Framing Energy and Environmental Planning Problems Using Many Objective Robust Decision Making

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Background: Long-term energy planning requires decision makers to incorporate predictions about highly uncertain futures in many areas such as natural resource costs, multi-sector demand, implications of international politics, and policy changes. It is common to try to quantify probable scenarios for all of these futures and attempt to plan infrastructure and operations that perform well in specific scenarios. In reality, the future is so deeply uncertain that even if a plan is developed to meet a standard in several scenarios, planners still do not have information about how the plan performs over the vast array of possible states of the world (SOW). For example it is difficult to use structural modeling to predict how energy prices will develop over long periods of time [1], so it is likely that a small number of scenarios of price trajectories will fail to capture the true performance under long planning horizons. Additionally, using a small number of pre-defined scenarios does not link the *creation* of scenarios to system performance under these scenarios. Small changes in some of the scenario values (e.g. energy price) could cause massive changes in the key measures of system performance.

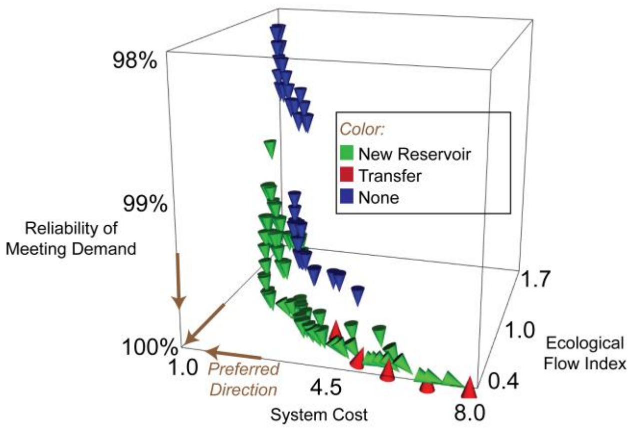
Many objective robust decision making (MORDM) offers a framework for exploring how robustly candidate solutions (plans) perform by subjecting solutions to thousands of combinations of possible SOW and discovering SOW in which the solutions perform poorly [2] . Performance is characterized by multiple objectives such as reliability of meeting demand, level of GHG emissions, cost, etc.

The framework begins with linking a multiobjective evolutionary algorithm (MOEA) to a simulation model to efficiently propose and evaluate alternative solutions in many objectives. This eliminates the need for planners to determine priorities between their performance goals *a priori*, such as claiming they prefer minimizing cost over minimal GHG emissions. The result of MOEA runs is a Pareto-approximate tradeoff set of solutions that balance the multiple objectives. The entire suggested Pareto-approximate solution set is then simulated under a broad range of possible SOW. In these new model runs the performance of each solution is again evaluated in many objectives, for each possible SOW. Plots of robustness can be created, which show to what extent solutions' performance degrades under the extreme SOW. These plots can be used to suggest which of the candidate Pareto approximate solutions to select for further study.

A second area of focus is characterizing which values of the SOW cause unacceptable performance in one or more objectives. MORDM uses statistical techniques to "discover" these critical SOW. Results of this technique enable planners to learn which uncertainties their solutions are more susceptible to and which do not pose a performance threat. These steps of MORDM build on techniques from the robust decision making literature [3]. Once these robustness tradeoffs are understood, solutions that can be proven to minimize risk are chosen or the uncertainties that cause the greatest risk and magnitude of poor performance can be hedged against in existing systems.

Contribution to Scenario Analysis: The motivation for MORDM is that planners may not know or fully agree upon the most important driving factors of their system, or their preferences between conflicting objectives. MORDM therefore provides *a posteriori* decision support that uses interactive visualizations to show planners the conflicts between objectives, how robust solutions' performance is to deep uncertainties, and the most important uncertain factors for their systems.

The MOEA is used to automatically suggest combinations of management strategies that are appropriate for a system. These management strategies can themselves be considered "scenarios" that can be examined by decision makers. The figure shows a sample result from a prior water resources infrastructure planning study [4]. In the figure, each cone represents a new portfolio of infrastructure for the system. Spatial axes show performance measures, while the color indicates a critical planning decision (whether to build a new reservoir, enact a given transfer scheme, or do neither). Such a plot could be extended to energy planning, where the colors would indicate whether new renewable technologies were enacted or not.



Finally, our presentation will provide a complement to Prof. Lempert's keynote speech. MORDM contributes to the robust decision making literature by including a method to generate new plans and evaluate them with respect to multiple objectives. Approaches such as MORDM support a "bottom up" approach to performing scenario analysis, linking the creation of scenarios to multivariate measures of system performance.

Outline of Presentation: The presentation will begin by reviewing the MORDM concept and an example application to risk-based water portfolio planning in the Lower Rio Grande Valley (LRGV) in Texas, USA. In the LRGV, we develop portfolios of market-based and traditional supply instruments for a single city in an arid region. The city's market instruments use thresholds based on expected supply and demand, enabling us to consider different risk thresholds based on supply and demand variability. Performance in the LRGV model is based on Monte Carlo simulations of uncertainty, and the performance measures (e.g. the variability of cost) are similar to what would be done in energy planning. Computational scenario discovery within MORDM yields scenarios of uncertain factors for the LRGV; the results suggest that high evaporative losses are a critical uncertain factor for future planning.

The second half of the presentation will suggest future avenues of research to apply and extend MORDM to the energy domain, focusing especially on the nexus of energy and water planning. Components of an illustrative problem formulation will be suggested, including decision levers (factors that can change in a system), quantitative performance measures, relationships (how to map actions to outcomes) and uncertainties. We are open to building new collaborations and featuring new work in the proposed special issue that will result from the IQ SCENE workshop.

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