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A methodology for eliciting, representing, and analysing stakeholder knowledge for decision making on complex socio-ecological systems: From cognitive maps to agent-based models

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ABSTRACT

This paper aims to contribute to developing better ways for incorporating essential human elements in decision making processes for modelling of complex socio-ecological systems. It presents a step-wise methodology for integrating perceptions of stakeholders (qualitative) into formal simulation models (quantitative) with the ultimate goal of improving understanding and communication about decision making in complex socio-ecological systems. The methodology integrates cognitive mapping and agent based modelling. It cascades through a sequence of qualitative/soft and numerical methods comprising: (1) Interviews to elicit mental models; (2) Cognitive maps to represent and analyse individual and group mental models; (3) Time-sequence diagrams to chronologically structure the decision making process; (4) All-encompassing conceptual model of decision making, and (5) computational (in this case agent-based) Model. We apply the proposed methodology (labelled ICTAM) in a case study of viticulture irrigation in South Australia. Finally, we use strengths-weakness-opportunities-threats (SWOT) analysis to reflect on the methodology. Results show that the methodology leverages the use of cognitive mapping to capture the richness of decision making and mental models, and provides a combination of divergent and convergent analysis methods leading to the construction of an Agent Based Model.

1. Introduction

Managing complex socio-ecological systems, such as occur in water resource management, is a multi-actor, multi-scale, and dynamic decision making process:

- Multi-actor: actors (e.g. resource consumers, policy makers, managers) employ different strategies and decisions to satisfy their goals and interests. Goals, preferences, and perceptions of the resources differ across and also within actor groups. Such heterogeneity cannot be represented by an average actor for each group, which makes agreements on resource management more difficult to reach (Barreteau et al., 2001; An, 2012).
- Multi-scale: the complex behaviour of socio-ecological systems is strongly driven by the collective outcomes of decisions made by actors at multiple levels of the system (e.g. individuals, group, organizational). For example, regulations (among other factors) affect individual behaviour, and individual behaviour affects the resource state (Chave and Levin, 2003).

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- Dynamic and constantly adaptive: the goals and decision rules of actors change over time. Actors adapt to changes by learning from experience (Sterman, 2000).

This work is motivated by the need to understand and incorporate human elements (e.g. perceptions, decisions, and actions) into decision making and modelling in complex socio-ecological systems (Janssen, 2002). This need has been supported by findings in a range overlapping fields related to decision support for complex socio-ecological systems, such as: evidence-based planning, systems resilience, social learning, risk management, decision science, and Agent Based Models (ABMs). Their argument can be summarised in four points.

First, people's decisions and actions influence resource use directly and indirectly. To change resource-user behaviour and influence the resource dynamics, policies need to understand and target factors that influence how people make decisions, how their decisions affect the biophysical environment, and the feedback effects on future decisions. As Ludwig et al. (1993) point out managing natural resources is about managing people rather than the resource. Failure to account for micro-level decision making in designing policies may result in policy-resistant situations where the system's response to the policy implementation defeats the design purpose (e.g. increase in water prices to manage demand may lead to an increase in water use by increasing illegal connections to the supply system). In the resilience literature, understanding and unlocking human elements is a key mechanism for building the adaptive capacity of socio-ecological systems to withstand shocks, and to transform to more resilient futures (Vespignani, 2012).

Second, decision making (intuitive and deliberative) is influenced by the implicit and explicit theories that individuals and groups have about how the world works, should work, and the effects of actions on things they value (Argyris and shön, 1978). When individuals and groups make decisions to satisfy their own short term personal interests, this may often lead to long term resource overexploitation and the collapse of dependent economic and ecological systems, a situation commonly known in natural resource management as resource dilemmas (Moxnes, 1998). Explicitly expressing decision making and underlying assumptions, in a transparent way, gives decision makers an opportunity to: reflect on their practices, explicitly link actions and effects, and see the rationale behind other's practices. This fosters individual and group learning, and improves the prospects for communication, negotiation, trust-building, and hence, collective action (Pahl-Wostl et al., 2007).

Third, whereas there is a wide recognition of the role that integrated modelling and decision support tools can play in informing policy making and stakeholder communication, they are often criticised for their limited capacity to address the sheer complexity of the human and social dimensions of complex systems (Döll et al., 2013). There have been calls to move beyond simple treatments of human response as an input model scenario, or single parameter, and simplistic rational assumptions about human cognition and behaviour (Pahl-Wostl, 2007a). Forrester (1992) argued that it is not sufficient to model a "particular decision", but modellers need to capture and represent the decision rules or guiding protocols that generate a flow of decisions.

Finally, to increase a model's perceived utility and adoption of results, in particular for non-experts, modelling needs to link to the user's "reality", that is, their description of how the system works. If end users cannot see the relevance of the model to their daily practices because the model is opaque, and/or the model collides with how they think and act, there is a greater chance that users will end up losing confidence in the model. Therefore, there is scepticism in some modelling literature, for example (Sterman, 2000), of the utility of models that embody decision rules that are not based on empirical study of actual decision making.

A key challenge for addressing these needs is bridging the gap between capturing the highly qualitative, subjective and rich nature of people's thinking and translating it into formal quantitative data to be used in decision support tools (Kok, 2009). In light of this, the contribution of this paper is to present a step-wise methodology for bringing in the perception of stakeholders (qualitative) into formal simulation models (quantitative) with the ultimate goal of improving learning and communication about decision making in complex systems. This paper has three main objectives:

- Present the methodology (ICTAM) to elicit, represent, and understand individual decision making. It combines a qualitative/soft problem structuring technique (i.e. cognitive mapping) and numerical models, in this case ABMs.
- Use a case study to understand land and water use decision making in that context, viticulture irrigation, and draw wider lessons from it.
- Reflect on the use of the methodology, using strengths-weakness-opportunities-threats (SWOT) analysis.

The paper is organised around the above objectives. In the next section, we present the concepts and methods that we use in developing and implementing our methodology. In Section 3, we present the step-wise methodology. In Section 4, we use a case study to demonstrate the proposed methodology. We reflect on the design and implementation of the process in Section 5.

2. Concepts and methods

2.1. Decision making and mental models

Decision making theories are broadly classified into normative and descriptive perspectives. Classical decision theories articulate how people "should" make rational decisions. On the other side, descriptive and behavioural decision theories describe how people actually make decisions under inevitable limitations (e.g. information, cognitive, and time constraints). The latter perspective is especially vital for environment management where actor's decisions and actions substantially influence the resource behaviour and outcomes of management policies (Viscusi and Zeckhauser, 2006). Instead of cherishing normative assumptions about how a policy will work, effective planning needs to be informed by an understanding of how actors actually make decisions, and how their decisions may affect and be affected by changes in resource state and planned policies.

Mental models are a descriptive decision theory for explaining how people make decisions based on how they perceive their surrounding world (Craik, 1943; Johnson-Laird, 1983). They are cognitive constructs that people use when perceiving and interpreting information as a basis for decisions and behaviours. Mental models have the following features (Rouse and Morris, 1986). They are:

- subjective;
- encompassing of our ideas, perceptions, and beliefs about how the world works, e.g. cause and effect links;
- incomplete, flawed, and sometimes inconsistent, representation, especially when representing complex systems;
- context-specific and dynamic; people build their mental models based on a particular situation at a particular point of time. As time passes and context changes, people perceive new information, and update their mental models;