds suitable technologies and tools that would support and implement that framework. For this purpose, the paper draws upon a number of prior frameworks from cognitive, organization, and social sciences — namely, sense-making, distributed cognition, and actor-network theory. The following sections propose a set of conceptual shifts on cognitive, organizational, technical, and normative dimensions, which set the foundation for the desired framework.

4.1. The Pragmatic Shift: From Problems in the Mind to Problematic Situations in the World

The original DSS concept defined by Gorry and Scott Morton (1971) was based on two previous works. The first was Anthony (1965)'s classification of management activities into 1) strategic planning by upper management, 2) management control by middle management, and 3) operation control by first line supervisors. The second work was Simon's (1960) decision-making framework, which consisted of *intelligence* (search for problems), *design* (development of alternatives), and *choice* (analyzing the alternatives and making a choice). 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 some preset criteria. Indeed, it can be safely asserted that many subsequent models of decision making — e.g., optimization-based DSS (that involves three stages of *formulation, solution, and analysis*), multi-criteria decision analysis (MCDA), or the analytic hierarchy process (AHP) — are variations of the original Simon model, although they have become increasingly sophisticated in terms of the number and classification of involved criteria, in terms of mathematical formalisms, etc.

The second major impact of Simon's work is through the idea of "cognition as problem solving," which is mostly elaborated in his joint work with Allen Newell in Artificial Intelligence (AI), but its influence goes far beyond AI to areas such as organization and management science (Ekbia 2005). A key tenet of the problem-solving paradigm is its emphasis on mental representations (or symbols or models) of external situations. According to this view, people deal with the outside situations by building (more or less) faithful models thereof in their "heads." Therefore, all thinking (e.g., decision making) consists mainly of the manipulation of these internal models and symbols. Problems are in our heads, as are solutions to problems.

The above view of cognition, thinking, and decision-making dominated DSS for a long time. However, alternative views are on the rise — e.g., consensus building (Feick and Hall 1999), dialectic models (Elgarah et al. 2002), multi-agent simulation models (Bousquet and Le Page 2004), etc. A common tenet of most of these approaches is that rationality is not the modus operandi of decision-making (Ekbia and Reynolds 2005). 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: 9). In recent intellectual history, this idea goes back to *pragmatism*, advocated by, among others, John Dewey. A problematic situation, according to Dewey, is one which is "disturbed, ambiguous, confused, full of conflicting tendencies, obscure, etc." (Dewey 1940: 117). Thinking, therefore, consists of the process that would lead from such a situation to one which is less indeterminate, uncertain, obscure, and so on.

In the spirit of pragmatism, this paper proposes a shift of focus from the traditional view of problem solving in the head to the notion of dealing with problematic situations in the external world and of taking actions that would reduce the indeterminacy of those situations. What is the significance of this shift for DSS and for decision making in general? A number of things:

— By introducing activities into the picture, it emphasizes the *process* of decision making rather than its *product;*

— By downplaying mental models, it reduces the cognitive load of deliberation on decision makers;

— By starting from the external situation, it makes it more likely and probably easier for multiple decision makers to arrive at a common representation of the problem (which is a major step toward building consensus);

— By incorporating indeterminacy in the picture, it provides a positive characterization of situations, rather than the negative characterization built into the notion of wicked problems.

For practical purposes, one of the implications of this shift is that any decision-making process should involve a *problem-setting* phase (what Dewey calls the "institution of the problem") that would take us from a *problematic situation* to a *problem.* People often start with different understandings of a situation, and arriving at a common problem statement might indeed be a major step toward its solution. Dewey (1940: 119) says:

> Qualification of a problem as problematic does not, however, carry inquiry far. It is but an initial step in institution of a problem. A problem is not a task to be performed which a person puts upon himself or that is placed upon him by others – like a so-called arithmetical "problem" in school work. A problem represents the partial transformation by inquiry of a problematic situation into a determinate situation.

4.2. *The Constructive Shift: From Decision Making to Sense Making*

> Sensemaking rather than decision making may be the more central organizational issue. Whether there are decisions that need to be made and what those decisions might consist of are products of sensemaking. To be in thrall of decision making is to spend too much time on too narrow a band of issues that crop up too late after most of the important action is already finished." (Weick 2001: 4)

DSS have traditionally focused on *decisions as products* at the expense of the *process* that gives rise to decisions. Even when the process is considered, it is deemed as fact-driven — that is, as one that starts with data, builds facts, weighs alternatives, and arrives at a decision. However, a rather different picture arises if we shift our focus to the process. To do that, this section draws upon the framework developed by Karl Weick, who characterizes sensemaking as a process that is grounded in identity construction, retrospective, enactive of sensible environments, social, ongoing, focused on and by extracted cues, and driven by plausibility rather than accuracy (Weick 1995: chapter 2).

Among these, retrospection and enactment are most relevant to our purposes, although other properties of sensemaking might also be of significance for a reconceptualization of DSS. Studies of decision making in juries have indicated that they are largely *outcome-driven* — "*The outcome comes before the decision*" (Garfinkel 1967: 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 justified 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 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." (pp. 114).

Failing to understand the role of retrospection leads to biases in people's understanding of situations — e.g., when knowing the outcome of a process the reasons for that outcome seem obvious, necessary or intended, rendering other options unimaginable. 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" (1967: 115). This is the spirit of the constructivist shift suggested here — namely, the shift from the question of "what people know" to the issue of "how people go about knowing what they know."

The failure to understand the active character of sensemaking has resulted in a great many futile efforts and projects. Some AI practitioners, for instance, have tried, rather unsuccessfully, to capture human common sense in huge knowledge bases, arguing that this will inevitably lead to intelligent computers. In other words, they assume that common sense consists of a certain amount of knowledge that can be codified and stored in a computer in the form of logical assertions. The fallacy of this assumption lies in its failure to understand the active character of sensemaking — it emphasizes the *common* aspect of commonsense and marginalizes the active process of *making* sense (Ekbia 2002).

4.3 The Normative Shift: From Accuracy and Certainty to Plausibility and Transparency

The third major shift proposed here has to do with the values and criteria that should be used in a decision process. Traditionally, the emphasis in DSS has been on capturing, encoding, and providing as much knowledge as possible to decision-makers in order for them to be able to make *informed*, *documentable*, and *responsible* decisions (Pereira and Quintana 2002: 97). "Responsible" in this context 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 (ibid). Similarly, documenting the decision was 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 toward 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: 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). Those involved in policy-making have increasingly emphasized that the quality and transparency of the process is no less important than the certainty and validity of the outcome (Carver et al. 1991).

4.4 The Technical Shift: From Technology as Enabler to Technology as Transformer

The final shift proposed here is a technical one. To motivate this, it is important to revisit the notion of "problem solving" and see what role technology can play in this. Following Hutchins (1995), we argue that problem solving should be thought of as representing a problem so as to make the solution transparent. Hutchins uses the example of navigation to show how representational states are propagated from one medium to another by bringing the states of the media in coordination with one another (p. 117). In navigation, a problem is solved (i.e., a ship is ducked in harbor) by moving from features of the outside world (the name, description, or visual experience of a land mark) to an analog image on the alidade to a digital figure on the gyrocompass card to bearing record on a log to an angle measurement on a Hoey scale to physical state of Hoey arm and finally to a navigation chart that determines the next course of actions in terms of speed, direction, and so on. Hutchins uses this example to demonstrate why it is useful to think of cognition in the broad sense of "the propagation of representational state across representational media" (ibid). It also demonstrates how problem solving is a collective act distributed among people, devices (alidade, Hoey), and technologies (record logs, charts, etc.). Seen in this light, technologies are best thought of *transformers*, rather than *amplifiers*, of our cognitive abilities. Hutchins (1995: 154) puts the point this way:

> When we concentrate on the *product* of the cognitive work, cultural technologies, from writing and mathematics to the tools...appear to amplify the cognitive powers of their users. Using these tools, people can certainly do things they could not do without them. When we shift our focus to the *process* by which cognitive work is accomplished, however, we see something quite different... The application of these abilities must be "organized" in the sense that the work done by each component ability must be coordinated with that done by others...None of the component cognitive abilities has been amplified by the use of any of the tools. Rather, each tool presents the task to the user as a different sort of cognitive problem requiring a different set of cognitive abilities or a different organization of the same set of abilities."

In other words, "these mediating technologies do not stand between the user and the task. Rather, they stand with the user as resources used in the regulation of behavior in such a way that the propagation of representational state that implements the computation can take place" (ibid). This view of technology is also in alignment with actor-network theory (Latour 1987; Law 1999), which explains social and technological developments in an intertwined fashion, with both human and non-human elements (technologies) capable of affecting and shaping each other's behaviors. We suggest that this view is also useful in thinking about DSS and their role in human decision-making. That is, DSS might be most effective if used as transformers of problem representation.

5. In Search of a Methodology

Having outlined the main features and ingredients of the proposed framework, it is important to find a methodology for supporting it. Ekbia (2005) provides an outline of this methodology, of which the following are the majors steps:

5.1 *Problem Setting*

> When we set a problem, we select what we will treat as the "things" of the situation, we set the boundaries of our attention to it, and we impose upon it a coherence which allows us to say what is wrong and in what directions the situation needs to be changed. Problem setting is a process in which, interactively, we name the things to which we will attend and frame the context in which we will attend to them" (Schön 1983:40).

The first step is problem setting, the purpose of which is to turn a problematic situation into a problem. This is an ongoing, iterative, and reversible process during which the actors try to achieve a common understanding of the situation. As Schön describes above, this mainly consists of naming the objects (or even the situation as a whole) and setting the boundary (of attention). Using the dual metaphors of puzzles and stories, this is the equivalent of naming the pieces of the puzzle (to the extent that they are known) and maybe giving possible titles to the story. The product of this step would be a "laundry list" of main objects and a schematic outline of the major issues, constraints, and concerns.

5.2 *Bricolage: Elicitation and Representation*

Once the objects are named, the next step would be to assemble them in an improvisatory manner.[1] For this purpose, one can elicit the actors for whatever knowledge they have about the objects and the situation as a whole. This might consist of expert knowledge, management constraints (such as cost issues), local knowledge of a citizen, and so on. Since part of this cannot be formalized (in the sense of encoding and storing in a knowledge base), various representation schemes should be used to capture and preserve the input provided by different actors — e.g., database tables, knowledge base (KB) rules, frames (schemas), hypertext, images, photos, etc. The participatory character of this phase is also very important. The bricolage phase produces a semi-structured representation of

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[1] The French word bricolage means to use whatever resources and repertoire available to perform whatever task one faces (Weick 2001: 62). The relevance of this for decision making is the idea that objects "are not known as a result of their usefulness; they are deemed to be useful or interesting because they are first of all known" (Levi-Strauss 1966: 9).

the pieces of the puzzle (similar to when children spread out their pieces of the puzzle on the floor before placing them).

5.3 Coordination

Following the initial assembly of bricolage, a process of filtration and refinement is needed to eliminate or reduce redundancies, mismatches, and conflicts. An explicit attempt should also be made at this stage to transform, to the extent possible, informal representations to formal ones. Ideally, the goal of this stage is to develop *a model* agreed upon by all the actors, but in practice it is very unlikely that this happens. There is always a residue of local, implicit, and informal knowledge that cannot be formalized and needs to be presented in an informal manner.

5.4. Narration

The purpose of narration is to give structure and meaning to an otherwise incoherent ensemble of data, objects, models, etc. One of the problems of using DSS effectively is the complexity of models and the challenge that this poses to users in terms of comprehension and accessibility. Narration can help users make sense of the models using tools that could be formal or informal, mathematical or descriptive, textual or visual, and so on.

5.5. Simulation and Visualization

The crucial point about simulation is the experimental and, preferably, visual nature of this phase. People can do this individually or in small groups at their own pace and leisure in order to come up with scenarios that are meaningful to them. They will, of course, have to describe and justify their scenario(s) in the retrospection phase. Whatever the form, the purpose is to give users a chance to experiment with ideas, to understand the consequences, to be able to associate with others, and so on.

5.6. Retrospection and Validation

This is probably the most challenging phase, and its purpose is for actors to relive and review the decision-making process by trying to explain it to others. In this manner, retrospection is utilized as a means of validating, legitimating, and making the process transparent. In this fashion, issues of uncertainty will be at least partly handled.

Needless to say, this whole process is iterative and reversible at every one of the six steps, as people might discover in the act of retrospection that critical aspects are missing, conflicts are still outstanding, or goals are not achieved.

6. Discussion: Putting Things to Test

Having outlined the above framework and its supporting methodology, we would now like to present and discuss its application to the DTP. As we pointed out earlier, this discussion is largely a retrospective reconstruction of what *actually* happened in DTP in terms of the decision-making process and the application of EMDS in it.

Our initial intent was to define the problem in a series of decision framing workshops. This was not feasible for reasons noted earlier. In actuality the problem had been pre-defined through a series of documents (plans) and meetings that had occurred independent of our involvement. However, this did not mean that all the parties has a common understanding of the problem. The domain experts and land managers provided the laundry list of criteria, values, and constraints to the decision process. Our task was to bring these into alignment. We organized the list into several elements including criteria, data, parameters, and weights (or values). The list was then cross checked with other known sources of information (scientific literature, previous modeling efforts) and used as the basis for bricolage, elicitation, and representation.

The bricolage process involved acquiring, inventorying, and assessing relevant data layers. Three representation schemes were used to represent the results: 1) knowledge network diagrams 2) tables and 3) cartographic displays. Several meetings were held with domain experts. During the meetings domain experts would suggest possible data sources. We would assemble the data sources, identify the ranges and domains of relevant data attributes, and then present our findings to the domain experts. Meetings and emails were used to facilitate in iterative design process where different modeling methods, parameters, and metrics were presented, critiqued, and refined.

The assembly and elicitation process was iterative and self-reflexive. Data and knowledge were assembled, presented to domain experts and then used as the context for eliciting parameters, and metrics pertaining to the model. For example, several sets for roads data were gathered and several methods of determining road density and fragmentation were presented. Experts would review and input on these methods, and when unsatisfactory, the team would resume the assembly process. The assembly process determined what types of detail is required in the elicitation process, and the elicitation process served to evaluate the validity of the assembled contents as they pertained to the model.

The coordination, narration, and simulation processes were combined into one day-long meeting with the land managers and domain experts. The day began with the narration where process, methods, and results were presented through a series of slides, posters, and interactive map displays. We then presented the land managers with several options for understanding and exploring the problem. These included large hard copy maps, whiteboards, interactive models, and electronically displayed maps. The DSS tool, EMDS, was but one of several methods for exploring different decision options. We had intended to run the land managers through a set agenda of presenting the results, exploring scenarios, and reaching a conclusion. The meeting rapidly (de)evolved into several small groups discussing, interrogating, and exploring through their medium of choice. Some land managers were having private discussions in the corner. Others were congregating around one of the dozen or so large hard copy maps prepared for the meeting. Still others were interested in interrogating the model or exploring other data sources and looking at 3D visualizations of certain areas. We were better able to meet the needs of the decision makers by facilitating the decision through and ad-hoc ergonomic approach rather than a prescribed meeting agenda.

7. Conclusion

Decision support systems have demonstrated their effectiveness in arenas where the mandates of the situation are beyond individuals' grasp and judgment — e.g., in ecosystem management. However, the growing complexity of such situations demands a tight coupling of humans and technologies that seems to surpass the capabilities of current DSS. We argued in this paper that current systems are limited in their capabilities for a number of reasons: i) their reliance on a mentalistic view of cognition; ii) their fundamental assumption of a principally rational model of decision making; iii) their emphasis on criteria such as accuracy and certainty that are not fully attainable in most real-life situations; iv) the loose coupling between technologies and their embedding environments (including human beings). We also demonstrated that the development of DSS in the last few decades has been largely bottom-up — that is, it has typically moved from tools to techniques to concepts. To overcome these limitations, we adopted a top-down approach and suggested a number of shifts, which were outlined throughout the paper.

The top-down approach followed here freed us from the 'tyranny' of technology, and made it possible to view DSS as a collection of people, tools, methods, et cetera rather than one or more software applications. The top-down approach and the proposed shifts made it possible for us to revise some of the fundamental assumptions of current DSS. In particular, it allowed us to understand and articulate decision-making as a constructive process of sense making that can potentially lead to alternative realities (rather than the rational weighing of current alternatives), as the retrospective justification of perceived outcomes, and as the coordination among various actors (people, institutions, technologies, documents, and so on). The constraints of present information-rich but fuzzy and uncertain decision environments also led us to postulate transparency and plausibility as norms that should govern decision-making. These shifts are compatible with recent trends in DSS (Forgionne et al. 1991) and in AI (Pomeral 1995, Gupta and Sharman 2004, Ekbia 2005), which has always functioned as a reference discipline for iDMS (Simon 1987, Eom 1998, Goul et al. 1992, Mora et al. 2003).

The above conceptualization led us to a methodology that would potentially support it. We proposed a six-step method that begins with problem-setting and, having gone through the intermediate steps such as bricolage and representation, uses retrospection as a validation mechanism. Together with established formal methods of knowledge representation and sharing, scenarios and narratives have a central role to play here. The growing repertoire of visualization techniques will prove very useful for this purpose. Our discussion of the technical and practical aspects of decision-making brought up the central question of how to realistically implement the methodology proposed in this paper and how to most effectively integrate new technologies into the decision-making process. We demonstrated the practical application of this methodology in the case of the Desert Tortoise Project. Given the scope, complexity, and significance of this project, we believe that our case study lends strong support to the concepts and methods proposed here.

We should also emphasize, as an important pragmatic consideration, the match between technical tools and their embedding environment. Various arenas — academic, business, government, participatory (grass-root,) non-profit, and so on — call for different DSS implementations and tools, and that the one-tool-fit-all view of DSS is misguided (Forgionne 1991). Therefore, despite our desire to come up with a set of universal properties and features for DSS, we cannot go beyond the most general outlines of such properties. Each particular context demands its own specific properties and features. We are, therefore, aware that the set of concepts, methods, and tools developed and proposed here might only apply to certain contexts and not others. But we do hope that, by offering a new perspective, they open up new possibilities for diverse and contextually specific tools and designs.

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