Evaluating simulation-derived scenarios for effective decision support

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Scenario planning traditionally relies on *qualitative* methods to choose its scenarios. Recently, *quantitative* decision support tools have also begun to facilitate such choices. This study uses behavioral experiments and structured decision-maker interviews to evaluate the results of "scenario discovery," a quantitative method that defines scenarios as sets of future states of the world in which proposed policies fail to meet their goals. Statistical cluster-finding and principal component algorithms applied to large databases of computer simulation model results then help users to identify such scenarios. The two experiments examine the results of this process and demonstrate a user preference for increased accuracy and simplicity achieved through rotating the space of uncertain model input parameters, but primarily when the rotated parameters are conceptually similar. Interviews with experts suggest utility for both qualitatively- and quantitatively-derived scenarios. The former were easier to understand and had the most utility for scoping. The latter were perceived as containing more relevant information and having more utility for understanding tradeoffs and making choices among them. Overall, this study suggests the value of quantitative tools for facilitating scenario choice, while also highlighting the importance of formal evaluation in judging the utility of new methods for decision support.

1. Introduction

Scenario planning has long helped decision makers manage in the face of an uncertain future [1–3]. Traditionally, such planning exercises have largely relied on *qualitative* methods to choose their scenarios. In particular, the commonly-used intuitive logics approach [2,4] uses expert judgment, often assembled in participatory exercises with stakeholders, to identify the scenarios and their key driving forces [4]. Recently, to address challenges to the effective use of scenarios (described in more detail below), researchers have begun to employ *quantitative* decision support tools to facilitate an empirical approach to the choice of scenarios. This paper aims to evaluate, using behavioral experiments and structured decision-maker interviews, the ability of one such method, called scenario discovery, to perform this function.

From the beginning, scenario practitioners have assembled data to help inform the judgment and creativity of those involved in the scenario development process. For example, practitioners have long been using exemplar runs of computer simulation models to flesh out scenario logics and demonstrate scenarios' internal self-consistency in what has since become called a "story and simulation" approach [5]. But the fundamental steps of scenario choice and design have long rested on human intuition unaided by any quantitative tools.

In recent years this has begun to change. Researchers have proposed an array of quantitative decision support tools that run computer simulation models many times and then use this information to inform the choice of a small set of scenarios [2,6–8]. For instance, Schweizer and Kriegler [9] use cross-impact analysis to measure the consistency of scenarios. Using their approach, they recommend augmenting a commonly-used,

story-and-simulation set of greenhouse gas emissions scenarios with additional members that represent combinations of driving forces very different and more self-consistent[1] than those originally proposed. Other groups have proposed quantitative methods that help identify sets of scenarios that are maximally diverse over a set of important attributes [10,11]. Growing interest in such quantitative decision support for choosing scenarios has been driven by improved capabilities of computer decision support tools, the literature on the potential shortcomings of purely qualitative methods of scenario development [12–14], and improved understanding of how to use such tools to facilitate decision making. In particular, this decision support literature emphasizes the importance of evaluating decision-support processes and tools.[2]

This study focuses on evaluating the ability of "scenario discovery" [15–17], a particular form of computer-assisted scenario development, to support effective decision processes.

1.1. What is scenario discovery?

The literature describes different types of scenarios. Of particular relevance here, some taxonomies distinguish exploratory [18] or problem-focused [19] scenarios from normative [18] or solution-focused scenarios [19]. The former aim to help decision makers understand the contours of a problem and to see it in new ways [20,21]. The latter aim to help explore and compare potential solutions to a decision problem.

Scenario discovery rests on a solution-centered formulation. The approach defines a scenario as a set of future states of the world that illuminate vulnerabilities of a proposed policy, that is, futures where a policy fails to meet its goals.[3] Scenario discovery uses analytics to implement this concept. The approach begins with a computer simulation model that projects a policy's performance, using one or more outputs of interest, contingent on various uncertainties in those inputs. The model is run many times over an experimental design that samples different combinations of values for the uncertain model input parameters. Some criterion applied to the model outputs distinguishes those cases where the policy fails from those where does not fail. Statistical data-mining algorithms applied to the resulting multi-dimensional database then identify combinations of constraints on a small number of input parameters that best identify the cases in which a policy fails.

In essence, scenario discovery uses cluster analysis to project large, multi-dimensional databases of hundreds or thousands of simulation model results onto two or three-dimensional spaces, suggesting both the most important axes to define those spaces and the regions of most interest to decision makers. The

approach has recently been employed in a range of research studies [22–30] and organizations such as the U.S. Bureau of Reclamation [31], World Bank [32], and Metropolitan Water District of Southern California [33] have begun to incorporate the approach into their planning activities. The concept of scenarios that illuminate vulnerabilities has also become more common in the literature [34].

Scenario discovery was developed to address shortcomings of qualitative scenario processes [13,35], which in particular appear when scenarios are used in contentious public policy debates [15,36]. Specifically, scenario discovery aims to help generate scenarios whose meaning is unambiguous and which are difficult to reject as arbitrary or biased, even in situations where participants have strongly divergent views about what futures are most important, likely, hopeful, or interesting. These attributes are intended to enable the products of scenario discovery to contribute more effectively to a choice among decision options.

Scenario discovery also aims to serve an exploratory role by identifying futures in which a policy performs unexpectedly well or poorly [37,38]. In particular, when used to support a robust decision making decision support process, scenario discovery aims to explicitly separate choice and decision structuring tasks [15]. This separation provides a means to include probabilistic information in a scenario analysis to facilitate the comparison of alternative decision options (a choice task), without also undermining scenarios sense of possibility, not prediction, that makes them less threatening to individuals' holding worldviews potentially inconsistent with the scenarios' implications [39]. This latter attribute is central to scenarios' exploratory role, allowing them to expand the range of futures and options decision makers consider (a scoping or decision structuring task).

1.2. Evaluating scenario discovery

This paper aims to systematically evaluate these claims about scenario discovery, and in particular whether the approach can help organizations deal with deep uncertainty and complexity [39], in a way that is unambiguous and not seen as arbitrary, while at the same time avoiding unreasonable cognitive difficulty [see, e.g., 40]. A set of behavioral experiments largely focus on the interpretability of such scenarios, that is, whether the cluster finding algorithms and associated displays actually communicate the information they are intended to convey. Notably, the experiments test whether the scenarios convey this information in a fashion that reduces cognitive difficulty and increases understanding, two critical barriers to effective decision support [41,42]. Structured interviews with decision makers largely focus on utility, that is, the extent to which the scenarios perform the functions they were designed to serve.[4] Specifically, the interviews aim to test the extent to which scenario discovery generates scenarios

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[1] In the literature on scenarios, self-consistent refers to a scenario that does not contain clearly contradictory assumptions. For example, a scenario that assumed both high oil prices and high oil consumption might be judged inconsistent if it also lacked any factors that explained this dissonance.

[2] Decision support is defined here as organized efforts to produce, disseminate, and facilitate the use of data and information to improve the quality and efficacy of decisions.

[3] More generally, the concept also defines scenarios as sets of futures where a policy meets its goals, performs better or worse than some other policy, or meets some other criteria relevant for a policy analysis. For simplicity, this paper will focus on scenarios illuminating futures where a policy does not meet its goals.

[4] As described in more detail below, interpretability may be considered one aspect of usability, or whether or not it is feasible to use a scenario, if one wishes to do so. This, in turn, may be considered a necessary condition for overall utility, which has to do with the extent to which the scenarios contribute to effective decision support. This terminology is consistent with that of the National Research Council (2009), which describes effective decision support as increasing usefulness of the information, improving relationships between knowledge producers and users, and promoting better decisions.[43].