TITLE: THE CUMULATIVE TRADITION OF DECISION SUPPORT SYSTEMS RESEARCH: NEW PERSPECTIVES ON SUCCESS

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Introduction

The opportunities and challenges of agricultural Decision Support Systems (DSS)[1] in connecting science and practice are well rehearsed in the academic literature. The focus has mainly been on issues of poor uptake by practitioners. These have been problematised and theorised from different perspectives, largely in relation to the epistemological gap between the hard and soft approaches respectively of science and practice. Given the rapidly changing context in agriculture (social, technological, environmental, institutional) it seems a good time to re appraise the role of DSS and ask questions about their future development and relevance.

The history and philosophy of agricultural DSS has been well documented (Power (2003). Analysis dating back to the discipline of information systems (IS) includes the study of both the social and technical aspects of the use of information technology for decision making and problem solving (Lyytinen, 1987). This body of work supports the view that there is little evidence of uptake or sustained usage, a failure seen to be consistent across all organisations and industries (Newman *et al.*, 2000). As a result DSS have been subject to close scrutiny in a number of reviews internationally (Matthews *et al.*, 2006). Collectively scholars have addressed the question: why are the expectations for DSS usage rarely realised and how can this challenge be addressed? Over time they have built up an extensive understanding of why the optimism for DSS amongst the scientific community does not match the evidence of practitioner usage. There are a corpus of work documenting key factors to enable functioning and sustained DSSs. These date from Little (1970) who identified criteria for functioning Information Systems[2]: robustness, ease of control, simplicity, and completeness of relevant detail and have been revisited by several researchers since (e.g. Rose et al., 2018). The importance of incorporating user input through participatory DSS development has also been recognised with developers soliciting user-feedback about tool performance and ease of use (Ingram et al., 2016; Rose et al., 2018). The value of involving users in genuine co-

[1] Decision Support Systems (DSS) and Decision Support Tools (DST) are sometimes used interchangeably. DSS are computer-aided management systems which are typically based on scientific models developed with the purpose of enhancing farmer decision-making. They are often developed into DST. DSS is used in this paper to refer to both system and tool.
[2]Information Systems preceded and preshaped the era of the agricultural DSS (McCown 2002).

design (Cerf et al 2012; Berthet et al., 2018; Prost et al., 2012; Volk *et al.* (2010);understanding farmers' situated knowledge (Lundström and Lindblom, 2018); and acknowledging farmers' different decision-making styles (Jørgensen et al 2007), have also been identified as important in improving the usability of DSS.

However, research still tends to focus on implementation issues, performance and uptake, with less attention being paid to questioning the assumptions underpinning DSS, the institutional context, the impact and learning achieved and how to assess it. For this reason, according to McCown (2002), DSS are in danger of being relegated to history without an adequate understanding of reasons for its market failure.

In Australia (and to some extent New Zealand) the evolutionary process of crop model based DSS in agriculture has been extensively reviewed and documented (Woodward *et al.*, 2008) with periodic questioning and reflection which has brought about considerable collective learning and reorientation in tool development. This is an evolving and dynamic domain, as agronomic understanding advances, new technologies appear, and new perspectives emerge, and farming demographics change, each prompting further analysis and questioning the relevance of DSS. As Hayman et al (2003) noted in 2003 the "unfolding history of DSS in Australian dryland farming systems provides an interesting case study of the challenges facing agricultural scientists intervening in the world of farm management decisions". This work offers a nuanced understanding of the reasons for limitations in DSS.

This paper aims to explore these developments through a critical review of the DSS literature with particular reference to how a cumulative tradition around DSS has emerged in Australia, and aims to advance theoretical development by introducing this new lens for analysis. The paper is a 'perspective paper' drawing on the literature and personal communications with researchers in Australia as part of an OECD Research Fellowship (2019).

Agricultural Decision Support Systems

The format of decision support depends on the extent of data aggregation and analysis, ranging from simple monitoring and alerts, online calculators to sophisticated models that provide scenarios for, or assess the effects of, different management options. In this paper we refer to the latter which are called DSS[3]. Meinke *et al.* (2001), refers to all DSS as 'normative' approaches of simulation based information provision, including software products and dissemination of such information via printed or Web-based media. Agricultural DSS are however mostly computer and internet-based information systems defined as typically software applications commonly based on scientific models describing various biophysical processes in farming systems and the response to varying management practices (Jakku and Thorburn, 2010). Lynch (2003) called these systems "intelligent support systems". These DSS are usually based on an understanding derived from a statistical- and/or process-based analysis of factors affecting crop outcomes such as yield (Stone and Hochman, 2004).

Over the last 40 years, significant resources have been devoted to the development of computer-based decision support systems (DSS) derived from cropping systems models (such as APSIM). Grain production is inextricably linked to the climate in Australia, and dryland farmers in particular encounter a high level of risk and uncertainty in their

[3] Models (the mathematical representation of a system) are distinguished from DSS (interfaces through which users access knowledge from a model).

agronomic decisions. DSS (with particular reference to plant available water in the soil) have aimed to support their decisions in this context (Freebairn, et al., 2018). DSS development in Australia has been funded, principally via public sector research initiatives (Federal and State Government) with external funding from the Grains Research and Development Corporation, (supported by producers via levies plus matching funds from the Federal Government).

Reflecting on DSS: what has been learned?

Extracting lessons from experience

As Woodward (2008) notes, the history of model based intervention in agriculture has been notably charted and analysed in a series of papers (Hayman, 2004; Nguyen *et al.*, 2006). Overall this literature can be characterised as reflective and formative, addressing the accumulated evidence that most DSS fail in the agricultural market place. Periodically authors suggest it is time for a reappraisal, or a reinvention, or as Cox (1996), who is highly critical, remarked, a "need to pause and think about current levels of R&D investment in information technology to support the management of agricultural production systems". Collectively this literature refers to the lessons that have been learnt through R&D (e.g. Pannell, 1996), Newman (2000) described the process of DSS development as "learning as we go", and Nelson remarks "while early expectations of computerised decision support systems (DSS) as the connecting vehicle between research and practice have gone mostly unrealised, some lessons have emerged from the attempts". Hochman et al. (2009) refer to the Yield Prophet DSS as being grounded in the learning from 18 years of exploring model-based decision support with Australian dryland farmers. Stone and Hochman (2004) ask "have we been asking the right questions?" and go on to say " We don't see DSS as a lost cause, provided that scientists learn hard-won lessons from their collective achievements and failures". McCown (2002) aim to improve understanding so that researchers "don't naively repeating earlier mistakes" While McCown et al. (2009) refer to "extracting learnings from experiences" and aim to interpret the rich set of experiences from the FARMSCAPE project, in ways that are meaningful for future action (or inaction). These observations follow previous earlier reflective and comprehensive accounts: EPIPRE (Zadoks, 1989) and CALEX-Cotton (Plant, 1997; Goodell et al., 1993).

Drawing on these experiences the literature also commonly refers to an 'emerging consensus' about how to tackle DSS limitations, or so called implementation challenges (Hochman and Carberry, 2011).

Of the many findings in this body of work, two key issues have been revealed that question the underlying assumptions of DSS. Firstly, users need to be involved in the tool development process to be effective. Secondly, and in connection to the first, tools are used more as learning than decision support tools.

Emerging consensus

A common failure of early DSS was that they were developed by researchers using their scientific paradigm, and so failed to take adequate account of user and other stakeholders' perspectives (Cox,1996). The importance of stakeholder involvement has long been noted, Nelson et al. (2002), for example, charts DSS research and development that has facilitated interaction between researcher and farmer back to 1980s (Hearn et al., 1981;Kingwell and Pannell, 1987;Woodruff, 1992). As experience grew the importance of involving stakeholder partnerships to improve relevance of research and analysis to decision-makers emerged as the key common theme in discussions on effective DSS. In line with this a body of work was built up describing the value of participatory DSS development from model- based intervention (Keating and McCown, 2001; Lynch, 2000 Newman, 2002).

One case of particular significance is the development in participatory design of DSS (Carberry *et al.*, 2002) in the farming systems section of CSIRO. The FARMSCAPE programme represented a new paradigm of DSS in that scientists explored, together with farmers and advisers, how simulation could be used as an aid to decisions about grain production inputs in variable climatic situations. This programme was unique in that it used qualitative evaluation and monitoring to reflect on the development process and outcomes, providing detailed longitudinal insights and socio-technical analysis of the approach (McCown *et al.*, 2009).

The development process involving stakeholders enabled an interactive approach which allowed the full extent of the model's capacity as a learning tool to be realised. This built on observations of the way the DSS were being used to support intuitive thinking or to adjust rule of thumb decisions (Long and Parton, 2012), which was contrary to scientists' expectations. A consensus grew amongst commentators that DSS have an important use that had been frequently overlooked: that they can be used heuristically, that is, as an instrument of discovery. Thus, DSS were seen to have the capability to act as a computer-aided learning device, rather than solely as a decision-making tool. In particular the use of models for simulation-aided discussion and exploration of alternatives or 'what ifs?' revealed their capacity for prompting learning (Keating and McCown, 2001). As reported "researchers were surprised to find that yield forecasting and tactical decision making, anticipated to be analyses that were both site- and season-specific forecasts, had served farmers as ''management gaming'' simulations to aid formulating action rules for such conditions, thus reducing the need for an on-going decision-aiding service" (McCown et al., 2012, p1)

Walker (2002) notes that "DSS can be designed to account for the fact that farmers prefer to rely on intuition and experience by deploying them as structured learning tools so that the decision process, embedded in the tools, can be learned, adapted and adopted by decision-makers". This is supported by a number of other commentators who agree that DSS should be designed to help users understand how things work (Stone and Hochman, 2004) or to educate farm managers' intuition (McCown et al., 2009). Scientists also saw the DSS as important for planning management strategies for a coming season to critically evaluate the full range of possible outcomes and the probability of achieving those outcomes. As such, as Hochman et al. (2009) noted, scientists aimed to put the analytical power of APSIM into the hands of growers and agronomists to produce simple "what if" scenarios rather than provide deterministic decisions.

Assessing management alternatives in this way facilitates knowledge communication between stakeholders. DSS have been observed to mediate social learning through collaboration and learning amongst stakeholders and with the development team (Jakku and Thorburn, 2010); to play a role in heuristic learning and network building around the land use policy and planning issues (Sterk et al. (2009); and capacity building when used in groups (Krueger et al., 2012; Voinov and Bousquet, 2010).

This view, that DSS were more about learning support than decisions per se, led to a reorientation or definition of DSS as broader initiatives of knowledge transfer. It also led to a realisation that, while most farmers did not routinely use DSS, many have adopted lessons learned from the information and dialogue they generated, and that their use might be more transient, with users stopping using tools once they had "learnt the principles" (Long and Parton, 2012). Understood this way, DSS became more supportive and relevant to the end-users' decision-making process (Hayman and Easdown 2002; Walker 2002), and allowed improved communication and collaborative learning (Allen et al., 2017).

Conceptualising DSS

This period of discussion and reflection has been accompanied by an evolution in thinking conceptually about DSS amongst interested scholars in Australia drawing on different bodies of international work.

Decision making

McCown (2002a,b) emphasised the need to learn from the broader history of DSS and Operation Research (OR)[4] pointing to parallels with the long recognised 'implementation problem' identified 50 years ago in OR (Ackoff and Sasieni, 1968) and from social and management theory. Drawing on this they re-examined the role of DSS in the farmers' decision space "when DSS attempt to tell managers what to do by presenting an optimal solution based on expected value or expected utility rather than help the manager satisfy their needs in a real-world situation which is uncertain, complex and unstructured. DSS should also attempt to support a continuous flow of behaviour towards a set of goals rather than a set of discrete episodes that involve choice dilemmas" (McCown, 2000a)

The challenges of dealing with the epistemological gap between science and practice, and integration of hard and soft approaches is taken up by critics of DSS. They point to the fact that tools are built on erroneous normative assumptions that science driven DSS fill the farm level 'information deficit', and some argue against the use of tools completely describing the proposed use of models in this way as a 'category mistake', that is, it conflates different categories of knowledge, and different ways of knowing (Cox, 1996). Contributions to this theorisation come from practitioners (Nicholson et al., 2015) and those interested in how digital tools fit into farmer wider learning environment (Starasts, 2015).

New ways of thinking

Systems perspectives have informed DSS thinking from early analysis (Macadam et al.,1990). Referring to information systems development, Newman et al. (2002) identified the variance between formal methodologies and the actual subjective needs of developers as a disjuncture between rational and technical approaches of hard systems and the mostly social processes involving multiple perspectives of soft systems approaches.

Farming Systems Research perspectives heralded new ways of thinking about DSS and reoriented the focus towards epistemological and sociological reasons as a way of explaining why model- based interventions were not successful (Keating, 2001; McCown 2001, 2002), The combined experiences of previous projects, and of the Farmscape project in particular, indicated that developing a successful tool from a crop simulation model requires "a collaborative effort between farmers and scientists in which the model is used as a device to assist in organising knowledge of the participants, rather than as a source of knowledge in itself" (McCown, 2009). Thinking this way McCown (2009)

[4] Operational research looks at an organization's operations and uses mathematical or computer models, or other analytical approaches, to find better ways of doing them (Operational Research Society, 2006).

claimed to have reinvented the concept of computerised support for farmers' management decisions, and that DSS could be invigorated through transdisciplinary approaches. Also drawing on systems frameworks, Hayman and Easdown (2002) used an ecological framework to explore the technical, social and management constraints on the use of the WHEATMAN tool.

This aligns with Cox's (1996) view point, that we should question the assertion that the primary benefit of this activity was the production of DSSs intended to aid routine decision-making at farm level. In this sense he asserted that the most significant contribution of early attempts at decision support were not the actual production of DSS, but rather the bringing together of researchers and farmers to improve farm management. At the time Power (2003) argued that this shift in ideology and approach of the modelling community could trigger new ways of approaching research and DTS development, indicating that DSS could be responsive to not only technological shifts, but also new ways of thinking.

This in turn inspired other work and commentary on participatory DSS (Jakku and Thorburn, 2010; Eastwood *et al.*, 2012), and has prompted calls for a wider view of decision support to encompass all forms of scientifically-informed decision support that takes away uncertainty; and to understand a decision not as a single event but as part of a whole farm management and adaptive learning. Jakku and Thorburn (2010) developed a conceptual framework for guiding the participatory development of DSS. They saw the model acting as a "boundary object", facilitating a connection between farmers and advisors, extensionists and researchers to co-create knowledge. Their vision of the model applications process was to "facilitate co-learning" rather than "produce answers" providing a "more sophisticated and humble vision of the benefits derived from modelling (Thorburn et al., 2011) compared with the used/not used framing of earlier evaluations" (McCown et al., 2002).

Evaluation and the concept of success

These theoretical developments have led some to question how DSS are evaluated. Cox (1996) for example argued that the appropriate criteria of success lie in the effectiveness of the DSS development process in bringing different points of view to bear on an issue of common concern, not in the need to run process models whenever a routine decision has to be made. Stone and Hochman (2004) using qualitative evidence, provided a more nuanced analysis of success beyond extent of adoption of DSS, and proposed a set of 'success factors' which would require a change in attitude by many DSS developers.

Building on insights from the literature more broadly (outside Australia) scholars have linked evaluating success to overall framing of DSS, their development and the way impact is assessed. For information systems research DeLone and McLean (1992) argued that the ultimate dependent variable is "success" but point out that the concept of success itself has not been adequately defined or explained in the literature. They proposed six major interdependent dimensions of system success: system quality, information quality, use, user satisfaction, individual impact, and organisational impact. These underpin assessment of DSS today, although the DSS literature in agriculture tends to have a particular concern about the former dimensions, focusing on design and performance, but paying less paid attention to the latter two. They argue that, "shopping lists of desirable features or outcomes do not constitute a coherent basis for success measurement" and that more research is needed on individual impact and organisational impact. Other scholars have identified the need to consider the wider settings that decision making operates in, and with respect to this, the absence to data on project planning or evaluation of outcomes (Matthews et al 2011). Allen et al (2017) use an outcomes-based Theory of Change approach in conjunction with DSS development to support, both wider problem-framing and outcomes-based monitoring and evaluation, and show how placing the DSS within a wider context can “contribute” to long- term outcomes. These conceptual insights can enrich our understanding of DSS success by positioning the notions of success in the contemporary evaluation literature (Berriet-Solliec et al., 2014). They also raises the question of how problems are represented and how traditions draw and re draw the boundaries around their systems of interest.

Building a Cumulative tradition

A cumulative tradition, conceptualised in the field of Information Systems, is achieved when researchers build on each other’s and their own previous work; definitions, topics and concepts are shared; there is some definition of orthodoxy, while unorthodoxy is not discouraged (Keen, 1980; Eom, 1995). Arguably a cumulative tradition has been emerging as DSS development moves towards a level of maturity on the back of increasingly rigorous empirical work, reflection and theorisation; and as a shared understanding about basic concepts and entities developed amongst a community of DSS developers and researchers. In Australia (and NZ) this has been characterised by reflection processes allowing an emerging consensus on the two phenomena discussed above, evolution in thinking in line with empirical findings and experiences, as well as questioning assumptions including how success might be conceptualised. Despite contested understandings of implementation issues persisting (Hochman and Carberry, 2011), and researchers addressing different aspects of success making comparisons difficult, the body of work suggests that a cumulative tradition has been achieved (Fig 1).

A critical question remains however and that is to what extent have the lessons learned been acted upon? Stone and Hochman (2004) suggest that the factors leading to ‘success’ or ‘failure’ of DSS are generic, and that the lessons learned from one or other DSS can be applied when considering developing or deploying another. However they point to “our [researchers] collective inability to have learned from it [the evidence that DSS fail]”, and that many scientists continue to develop and attempt to deploy DSS. A review in 2012 for GRDC might support this, finding that over the previous years at least 68 computer-based tools have been developed to support decision-making in the Australian grains industry. It concluded that many tools are still being developed without much evidence of uptake but that some tools have a long life of use and experience [5].

Hochman and Carberry (2011) suggested that lessons had been learned but not necessarily enacted. They set out to determine what lessons can be learned from the literature and from the recent experiences of champions of DSS development and delivery efforts; and then to ascertain whether these lessons are accepted and absorbed by the DSS community of practice in Australia. In a survey of these champions there was a lack of unanimous support for any of the propositions they had derived from a literature review and they took this to indicate that, “after more than 30 years of agricultural DSS development, any statement in this domain is still contestable”. However in a workshop held with a selection of the same participants they uncovered “encouraging signs that these DSS development efforts have benefited from lessons of past experiences”. The

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[5] In 2011, 21 tools were listed (Climate Kelpie, 2010) available for supporting farmers’ management of climate related risks and another six tools for use by researchers concerned with climate risk management in agriculture showing that tool development was still supported and an active part of R&D.

champions reached a consensus on the key recommendations for future DSS development. In their conclusions the authors note that achieving these requires the commitment of a critical mass of appropriately skilled people involved in the development of a DSS. A shift in evaluation approaches from assessing DSS functionality and usability towards assessing how DSS facilitate learning, discussions and decision making has also become apparent and is a promising sign (Starasts, 2018).

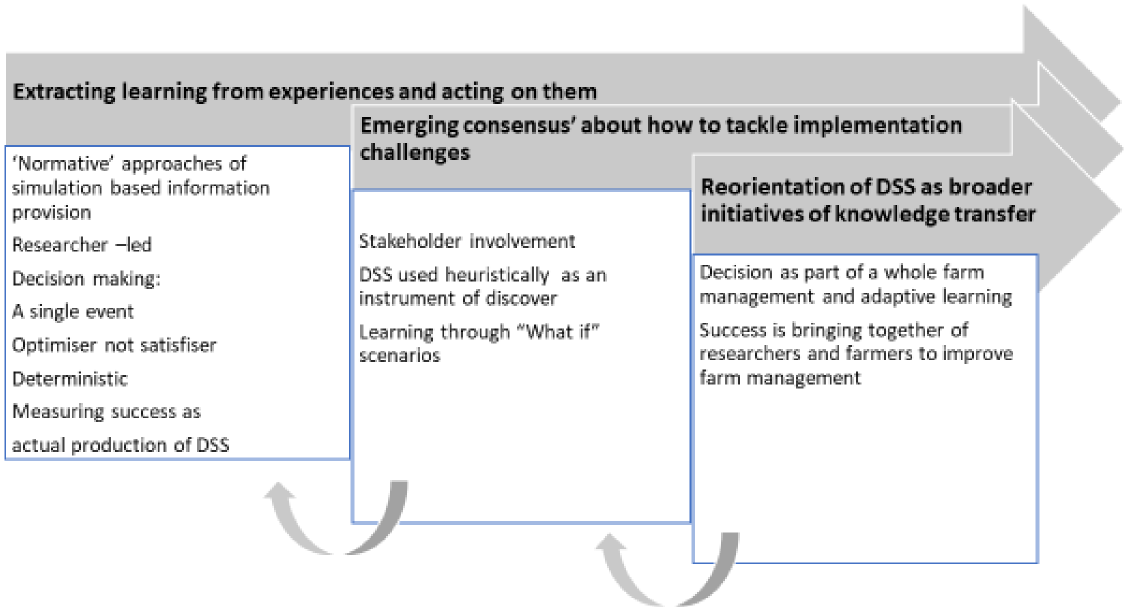

Fig 1 A Cumulative Learning Tradition in DSS

Organisational learning theory can potentially explain the difficulty in enacting lessons learned. Organisational learning is defined as a process of changing organisational actions through new knowledge and understanding, where learning involves mechanisms which link reflection and action. In R&D funding for DSS is often project based. Swan *et al.* (2010) question the value of project work in firms, which often occurs in iterations in an organisation, suggesting that even where there is significant learning generated within projects, there are often difficulties in capturing or translating this learning into new routines and practices at the level of the organisation. Their work suggests that firms generally only learn from projects, via the accumulation of experience amongst groups and individuals where the project context allows. This has some relevance to the research environment and the projectivisation of research projects arguably creating highly heterogeneous forms of learning which cannot always contribute to wider learning in organisations. It also questions to what extent the learning is embodied within the groups and individuals involved or whether it diffuses to organisations as a whole.

One way of capturing or translating learning into new routines and practices is to expand evaluation to include an explicit institutional[6] learning agenda to allow research managers to monitor and evolve new ways of addressing goals. From an Innovations Systems perspective, Hall *et al.* (2003) critiqued impact assessment research and argued that traditional assessment of 'success' needs to recognise systems of reflexive, learning interactions and their location in, and relationship with, their institutional context. Incorporating reflective approaches to assessing success and learning agendas as mechanisms to translate learning into new practices in organisations, could extend the concept of Cumulative Tradition to a Cumulative Learning Tradition.

New knowledge landscape

Australia's agricultural research, development and extension (RD&E) continues to be in a state of transition (Hunt *et al.*, 2014) and in need of reinvigoration, particularly given development in digital technologies (Ampt *et al.*, 2015; Eastwood *et al.*, 2017). Significantly the emergence of digital agriculture and big data heralds a radical change to the way growers are provided with, and access information, and make decisions. The impact of this disruption on the cumulative tradition of DSS in which researchers have built up a body of work, experience and learning deserves attention. While some see it as a threat and a loss of valuable diagnostic learning, other see opportunities for harnessing big data and the analytical powers of models to lead to a virtuous circle allowing a new generation of models and decision support (Capalbo et al., 2017).

Conclusion

We can argue that a cumulative tradition has emerged within the community of DSS developers and researchers. This has been characterised by reflection process allowing an emerging consensus as well as evolution in thinking in line with empirical findings and experiences. Enacting this learning could be enhanced with capturing or translating this learning into new routines and practices at the level of the organisation and extend this concept to a cumulative learning tradition.

[6] Institutions as distinct from organisations are existing sets of norms, rules, routines or shared expectations that govern actors' behaviour that determine how things are done.

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