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Identifying the decision to be supported: a review of papers from Environmental Modelling and Software

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Abstract: Two of the basic tenets of decision support system efforts are to help identify and structure the decisions to be supported, and to then provide analysis in how those decisions might be best made. One example from wetland management would be that wildlife biologists must decide when to draw down water levels to optimise aquatic invertebrates as food for breeding ducks. Once such a decision is identified, a system or tool to help them make that decision in the face of current and projected climate conditions could be developed. We examined a random sample of 100 papers published from 2001-2011 in *Environmental Modelling and Software* that used the phrase “decision support system” or “decision support tool”, and which are characteristic of different sectors. In our review, 41% of the systems and tools related to the water resources sector, 34% were related to agriculture, and 22% to the conservation of fish, wildlife, and protected area management. Only 60% of the papers were deemed to be reporting on DSS. This was based on the papers reviewed not having directly identified a specific decision to be supported. We also report on the techniques that were used to identify the decisions, such as formal survey, focus group, expert opinion, or sole judgment of the author(s). The primary underlying modelling system, e.g., expert system, agent based model, Bayesian belief network, geographical information system (GIS), and the like was categorised next. Finally, since decision support typically should target some aspect of unstructured decisions, we subjectively determined to what degree this was the case. In only 23% of the papers reviewed, did the system appear to tackle unstructured decisions. This knowledge should be useful in helping workers in the field develop more effective systems and tools, especially by being exposed to the approaches in different, but related, disciplines. We propose that a standard blueprint for reporting on DSS be developed for consideration by journal editors to aid them in filtering papers that use the term, “decision support”.

***Keywords**:* Decision support system, decision support tool

1. INTRODUCTION

We assert that two of the basic tenets of decision support system development are (1) to help identify the decision(s) to be supported, and (2) to provide analytical or computational facilities for best addressing those decisions. An example of a decision for wetland management would be that wildlife biologists must decide when to draw down water levels to optimise availability of aquatic invertebrates as food for breeding ducks. It is noted that such decisions may appear straightforward, but they are actually quite poorly structured due to the complexity of their ecological, spatial, temporal and strategic context. Furthermore, a system or tool to help a natural resource manager making that decision in the face of current and projected climate conditions could be developed. An example of an exceedingly complex problem would be how countries across the world might choose to respond to climate change in relation to biodiversity conservation. Both of these are examples of what one might call unstructured or underspecified problems (Simon, 1973; Sprage and Carlson, 1982). The second venue is one where DSS might even provide support in actually identifying critical decisions to be taken, and both may require a system that would help structure the problem itself. The phrases "decision support system" and "decision support tool" are used throughout many sectors utilising decision support, such as water resources, fish and wildlife conservation, climate mitigation and adaptation, agriculture, air quality, and protected area management. Andriole (1989) points out that there are multiple dimensions to decision support, but "at the core are the actual decisions that must be made." Our hypothesis is that such decisions are not always appropriately identified in scientific papers. This is based on our qualitative personal observations from editing and reviewing such papers, as well as from reviewing the work of others in various components of our professional lives with research and natural resource management entities on three continents. We hope that insights will be useful in helping workers in the field develop more effective systems and tools. D'Erchia et al. (2001) distinguished decision support systems from tools, with the former being based on an underlying model and having the ability to help structure the problem. We do not focus on this distinction, here, and use the acronym, DSS, to apply to both systems and tools. However, we do emphasise systems, and in that light, we do assess how frequently papers address unstructured problems.

It is important to ensure that future papers in this field clearly identify decisions and delineate how those decisions were determined. Volk et al. (2010) reported that the appropriate and methodological stakeholder interaction and the definition of "what end-users really need and want" are general shortcomings of all four examples of DSS that they compared. Ascertaining user needs is one of the key issues in building good DSS. Over fifty years ago in his foundational writings, Simon (1960) distinguished three main phases of organisational decision making (what we will term "decision phases"): (1) the gathering of "intelligence" for the purpose of identifying the need for change (later called "agenda setting" by Rogers, 2003); (2) "design" or the development of alternative strategies, plans, or options for solving the problem identified during the intelligence gathering phase; and (3) the process of evaluating alternatives and "choosing". As described by Courtney (2001), Gorry and Morton's (1971) original innovation was to distinguish among structured, semi-structured, and unstructured decision contexts, and then to define DSS as computer-aided systems that help to deal with decision making where at least one phase (intelligence, design or choice) was semi- or unstructured. Pidd (2003) elaborates decisions into three categories along a continuum of structured to unstructured, from puzzles (with agreeable formulations and solutions) through problems (with agreeable formulations and arguable solutions) to messes (with arguable formulations and solutions). McIntosh et al. (2005), McIntosh et al. (2011), and Oliver and Twery (1999) also discuss the nature and structure of decisions to be supported. The distinction between categories makes explicit the fact that decisions involve problem formulation as well as solution generation and selection, and that both dimensions must be considered. Sprague and Carlson (1976) argued that a definitional component of DSS was the need to evaluate alternatives that address decisions.

Ascough et al. (2008) identified the future research challenges for incorporation of uncertainty in environmental and ecological decision making. They found that several research traditions provide concepts, logic and modeling tools with the intent of facilitating better decisions about the environment (Jaeger et al., 2001). Policy analysis (built on the rational actor model including both benefit–cost analysis and risk analysis), is the most elaborate of these efforts (Boardman et al., 2005; Dietz et al., 2001). Over the past two decades, theory and research examining democratic deliberation are increasingly used as a basis for environmental decision making (Renn et al., 1995). Discussions of sustainability (linked to definitions of the concept and efforts to measure environmental performance) also can be viewed as attempts to improve environmental decision making. In most of these traditional environmental decision making approaches, the notion of what constitutes a "good" decision is fairly explicit. Many stakeholders or policy groups view good environmental decisions as utilitarian outcomes that provide the most satisfaction to a majority of people. This is done typically through a participatory process of decision making (Dietz, 2003). This is a particularly anthropocentric view, however. Advocates of sustainable, ecological, and environmental management usually note obligations to future generations or to ecological relationships. Most also voice concern for other species, for ecological processes, or for the biophysical environment.

2. METHODS

We chose to examine work reported in the journal, *Environmental Modelling and Software*, because the specific scope of that journal covers decision support research along with supporting elements such as model development, evaluation, and data analysis. Plus, we have a close association with that journal, as many of us serve on the editorial board. To determine the population of papers to be reviewed, we performed a full-text search in *ScienceDirect* for papers published in *Environmental Modelling and Software* from 2001 to 2011, including articles in press that used the phrase "decision support system" or "decision support tool". The resulting 468 papers were filtered to 117 by considering only those that involved the development, evaluation and application of a DSS or DST. Papers were also excluded if they focused on theoretical or general aspects without a case study application. A sample of 100 papers was randomly selected from the 117 and allocated among the authors of this paper for review. If a paper was not appropriate for a particular reviewer, e.g., they were associated with the development of that system, that paper was exchanged with one assigned to a different reviewer. At the outset, reviewers had agreed to review 10 papers each, and we had 10 reviewers. We arbitrarily decided not to ask reviewers to review more papers and complete all 117. Because the "sample" is nearly the full population of papers mentioning decision support systems from *Environmental Modelling and Software* for the last 10 years, we report straight percentages, only; and we do not feel it was appropriate to provide an assessment of precision. We did choose the sample randomly to reduce the possibility of bias within our population of the one journal.

Environmental DSS can be used in a variety of domains and contexts. To describe that variety, the review of the selected papers was performed using a set of 32 questions using an online questionnaire and database for use by those reviewing the papers. Questions were set up around the decision that was to be supported by the DSS, how the decision was identified, and how the DSS supports the decision.

Additional aspects were how uncertainty was addressed, how stakeholders were involved, aspects of system or tool design (stand-alone application, client-server architecture, etc.), and knowledge representation in the system. Based on our experience in DSS development and application, we identified a set of key aspects that described these main questions.

We first attempted to determine whether the author(s) followed the basic principle of identifying the decision to be supported. Important aspects of the type of decision to be supported were the domain of application, the decision making context, and the spatial and temporal (urgency, recurring of the decision, time horizon) scale at which the decision takes places. The type of decision was further characterised based on the kind of the decision to be made, i.e., did the decision involve choosing from a predefined set of options, or involve generating new options including the type of decision making situation in which the DSS was intended to be used. Second, we classified the techniques that were used to identify the decisions, such as formal survey, focus group, expert opinion, or sole judgment of the author(s). Two dimensions were used: (1) the techniques used to identify the decision to be supported, and (2) the techniques used to identify whether the DSS helped in decision making. Third, the primary underlying modelling system, e.g., expert system, agent based model, Bayesian belief network, and GIS was categorised. Finally, since decision support typically should target some aspect of unstructured decisions, we subjectively determined to what degree this was the case.

3. RESULTS

In our review, 41% of the systems and tools were related to the water resources sector, 34% to agriculture, and 22% to the conservation of fish, wildlife, and protected area management. Every other sector was each represented in less than 10%. Note that a system could involve more than one sector. Most DSS considered local (79%) and/or regional (32%) spatial scales. In regard to the decision making situation in which the DSS was used, 54% of systems were used for policy regulation and governance in response to specific legislative framework, 39% of systems were used for organisational decision making risk mitigation, and 23% systems were used for participatory collaborative decision making. Local government was identified as the end-user for 62% of the systems and tools.

We ascertained that only 60% of the papers that we reviewed did, in fact, identify the decision that was to be supported. Expert opinion was the most common method used for identifying decisions (25%), followed by sole judgment of the authors (14%), focus groups (13%), and formal surveys (8%). Fifty-two percent did not explicitly mention a method, which coincides with our finding that decisions were not always identified. As our team took stock of our original objective, we realized that added information might be useful to a wide range of decision support workers. Therefore, we present some of those additional particulars uncovered during our reviews.

In 65% of the cases, experts with no real stake in the decisions being made were involved in DSS development, contrasted with direct involvement of end users in 23% of cases; and, at most, up to 25% of cases involved “direct” stakeholders in development. 53% of papers did not identify the stage at which stakeholders were involved, if they were involved at all.

Regarding whether the systems aimed to address the issue of assisting with unstructured problems, 25% seemed to have this as a central or secondary purpose, and it was a side effect in another 28%. Forty-four percent of cases were assessed as providing no support to problem structuring activities, and 61% of DSS were assessed as providing no collaborative learning benefits.

Another criterion we evaluated was whether the systems would produce novel recommendations. In 73% of papers, the system did not contribute to generating decision options. Decision making is instead supported by assessing existing options (50%), interpreting data (40%), or assessing the situation (50%). A DSS frequently performed a combination of these functions, although 25% only assessed existing decision options, 13% only assessed the situation, and 10% only interpreted data. DSS results are most frequently presented graphically for users to interpret (65%), or presented numerically (52%).

We assessed the strategic or tactical nature of decisions, and 61% seemed to be dealing with longer term “strategic” decisions, those decisions considering impacts with a time horizon of greater than one year. Only about 12% of the systems were aiming at decisions that had to be made within seven days, and 21% addressed decisions with a time horizon between one week and a year. The time horizon was unclear in roughly 35% of the papers. Because a system or tool might fit more than one category, the percentages sum to more than 100%.

We assessed the kind of inferences performed by the DSS. Model-based predictions were used in 76%, classification of case situations in 21%, and deduction in 15%. There is also a fundamental need to investigate uncertainty and reliability of models that are part of a DSS, but 33% of the papers made no such mention and 63% of papers at best described uncertainty qualitatively.

4. DISCUSSION

We limited our assessment to one ten year time span of one journal, and we do not make inferences beyond that. The sectors being addressed by the DSS that we investigated were somewhat limited, and it was not our *a priori* interest to understand and describe the wide range of DSS being developed throughout the world. Our observation that it is common for DSS workers not to clearly identify a decision(s) for their system or tool to address is supported by our research on articles from the journal, *Environmental Modelling and Software*.

There are two major types of approaches to decision support that emerge from our analysis. In the first case, the DSS presents a set of alternatives and guides the user towards the evaluation of such scenarios with respect to the situation at hand. In the second case, the DSS has a more proactive role, as it is able to compute a possibly optimal (or satisficing) solution starting from available data. The first type of DSS is well suited for complex and unstructured problems, where it might be difficult to formalise the problem in such a way that an optimisation algorithm could process it. Sometimes, this approach allows for the integration of stakeholders in the exploration of the alternative choice(s) in the search for the best compromise. The second case works well for large, complex, but well structured decision problems, particularly in the presence of a limited group of stakeholders, where exploring the alternative’s space is too time consuming or to complex. In our opinion, the advantage of the second approach is that DSS generated solutions are typically optimal or near-optimal, and that such well-computed solutions can be generally better than any human-found solution.

Having said this, the dominance of expert driven development processes (63% of cases) and lack of stakeholder involvement (in less than 50% of cases) raise the question as to the extent to which DSS provides support suited to real decision making contexts and processes. Decisions are group activities, be they in organisational or participatory contexts, and as a consequence are also learning activities. That 61% of DSS were assessed as providing no collaborative learning benefit is concerning, and perhaps reflective of the dominance of expert driven development practices. It is difficult to see how DSS which do not promote learning within groups can be effective in fulfilling their roles as decision structuring or solving aides.

Most papers that we reviewed described DSS that support strategic/planning decisions rather than operational ones, and this fits well with their potential use as part of an adaptive management approach for ecological systems. Such systems either often change slowly, respond to outside drivers slowly or with complex lag times, or show threshold effects. Such characteristics make them hard to control or manage, and we speculate that this is why most DSS were designed for strategic decisions. We suspect that it is likely more feasible to conceptualise local and regional decision making frameworks than those at broader scales. Most DSS teams probably do not have the capacity to address long term and international problems. It would certainly not be impossible to do so, but one might expect there to be fewer such systems reported in the literature.

There are other aspects of decision support system development that we did not assess. Some of those are critical, such as whether systems were empirically evaluated (Sojda 2007), and we leave this for subsequent research. Other key features we did not tackle, or for which we only scratched the surface, were delineated by Sanchex-Marre et al. (2009) and relate to uncertainty management, temporal reasoning, how DSS access data, and the role of GIS in DSS.

5. CONCLUSIONS AND RECOMMENDATIONS

The papers reviewed varied in focus and scope, from those describing the features of the DSS and demonstrating an application, to those focusing on the software architecture integrating the DSS components or certain techniques used within the DSS. However, in our opinion, too large a proportion of the papers lacked information about the actual support, or the support of actual decisions. It is possible that this is due to the term DSS being misused or abused, yet we would expect decision support to be at the core of those studies. Indeed in some cases, the purported system or tool was actually a model or methodology that could be applied to assist in decision making, rather than a system or tool purposely built to provide decision support. However, it is possible that the lack of information on decision support, in at least some papers, was simply due to inadequate reporting of such aspects.

Given the variety of ways in which information about the decision to be supported could be reported, and the relatively high number of papers in which this information was missing or vague, we recommend the development of a blueprint or standard reporting protocol for DSS. Such a blueprint could be based on existing protocols like the protocol for individual based models by Grimm et al. (2006), or the ecosystem service assessment blueprint by Seppelt et al. (*in press*). Our proposed standard reporting protocols would outline the information we perceive as being essential in the description of a DSS – including the specific decision(s) to be supported and how this decision was identified, how the DSS facilitates decision making, the spatial and temporal scale of the problem, the involvement of end-users or stakeholders in its development, the evaluation of the DSS and validation of its outputs, and the uncertainty associated with the DSS and its outputs. The ultimate evaluation of any decision support system or tool is whether it accomplished the purpose for which it was intended (Sojda 2007). This requires that the decision to be supported is identified in the earliest stages of DSS development. By setting such minimum reporting protocols for DSS papers, we hope to improve the credibility and standards of DSS by ensuring studies developing such tools consider and communicate these key aspects of decision support.

Furthermore, we pose the question whether DSS has not become a buzzword, and in the process, lost some of its technical definition and rigour. As scientists in the field, we are excited by DSS coming into vogue, but suggest that funding agencies and other entities, scientists, and journals help ensure that the use of the term be more constrained, and especially to ensure that the decision(s) to be supported by the system or tool are identified, real, and informed; or perhaps, are even articulated by those with the responsibility for making them.

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