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Review

USING decision models to enable better irrigation Decision Support Systems

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ABSTRACT

Many attempts have been made to enhance irrigation decisions using Decision Support Systems (DSS). These have met with limited success for many reasons, one of which is well known: that DSS encode decision rules (waterbalances, financial models) narrower in scope than the criteria farmers really use to make decisions, thus their advice is of limited value or perhaps entirely irrelevant.

To assist irrigation DSS designers build more flexible systems, we suggest they heed decision theory and decision modelling, separately from domain-specific DSS tasks. They may then find better ways of modelling real-world decisions which might allow for wider ranging sets of decision rules than previously.

To facilitate this, we review three different decision modelling systems and with each model the seemingly straightforward irrigation decision “How much should I water today?”. In doing this we show how they can assist with wide-ranging rule integration. The systems we chose are: Decision Modelling Notation (DMN) from the business analysis community; the Decision Ontology (DO), a Semantic Web modelling system; and Decision Modelling Ontology (DMO) a formal ontology from Information Systems Engineering.

We have determined that each of these modelling systems have useful aspects for irrigation DSS designers, which we list, but that they are not equally useful. Also, none of the systems provide designers with both the best modelling system and best technology & tools. We complete our work with a list of requirements for a future decision modelling system based on the intersection of the strengths of the systems investigated and our perceptions of irrigation DSS need. We believe a future system is possible to make and could serve irrigation DSS designers better than any current system.

In future work, we indicate what steps might be taken with existing systems to evolve them in line with our future system requirements. Finally, we conclude with a summary of our findings.

1. Introduction

Designers of Decision Support Systems (DSS) for agriculture and the more specialised field of irrigation have long been able to prove that they can improve decision outcomes for users (Car et al. 2012), this author and more recently (Giusti and Marsili-Libelli, 2015), among many others). Despite this, (Mackrell et al., 2009) present a long list of publications by DSS designers lamenting uptake in Australia, especially amongst small business irrigators.

Deep analysis of this seeming paradox has been undertaken within Australia (McCown et al., 2006) and, also internationally (Matthews et al., 2008) since this problem is identified world-wide. Technical and social researchers within Australia have made multiple efforts to understand irrigation decision making there, specifically (Jakku and Thorburn, 2010), (Montagu et al., 2006), (Whittenbury and Davidson, 2009). Reasons given for this paradox include a perceived research practice/farming practice gap, socio-technical perceptions of trust and limited on-farm technology access.

One aspect of many of these reasons that is easily understood is the narrowness of DSS' decision logic compared with 'real world' decisions which forms part of the practice gap. DSS, such as that described in (N J Car et al., 2012), base their support on biophysical models only, not the much wider set of influences on a farmers' irrigation decision making that are well known, thus even when the DSS assist with better biophysical outcomes, they may be of no or negligible benefit to an irrigator overall. Possible technical DSS design methods to address this narrowness, specifically for irrigation DSS within Australia, have been proposed previously (Car et al., 2009; Car and Moore 2011b, 2011a) but few built. The methods proposed in these system designs focus on standardising data source representation for easier DSS data consumption, thus enabling the building of better capacity within the DSS's internal systems or interface to cater for a wider range of decision influences.

In this paper, we step away from explicit DSS design and irrigation DSS-relevant data management to review the state-of-the-art of formalised systems for modelling decisions themselves. We do this because

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we believe that many irrigation DSS that have been built, including some by this author, have not leveraged good knowledge of how decisions are actually made which is decision theory.

In Section 2, we give a few notes on the history of decision theory; how its use presents us with the opportunity of exploring new ways to assist with irrigation DSS adoption and our criteria for choosing the systems we reviewed.

In Sections 3, 4 and 5 we present reviews of the three decision modelling systems followed by a general discussion about the systems with direct comparisons in Section 7. We also present what we believe to be sensible requirements for a future decision modelling system. Finally, in Section 9, we conclude with a summary of our review findings and our reasons for proposing requirements for a future system for irrigation DSS designers' use.

2. Decision theory and computerised decision making

Decision theory – theory about decision making – as a philosophical or academic discipline has some of its roots at least as far back Aristotle's systematic investigations in *Prior Analytics* (Aristotle 350AD). The more statistical elements of decision theory stem from at least the 18th and possibly the 13th centuries CE (Wallis, 2014).

2.1. Decision logic

Logic and reasoning have received continued interest since Aristotle with many philosophers contributing including Averroes in the 12th C with extensive comments on Aristotle's work (Averroes 12th C). Averoes defended decision logic against his contemporaries who sought to rely on non-logical decision making, such as direct instruction from religious texts (Belo, 2016). In the 17th C *term logic* was introduced (Arnauld and Nicole, 1662) using rigorous semantics for logical propositions and requires differentiation between instances of things and concept classes of possible instances (Buroker, 2014). Such structured semantics and class/instance differentiation are particularly important for modern decision modelling systems. Philosophical logic has since become more suitable for automated reasoning with works by mathematical and early computational luminaries, including Leibniz, Boole (of "Boolean" logic) and Russell yielding the reasoning mechanism used currently by computers. This history of codifying logic has moved from ambiguity to certainty in the expression of decision concepts and from qualitative to quantitative processes for calculating decision outcomes.

Sets of logical propositions expressed for decision making – "decision rules" – can be used to calculate a result given a particular set of inputs; a "decision scenario". Collections of such rules were introduced to computer processing relatively early in the field of computer science, 1960s at least, with programming language extensions such as FORTAB (Armerding, 1962) useing "decision tables" and enabling calculations with them. Many modern programming languages still implement FORTAB-style tables, for example, current versions of the popular Python programming language contain a module called *decisionTable* (Uroš, 2015).

2.2. Decision processes

Theories for procedural decision making and scenario representation – not the formalised logic of weighing choice elements – are often reported as having been started by the Marquis de Condorcet drafting the French constitution of 1793 (Hansson, 1994), specifically his essay on voting systems (Condorcet, 1785), however some sources indicate a 13th century origin (Wallis, 2014).

General, systematic, procedural methods to assist individual decision making were proposed in the early 20th century by Dewey (1910) who suggested segmenting deciding into "five logically distinct steps":

(i) a felt difficulty;
(ii) its location and definition;
(iii) suggestion of possible solution;
(iv) development by reasoning of the bearings of the suggestion;
(v) further observation and experiment leading to its acceptance or rejection; that is, the conclusion of belief or disbelief.

Computer-based systems designed to systematically progress through scenarios ("states") have existed from the 1940s with models such as *finite state machines* (Aziz et al., 2014). Modern programming environments that are effectively finite state machines, such as Microsoft's Windows Workflow Foundation (Chappell, 2009), have been used in Australian irrigation DSS (Inman-Bamber and Attard, 2007) and likely many others DSS use of similar tools.

While state progression, decision logic and process flow are fundamental to modern computer operations, systems designed to model human decision making specifically, with steps similar to Dewey's, have come to exist only more recently. The three systems represent some of the earliest decision modelling-specific computational systems.

2.3. Recognising where decision theory might assist

One of the reasons for irrigation DSS's narrowness is the difficulty DSS designers have in "bolting together" seemingly incommensurate units of logic. For example, waterbalance and personal effort considerations relating to the decision "How much should I water today?" do not easily lend themselves to being optimised in standard equations. By considering both the logic and process aspects of decision theory, as outlined above, we hope to assist with this "bolting together" problem and others related to it.

Another well-recognised "gap" problem is that of on-farm DSS access (timeliness and ease of DSS use) that does not match laboratory conditions. While DSS have been built to cater for outdoor farming life and ease of use (Hornbuckle et al., 2006) and close-to ubiquitous support for computerised DSS has been realised in some locations (viz. Internet & mobile technology use in Australian households 2008–2015 in (Australian Bureau of Statistics, 2009) and (Australian Bureau of Statistics, 2016)) decision theory may indicate better ways of staging DSS use or incorporating it into daily farming life.

Systematic, system-independent, decision representation using decision theory may also allow an irrigation knowledge base to be created which may assist in establishing decision best-practice.

2.4. Decision modelling system selection

Here we look to computerised expressions of decision theory only so to directly incorporate its lessons into future DSS. Multiple computerised decision theory-based systems exist and we explore three in this paper:

1. Decision Modelling Notation (DMN)
2. The Decision Ontology (DO)
3. The Decision-Making Ontology (DMO)

These systems represent decision logic and processes in system-independent and standardised ways. The first system, DMN (Object Management Group, 2016), is the most widely adopted decision modelling system we could find. It has a large, professional, user base and support network, mainly within the business analytics community. The second, DO (Nowara, 2017), while still in development and with a negligible user base, has been developed under the auspices of a rigorous and renowned information standards body, the World Wide Web Consortium[1]. The third, DMO (Kornyshova and Deneckère, 2010), has had many years of rigorous academic development within a non-

[1] https://www.w3.org