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Abstract: Drawing on the literature of agricultural decision support systems (DSS) and experience in developing tools for policy support and evaluation, this paper argues that while in the main such tools have failed to live up to expectations it may be that the expectations were unrealistic. The design-use gap of DSS for environmental management is partially the inevitable cycle of expectations (unbelief-euphoria-disappointment and maturity or abandonment) experienced by any innovation. The environmental problems facing land managers and society are dauntingly complex. Yet more or better quality information does not inevitably lead to better management. Many of the issues that face land-use policy and practice have a strong normative component, are highly uncertain and are contested. Information without supporting institutions is also unlikely to result in the levels of cooperation between land managers needed to deliver environmental and ecological outcomes at scales above the individual land management unit. A number of techno-centric silver bullets to the design-use gap have been identified including GIS integration and the perennial user friendliness and transparency. More recently frameworks, standards and reusable components have been proposed. A growing body of evidence exists, however, that indicates the usefulness of tools depends much less on their technological or indeed scientific sophistication but on having a clear understanding of their role (e.g. calculator, record keeper, systems analysis or learning environment) and how the researcher will interact with the stakeholders. The latter, it is argued, goes beyond the *include stakeholders* panacea and challenges research commissioning based on a design – build – deliver – use paradigm. The paper proposes multi-perspective deliberation as an approach to bridging the design-use gap with the researchers acting as facilitators and the tools or their outputs acting as boundary objects through which issues can be explored.

Keywords: decision-support; deliberation; simulation-modelling; agriculture; environment

1. INTRODUCTION

This paper argues that in seeking to close the design-use gap for tools applied to environmental management and policy there are significant lessons to be learned from the previous experiences of researchers developing agricultural decision support systems (DSS). It is argued that DSS, in common with other innovative technologies, have or will pass through sequential phases of unbelief, euphoria and disappointment followed by maturity or abandonment (Nissen, 1995). For DSS the disappointment is that the tools simply are not used. Explanations for this failure typically focus on issues of design, content and usability and techno-centric solutions are presented. This paper contends that the failure of DSS is best understood not by focusing on the tools but their developer's inability (due to backgrounds dominated by natural and computing sciences) to understand and engage with the processes of agricultural and environmental management and policy. The paper argues that there are institutional factors beyond individual projects that need to be considered in explaining the gap between deign and use for DSS.

Given the apparent failure of the DSS paradigm what were the expectations of DSS that meant they were expected to be *well-suited* to the problems of land management. Early analysis of DSS (Keen and Scott-Morton, 1978) characterised DSS as being applied to problems with sufficient structure but where the managers judgement is crucial and thus extend the range and capability of managers and improve their effectiveness. The tool should be controlled by managers, and support rather than automate decision processes. It is difficult to fault these as aspirations for DSS but by 1995 expectations for DSS had risen to potentially euphoric levels. Turban's (1995) definitions of DSS see them applied to *ad hoc* and unexpected problems; providing a valid representation of the real world system and support within a short time frame; evolving as the decision maker learns more about the problem and being developed by non-data processing professionals.

During the same period (1990's to early 2000's) there was significant change in land use policy in the E.U. and stakeholder expectations had an increasingly post-productivist emphasis with a consequent a desire to evaluate a wider range of land use options and investment in DSS R&D.

1.1. Characterising the design-use gap

With increasing recognition of the design-use gap a number of explanations were advanced. DSS were too complex, not transparent enough, difficult to use and produced answers that were difficult to interpret. Solutions included making the model spatial, adding graphical user interfaces, using web access, building frameworks, defining standards, creating toolkits and encapsulating reusable components. All of these were desirable, some even necessary, yet all addressed issues that were easy to recognise for natural and computing scientists, who, in the main, made up the bulk of the development teams. By situating agricultural DSS in a wider planning and models-for-management paradigm, however, McCown (2002b) identified parallels with the earlier problems for the use of models and DSS in business and industrial management. From this analysis came the conclusion that the design-use gap results from DSS developers failures to appreciate and engage with the institutions that underpin decision making.

Much of the motivation for DSS development has its origins in the desire by policy makers or other stakeholders to change the behaviour of land managers in certain desirable ways (McCown et al., 2005). The lack of success in such undertaking is partially because more information does not mean different decision unless the information addresses the largest sources of uncertainty for the decision maker. This is especially important since most land managers are *satisfiers* rather than *optimisers*. Existing patterns of behaviour, underpinned by culture and values are also highly resistant to change (Burton, 2005) and are thus unlikely to be significantly influenced by software tools alone, however sophisticated. Given the lack of success for agricultural DSS intended for individual practitioners and production oriented, it should not be surprising that where post-productivist goals and trade-offs are concerned, and issues of cooperation are significant (for example, in delivering benefits at catchment and landscape level), then the difficulties of making DSS operational are compounded.

Further analysis by McCown (2002a) identified specific roles where DSS had been successful There roles were as 1) *calculator* (end-user, single-issue, tactical and quickly subsumed into experience), 2) *record keeper* (end-user, statutory, supporting best-practice, ongoing), 3a) *flexible simulator* (consultancy, counter-factual, strategic, policy and practice), 3b) *learning environment* (consultancy, multiple-perspective, practice and policy). Beyond identifying the specific role for a DSS, success was seen to depend on the credibility of the DSS outputs. Credibility was difficult to define, but one key factor was the ability of the system to adequately reproduce a practitioners *situated internal practice*, or how the system currently operates. DSS were also used when they allowed decision makers to internalise decision-making where they had previously relied on consultants. DSS were not used when their use ceded agency from decision-maker to software.

French and Geldermann (2005) report similar roles for DSS specifically addressing environmental questions. As with earlier analyses, one axis of French and Geldermann's conceptual model for the roles for DSS is the degree of structure in the problem, but with DSS and related methods operating within the highly structured end of the spectrum, with unstructured questions addressed through soft modelling and decision analysis. For the other axis they identify four levels of decision support, and these levels have resonance with McCown's roles for DSS. At Level 0 there is acquisition, checking and presentation of data. At Level 1, there is analysis of current and forecasting of future(s) states. At Level 2, there is simulation of: the consequences of strategies; the feasibility of solutions and the quantification of advantages and disadvantages. Finally at Level 3, there is analysis in the face of uncertainty and the balancing of benefits and disbenefits. It can be argued that the most successful DSS, in terms of uptake, have been the simpler tools at Levels 0 or 1 (manipulation and presentation of data), with much less success in delivering the added-value claimed for DSS (e.g. counter-factual of analysis scenarios or accounting for uncertainty) at Levels 2 and 3.

1.2. Tools within processes

Looking beyond the natural and computing science literatures it can be seen that deploying DSS cuts across a wide range of issues where lessons should be learned from the social sciences. Rauschmayer, in his evaluation of methods for the resolution of environmental conflicts, signposts the following issues that need to be taken into account in the use of DSS (Rauschmayer, 2006). 1) *Information* - the breadth considered valid within the analysis, how knowledge and values are integrated, who participates and how is uncertainty handled. 2) *Legitimacy* – inclusion and representation (decision makers, stakeholders and citizens). 3) *Social Dynamics* – potential for positive and negative outcomes and 4) *Cost* of the process.

DSS represent a class of tools that had their origins in a business environment, with formal hierarchies and identifiable decision makers, which are now being applied in less well-defined, and arguably more complex, social contexts. The questioning of the technological basis of software-based analyses can hide value-based disagreement with the tools' outcomes and their implications. The contested nature of science also means that the outcomes of any analysis will rarely be definitive and will incorporate some uncertainty. Given this environment, Jakku and Thorburn (2004) propose the use of DSS outputs as boundary objects to encourage deliberation (Dryzek, 2000) between stakeholders since they are *real*, yet not personal.

Examples of deliberation-based analyses include researcher and practitioner forums such as Making Aberdeenshire Farms More Profitable - (Scottish Enterprise Grampian, 2001), computer supported role-playing games where communities can explore options for cooperative resource management (AtollGame (Dray et al., 2005)), and participatory action research such as FARMSCAPE (Carberry et al., 2002). The latter provides an example of the success of combining DSS deployment with monitoring, experimentation, and stakeholder communications.

The remainder of this paper presents, as a case-study of the DSS development process, a scoping study for a model-based tool proposed for use in policy-relevant assessment of farming-systems sustainability. The paper interprets the outcomes of the scoping-study against the existing theories of DSS development outlined above and proposes that there are further institutional factors that need to be considered in successfully interpreting the design-use gap for agricultural and environmental DSS.

2. PROJECT BACKGROUND

The software tools developed by the authors have their origins within farm-systems research and development conducted in Scotland from the 1970's. DSS was seen as a further phase of research beyond the systems analysis, systems synthesis, and model building. DSS was differentiated from these activities by the need to recognise external client satisfaction rather than only judging outcomes via peer review. Early activities focused on the integration of system models with geographic information systems (Matthews et al., 1999). These prototypes received more positive stakeholder feedback than expected, with individuals able to contextualise and generalise from the information provided, perhaps since they were experts in dealing with imperfect and messy data. Development continued, following McCown's flexible simulator path, addressing issues of climate, soils, cropping, livestock, resource scheduling, and physical and financial accounting (Matthews et al., 2006b). This sought to develop tools capable of addressing a range of land use issues. There was flexibility in the metrics available for evaluating alternatives, integration to allow comparison between variables or between cases, and a consistent framework of analysis. Attention was also paid to the sources of error and uncertainty within the models e.g. Rivington et al., (2005). Formal market testing, however, indicated that there was little prospect of commercial success for tools being sold as stand-alone software. The market research was also informative in revealing the barriers to the use of DSS and the expectations of the technology. The survey is discussed further in Matthews et al. (2005).

The multi-objective nature of land-use planning was recognised and methods developed to explore the structure of the trade-offs between objectives using multi-objective genetic algorithms (Matthews et al., 2006a). These methods allowed for a *search-then-decide* strategy setting out a range of options without the need to define, *a priori*, systems of weightings. The utility of the tools was tested with stakeholders and this process proved to be such a rich source of information (particularly heuristics and management norms, but also in effectively reformulating the analysis to make it more relevant) that the use of outcomes of analysis within deliberative inclusive processes (DIPs) was adopted. This DIPs approach has been used to look at the effects of reform of the E.U. Common Agricultural Policy on upland agriculture and identified the reforms as having the potential to drive a process of extensification

3. MATERIALS AND METHODS

As part of the U.K. Rural Economy and Land Use Programme[1] (RELU) an inter-disciplinary project team was put together to scope the development of a model-based tool, to be used in undertaking

[1] http://www.relu.ac.uk

policy relevant assessments of agricultural sustainability. The team had both natural and social scientists and the focus was on developing a sustainability assessment framework (SAF), under-pinned by systems modelling and making case-study based assessments of sustainability.

Before consulting with stakeholders the project team developed a conceptual model based on their previous experience. The model was premised on allowing stakeholders to define the content, organisation, relative weighting, and presentation of the sustainability assessment to reflect their individual perspectives. This would enable the comparison of perspectives in a process of deliberation. The conceptual modelling paid particular attention to the process of indicator selection by stakeholders and focused on the ways to assist them by 1) including domain experts within the analysis and 2) benchmarking models for their suitability to provide indicator values.

Following the conceptual model building, a stakeholder survey was undertaken. The survey had the following goals:

1. To explore the requirement for sustain-ability assessment tools by examining organisational roles and information needs in the policy process.
2. To explore how the wider policy making community currently approached assess-ment of sustainable farming, and to deter-mine if this is consistent with a SAF;
3. To identify areas for future development.
4. To identify potential end user partners;

Eight semi-structured face-to-face interviews were undertaken with a selection of representatives from the UK agricultural policy community. The sample was selected in order to get a balance of perspectives from organisations with differing roles in the policy process and with differing geo-political foci. Four distinct groups were targeted for interview: Government Departments; Government Agencies; environmental interest groups, and agricultural interest groups. It was recognised that this was not a comprehensive selection of all relevant stakeholder groups. These were, however, considered to be the main target groups of stakeholders for the project. The interviews were preceded by sending interviewees a short poster-style document outlining the aims and objectives of the project, a project schematic explaining the proposed approach, and an outline of the topics to be discussed in the interviews. The outcomes of the interviews had the effect of radically altering the conceptual framework and reconsidering the factors that influence the usefulness of model based tools.

4. RESULTS

The initial conceptual framework had seen a policy relevant sustainability assessment being developed in four phases, engaging, scoping, building and operational. Engagement would seek to identify the perspectives, issues, and forms of sustainability analysis needed. Scoping would seek to take the requirements from engagement and determine the degree to which models and tools existed that could meet the requirements. Building is self-explanatory and the Operational phase would give thought to how the systems would be used in practice.

The team started from the premise that to understand the effects of policy on the sustainability of farming systems, it is important to understand the detail of the interaction of management decisions and local environments. The models proposed to support the sustainability assessment were farm and catchment scale, with a core model or hub handling the integration of outputs from a range of specialist modules. The use of the tools would provide case-studies as part of a deliberative process with practitioners and policy makers. This conceptual framework proved, during the process of the stakeholder interviews, to be flawed at several levels with significant mutual incomprehension of the scientific and stakeholder priorities.

The team's underlying systems-engineering approach of *requirements-scope-build-use* proved to be ineffective. The approach had sought to avoid the problems associated with defining sustainability by allowing for multiple definitions, theoretical perspectives, and forms of analysis. This proved to be necessary yet not sufficient. In the main, the policy stakeholders interviewed were unable and often unwilling to articulate preferences for sustainability assessment beyond an assertion that *triple bottom line* is the overarching principle. There was little evidence of the penetration of ideas from research into policy spheres (such as sustainability gap or trade-off analyses that require either targets or weightings). There was recognition by policy makers that indicators are desirable or necessary, but this was often seen as having been imposed in a top-down fashion and inadequately resourced. Lacking a theoretical understanding of the development and use of indicators, policy-led initiatives tended to fall back on *ad hoc* sets without consistent cross-indicator targets or relative priorities. The indicator sets are thus not linked to, and therefore used within, particular processes.

Another criticism, made by organisations concerned with national-scale policy, was that farm-scale, case-study based analyses were not relevant to the formulation of policy at national scale. Their desire was for simple models that led to results which could be easily *scaled up*. In particular, there was the desire for models that incorporated land-manager decision making within the model. In response the authors argued that macro-scale policy analysis and initiatives alone are likely to prove inadequate as a basis for guiding a process of sustainable development if they are based on assumptions that are overly simplistic. The unique contribution that case-study based analysis could make was to engage with practitioners to better understand the complex interactions between land-management practices, the values that underpin them, the drivers that influence them most strongly, and the consequences (both biophysical and socio-economic). This provides a means of testing and refining the assumptions that underpin analyses conducted at larger scales.

From an associated literature review and further dialogue with stakeholders it became clear that, despite the negative initial response to the idea of formalised, model-based, sustainability assessment, it was perhaps not the component tools themselves but the overall approach that was over-engineered. The approach was too inflexible and therefore failed to mesh with existing policy- or practice-led initiatives. In a further round of consultation towards the end of the scoping study it was possible to make more positive progress in engaging with the policy community (including some of the organisations critical of the initial proposals). This has resulted in a further research proposal supported by nine organisations.

The proposal identified Win-Win[2] resource management as a potentially key approach in increasing the sustainability of U.K. farm systems and one in which sustainability science has a role to play. Win-Win case-studies for particular farm-systems[3] were seen by stakeholders as a tool that could proactively influence stakeholder behaviour. The benefits would, however, have to be credibly demonstrated to a sceptical sector more accustomed to Pay-Win with the inevitable question of who does the paying?

A number of limitations within the existing study (Bragg et al., 2005) were identified by the report's authors: lack of a systematic methodology that allowed comparisons between enterprises and between sectors; incomplete and unverifiable data; a lack of information on per-ha or per-animal basis (thus limiting the study's potential for extrapolation or aggregation); sectoral coverage that was incomplete; savings and costs that related to farmers' time were rarely calculated and finally there was a lack of awareness of how to achieve the Win-Win opportunities among land-managers – often since the costs of current practice are not accounted. All of these limitations could be addressed by the authors' tools and methods so that the research proposed was seen as directly relevant by the stakeholder groups.

5. CONCLUSIONS

Reflecting on the process of scoping the policy-relevant assessment of the sustainability faming systems it became apparent that there are wider institutional factors that need to be considered in addition to the existing theories of what underpins successful DSS development. The critical theories developed, most notably for agricultural DSS by McCown et al, but by others such as French and Geldermann for environmental models and DSS, stress the need to understand the role which the DSS will play, the decision making milieu within which the tool will be used and the people with which the tool will be used. Most particularly it is recognised that for the more complex DSS (whose capabilities are those originally identified as most desirable), the use of the tools will be *with* rather than *by* the stakeholders or clients.

The existing theory of what makes a successful DSS project has not, however, been recognised by many funding or stakeholder groups. The paradigm for many research based DSS projects remains one of *scope-design-build-use.* This paradigm is flawed, with abundant evidence of a design-use gap. The paradigm also makes DSS vulnerable to failure when the scope of the project is uncertain and/or contested. This was particularly evident for the author's project where supporting the comparison of alternative perspectives on sustainability through deliberation was not seen as desirable by most agencies. These organisations had narrow, yet poorly defined, conceptualisations of sustainability assessment and an inclusive, critical modelling approach was not

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[2] Win-Win resource management was defined by Bragg et al. as patterns of land use and management that result *both* in financial benefits for the farmer through cost savings or increased revenue *and* environmental benefits through improved resource management practices.

[3] Farm-systems refer here to individual management units but recognises that these require to be set in their wider contexts both socio-economic (e.g. markets and supply-chains) and biophysical (e.g. catchment and landscape) contexts.

seen as appropriate. The scope-design-build-use paradigm is perpetuated by a *purchaser-provider* relationship between end-users and researcher. The short-term commissioning and competitive tendering for such projects makes it more difficult to form long-term partnership where it is possible to question conceptualisations that are narrow, conservative or out-of-date when set against the state of the scientific art.

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References

Bragg, S., Inman, A., Manning, C., and Pitcairn, J., *Assessment of 'Win-Win' Case Studies of Resource Management in Agriculture*, Report, Environment Agency, 2005.

Burton, R. J. F., Seeing through the "good farmer's" eyes: towards developing an understanding of the symbolic value of "productivist" behaviour., *Sociologia Ruralis* 44, 195-215, 2005.

Carberry, P. S., Hochman, Z., McCown, R. L., Dalgliesh, N. P., Foale, M. A., Poulton, P. L., Hargreaves, J. N. G., Hargreaves, D. M. G., Cawthray, S., Hillcoat, N., and Robertson, M. J., The FARMSCAPE approach to decision support: farmers', advisers', researchers' monitoring, simulation, communication and performance evaluation, *Agricultural Systems* 74(1), 141-177, 2002.

Dray, A., Perez, P., LePage, C., Aquino, P. D., and White, I., Companion Modelling approach: the AtollGame experience in Tarawa atoll (Republic of Kiribati), In: Zerger, A and Argent, R M, (eds.), *MODSIM05, International Congress on Modelling and Simulation*, 1601-1609, 2005.

Dryzek, J., *Deliberative democracy and beyond: liberals, critics, contestations*, Oxford University Press, Oxford, 2000.

French, S. and Geldermann, J., The varied contexts of environmental decision problems and their implications for decision support, *Environmental Science and Policy* 8, 378-391, 2005.

Jakku, E. and Thorburn, P., Sociological concepts for understanding agricultural decision support systems, In: Richmond, K, (ed.), *TASA 2004 Conference Proceedings*, 2004.

Keen, P. G. W. and Scott-Morton, M. S., *Decision Support Systems, An organisational Perspective,* Addison-Wesley, Reading, MA, 1978.

Matthews, K. B., Buchan, K., Sibbald, A. R., and Craw, S., Combining deliberative and computer-based methods for multi-objective land-use planning, *Agricultural Systems* 87, 18-37, 2006a.

Matthews, K. B., Schwarz, G., Buchan, K., and Rivington, M., Wither agricultural DSS? In: Zerger, A and Argent, R M, (eds.), *MODSIM 2005 International Congress on Modelling and Simulation.*, 224-231, 2005.

Matthews, K. B., Sibbald, A. R., and Craw, S., Implementation of a spatial decision support system for rural land use planning: integrating GIS and environmental models with search and optimisation algorithms, *Computers and Electronics in Agriculture* 23, 9-26, 1999.

Matthews, K. B., Wright, I. A., Buchan, K., and Davies, D. A., Assessing the options for upland livestock systems under CAP reform: developing and applying a livestock systems model within whole-farm systems analysis, *Agricultural Systems* in press2006b.

McCown, R. L., Locating agricultural decision support systems in the troubled past and socio-technical complexity of 'models for management', *Agricultural Systems* 74(1), 11-25, 2002b.

McCown, R. L., Changing systems for supporting farmers' decisions: problems, paradigms, and prospects, *Agricultural Systems* 74(1), 179-220, 2002a.

McCown, R. L., Hochman, Z., and Carberry, P. S., In search of effective simulation-based intervention in farm management, In: Zerger, A and Argent, R M, (eds.), *MODSIM05 International Congress on Modelling and Simulation*, 232-238, 2005.

Nissen, V., *An overview of evolutionary algorithms in management applications*, In: Biethahn, J. and Nissen, V. (eds.), *Evolutionary Algorithms in Management Applications*, 44-97, 1995.

Rauschmayer, F., Evaluating deliberative and analytical methods for the resolution of environmental conflicts, *Land Use Policy* 2006.

Rivington, M., Matthews, K. B., and Bellocchi, G., Evaluating uncertainty introduced to process-based simulation model estimates by alternative sources of meteorological data, *Agricultural Systems* 2005.

Scottish Enterprise Grampian, *Making Aberdeenshire farm systems more profitable*, Report, Scottish Enterprise Grampian, 2001.

Turban, E., *Decision support systems and expert systems*, Prentice-Hall International, Inc., 887 pp., Eaglewood Cliffs, NJ, 1995.