Decision Making under Uncertainty:

Introduction to Structured Decision Analysis for Performance Assessments

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(and lots of others at Neptune)

Improving the quality of environmental decision making.
This is our Perspective

• We like to be objective
• Currently, radioactive waste disposal is an obstacle to the nuclear industry
• A paradigm shift is needed for better decision making
• We think this is important if we want to make better (optimal) use of our limited resources
• We think this is important if we want to defensibly support the nuclear industry
• We think this is important if we want to help future generations
Overview

• Why a decision analysis approach might be helpful:
  • Brief historical PA context – what and why
  • Possible paradigm shift – what and why
  • Decision analysis overview
  • A decision analysis framework tool
  • Some applications
  • Research needs
  • Summary
Why Do PAs Need Improvement?

• Traditionally, PAs have supported the *status quo*
  • Focused on demonstrating compliance rather than on optimal decision making
    (for disposal, closure, long-term management)
  • Mis-applied conservatism leading to
    • poor (sub-optimal) decision making
    • unnecessarily increased costs
    • opacity to stakeholders (and to reviewers)
  • Difficult to communicate and defend
Past Approach to PA

• Fate and transport modeling
  • Process-level modeling
  • “East coast” mentality – groundwater focused
  • Insufficient coupling of processes

• Deterministic for low-level waste
• “Conservative”
• Default receptor scenarios
• Aimed at compliance

Initiated about 30 years ago without the technology available today
Improved Approach to PA

• Fate and transport modeling
  • Systems-level modeling (supported as necessary)
  • Consider all pathways & coupling of processes
• Move towards probabilistic (not fully there yet)
• Still too conservative (but better)
• Some consideration of site-specific scenarios
• Some consideration of site management
  • But not optimization yet

*We learned in the past 30 years – we applied some of what we have learned, and there is further to go*
• Revisions to 10 CFR 61 and 435.1 don’t get us there
Focus Order of Current Approach to PA

1. Science (fate and transport modeling focus)
   • Hydrology, hydrogeology, geochemistry, soil science, plants, animals, etc.

2. Risk/dose assessment
   • Human health – risk or dose
   • Ecological risk

3. Statistics and Decision Analysis
   • Bayesian for decision modeling

4. Stakeholder engagement/communication
Re-thinking – Change Focus

• Holistic approach to solving decision problems
• Decision focused – top down – a paradigm shift
  1. Stakeholder engagement/communication
  2. Statistics and Decision Analysis
     • Bayesian for decision modeling
  3. Risk assessment
     • Human health and ecological risk
  4. Science
     • Hydrology, hydrogeology, geochemistry, soil science, plants, animals, etc.

_all aspects are important, but the ordering has shifted_
Decision Risk
Potentially Unacceptable Health Risk
Radioactive Waste Disposal Example
More complicated risk problem?
Decision Analysis for PA (and other complex environmental decisions)

• Decision Analysis can provide a different approach to the way in which Radioactive Waste Disposal is considered/evaluated
  • A “Paradigm Shift”
  • A “Revolution”? – really an “Evolution”

• Some environmental programs are moving forwards in this regard (e.g., EPA sustainability, watershed management and land use programs)

• Food safety is moving in this direction (FDA)
  • Although both NRC and DOE have previously performed cost-benefit analysis (using population risk)
Why Does PA Need a Makeover?

If we want nuclear industries, then we need to:
• Make the best use of our existing disposal facilities
• Move beyond compliance determinations
• Optimize use of ever more scarce funding
• Remove conservatism
  • over-engineering, creating problems that do not exist
  • use “reasonable realism” – will improve communication

So, stop wasting money

* nuclear industries (which really means the current generation of tax payers) foots the unnecessary bill*

and maximize benefits to all stakeholders
Decision Analysis – Basic Principles

• Decisions are made by evaluating decision risk
• Human health and environmental risk are components of decision risk for some types of problems (environmental, food)
• Some decisions should be made with respect to populations rather than individuals
• Decision risk decreases with time (social discounting) – need “insurance” to address possible future concerns
• Modeling is performed in the context of decision risk
Thoughts?

• “All models are wrong, but some are (hopefully) useful” (George Box, 1979)
• “Models should be as simple as possible and no simpler” (Morgan & Henrion, 1990)
  • Smarter tools, not bigger ones
  • 10 commandments of policy/risk analysis
• Remove “conservatism on top of conservatism on top of conservatism....” – otherwise GIGO
• Radioactive waste management tail is wagging the nuclear industry dog
  • and we still have legacy waste to deal with
Perspectives

- Environmental problems are diverse, however...
- ...the basic **process** for finding solutions should be the same
  - Past efforts, such as DQOs, tried to address this
- Regulations and guidance essentially developed 30+ years ago
  - I.e., we can benefit from 30 years of changes in technology, improved methods, and lessons learned
- Obstacles?
  - Difficult to change regulations/guidance
  - Old dogs; new tricks
Lessons Learned

• There are some difficult environmental risk-based problems
  • Thoughtful solutions are needed for good decisions
    • This requires effort
  • Conservatism often leads to poor decisions
  • Deterministic models do not allow uncertainties to be evaluated properly
  • Decision objectives should drive modeling needs
  • Solutions should be site-specific
    • “Cookie cutter” solutions don’t work
  • Stakeholders should be involved throughout
    • Stakeholder values should be included
Site-specific Decision Making

Site-Specific Exposure Scenarios can make a difference in distinguishing site performance.
Problems of Conservatism

There is conservatism in
- regulations and guidance
- performance objectives
- deterministic modeling (and modeling tools)

Conservatism on top of conservatism on top of conservatism...

The resulting dose and risk calculations
- might not actually be conservative because of competing influences, and
- cannot be meaningfully interpreted probabilistically or for decision making

It is fine to make conservative decisions, but not to make difficult decisions based on “conservative” models.
ALARA opens the door

10 CFR 20.1101(b) requires that:

“The licensee shall use, to the extent practicable, procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are as low as is reasonably achievable (ALARA).”

ALARA implies objectives, implies values, and implies decision analysis
Decision Analysis for PA

- PAs should be decision tools
- Decision-focused, addressing
  - stakeholder values, costs and benefits
  - uncertainty (with probabilistic modeling)
- Sustainable – 3 pillars of sustainability
  - economics, environment (ecology), society
- Transparent
- Defensible
- Adaptive depending on meeting objectives
  - consideration given to compliance
What is Decision Analysis?

• “Formalized common sense”
• A set of tools for structuring and analyzing complex decision problems
• An approach for making logical, reproducible, and defensible decisions in the face of:
  • Technical complexity
  • Uncertainty
  • Costs and value judgments
  • Multiple, competing objectives
Stakeholder driven Decision Analysis

• Actively **involve** stakeholders, customers or users at **all stages** of the decision analysis process (instead of only at later stages, which is more typical)

• **Identify** objectives, decision options, and events that **define** the decision analysis

• Clearly **communicate** judgments about costs and values, uncertainty (probabilities), and risks
Decision Analysis Cycle

- Identify objectives and decision options
- Build a model with available information
  - Probabilistic model (uncertainty)
  - Costs and value judgments
- Evaluate model – uncertainty analysis
- Perform sensitivity analysis and value of information analysis
- Can decision be made or should more information be collected? (gets at confidence in the decision)
- Iterate

Open, transparent, defensible...
Fully operationalizes the Scientific Method “Bayesian DQOs”
Bayesian Paradigm Shift

• Decision analysis is based on representing and revising beliefs for choosing actions in situations of uncertainty
• Bayes’ theorem provides the crank for revising beliefs in light of new evidence
• Bayesian approach leads to maximizing expected utility (minimizing expected loss)
Decision Analysis Results

- In the long run, it is best to choose the alternative (decision option) that provides the best expected outcome, given what you know or believe about future events.

- This is the basis of cost-benefit analysis.

- Evaluate sustainability: economics, environmental and social pillars

- Aim to Maximize expected societal welfare

Also – Risk management, Economic analysis....
Roots of Decision Analysis

- Bayesian probability theory (Bayes, 1765)
- Utility theory (von Neumann & Morgenstern, 1947)
- Bayesian Statistical Decision Theory (de Finetti, 1930s, Savage, 1954, DeGroot, 1970)
- Behavioral Science (von Winterfeldt and Edwards, 1986)
- Risk and Policy Analysis (Morgan and Henrion, 1990)
- Structured Decision Making (Gregory et al., 2012)
Roots of Decision Analysis

• Decision Analysis established as an applied discipline and a field of research in the late 1960’s

• Howard Raiffa (Harvard)
  • emphasis on decision analysis as a method with real world applications
  • Initial elicitation methods

• Ron Howard (Stanford)
  • emphasis on influence diagrams and economic analyses in the face of uncertainty
Benefits of a Decision Analysis approach

• Easier to understand
• Easier to communicate and explain
  • Because it represents what we think we know and our uncertainties about that
    • I.e., it’s honest
  • Rather than what we know to be wrong, inaccurate, or mis-applied
• Consequently, more difficult to disagree
  • Helps avoid redo, or another stone
Common Application Areas

- Oil and gas industry
- Risk analysis (business decision risk)
- Pharmaceutical and biotechnology industries
- Public sector applications
  - Department of Defense
- Environment – moving in this direction
  - White House circular in 2001
Environmental Evolution

• Strong evidence of an evolutionary change:
  • OMB – policy analysis
  • DOE
    • Enterprise Risk Management effort (2004)
    • Risk-informed decision making
  • EPA CREM
  • NRC NUREG – risk-informed guidance
  • NAS documents – perform risk assessment
  • Professional societies – SRA, INFORMS
  • Impact of changes in education system
EPA Examples

- SMARTe – Sustainable Management Approaches and Revitalization Tools
  - *Brownfields revitalization*
  - Re-imagining Cleveland
  - *Regional land use planning*
- DASEES – Decision Analysis for a Sustainable Environment, Economy, and Society –
  - *Land re-use*
  - *Watershed management*
  - *Coral reef management*
  - *Social network tool for stakeholder involvement*
- Asbestos remediation
- Vapor intrusion characterization
Other Agencies

• DoD – cleanup chemical warfare agents
• MMRP – characterize and remediate UXO
• FDA – prioritizing resources for mitigating foodborne illnesses
• Climatology – fire prediction, ecological observatory design
• Risk management, environmental liability issues for commercial industry

_The evolution is happening!_
Tight budgets – need to focus on better solutions, need some optimization
Radiation Projects

- NTS (NNSS) Areas 3 and 5 Radioactive Waste Management Sites – optimized disposal and closure
- Energy Solutions, Clive, Utah – optimizing disposal and closure
- Waste Control Specialists, West Texas – optimizing disposal
- LANL – options analysis for RH TRU
- NTS (NNSS) – options analysis for Smoky Site
  - Saved $200M, still protective, defensible, transparent
ALARA/DA precedents?

- Application of population risk using cost measures
- Initially $1,000 per person rem with no discounting (NUREG/BR 0058, Rev 2, 1995)
- “Upgraded” to a distribution from $1,000 - $6,000 per person rem per year with a 7% discount rate (NUREG 1757, 2003)
- Updated to $2,000 per person rem with discounting (NUREG/BR-0058, Rev 4, 2004)

Implies need for Population Risk Assessment
PA as a Structured Decision Analysis Process

- **Objectives**
  - Minimize risk
  - Minimize costs
  - Maximize societal benefit
  - E.g., Minimize exposure from
    - plant uptake
    - GW transport

- **Means**

- **Alternatives**
  - 4m Cap
  - 2.5m Cap
  - ET Cap

- **Features**
- **Events**
- **Processes**

- **Measures**
  - Mrem/yr
  - Dollars
  - Public acceptance score
  - Environmental justice score

- **Sensitivity Analysis**
  - Value of Information

- **Viable Alternative?**
  - No
  - Yes
  - Adaptive Management
Economic or Cost-Benefit Issues

• Market and non-market costs and benefits
  • Market – Engineering costs
  • Non-market – Risk reduction
• Decision management options
  • Engineering options
  • Storage and retrievability
  • Trust funds – e.g., for generational re-evaluation (changes in society/technology), facility maintenance
  • Insurance – disasters, problems
• Additional considerations
  • Discounting
  • Generational equity issues
  • Population risk/dose
Objectives Hierarchy

1. Maximize sustainability of radioactive waste storage (ALARA)
   - Meet schedule
   - Maximize public acceptance

2. Minimize costs
   - Minimize engineered design costs
   - Minimize maintenance cost
   - Minimize transportation costs

3. Satisfy regulatory compliance objectives
   - Meet individual member of the public dose requirements
   - Meet public notification
   - Meet ground water protection requirements
   - Meet occupational dose limits
   - Meet public participation requirements
   - Meet intruder dose requirements
   - Meet site stability requirements
   - Minimize population dose

4. Maximize generational equity
   - Maximize intra-generational equity
   - Maximize inter-generational equity
Measures

Each of the final objectives should have measures for assessing whether the objectives is attained. A good measure should be:
- interpretable
- meaningful
- operational
- measurable

Details for a measure can be edited by selecting a measure in the table below and clicking "Edit Measure."
PA “Objectives Hierarchy”

- Maximize sustainability of radioactive waste storage (ALARA)
- Meet schedule
- Maximize public acceptance
- Satisfy regulatory compliance objectives
- Minimize costs
- Minimize population dose
- Maximize generational equity
- Meet occupational dose limits
- Meet public participation requirements
- Meet public notification
- Meet individual member of the public dose requirements
- Meet intruder dose requirements
- Meet ground water protection requirements
- Meet site stability requirements
Other considerations for PA DA

• Discounting
  • Temporal
  • Social
  • Spatial
  • Technological

• Value of Future Generations

• Compliance Period implies no discount rate for the duration, and then a value of 0 thereafter
  • This is a discount function, rather than a simple rate
  • Current generation bears the full cost (pay now to protect future generations)
  • This approach can have unintended consequences for near-term generations.
Decision Analysis Framework

Structure:

• Understand Context
• Define Objectives
• Define Options
• Evaluate Options
  • Modeling, sensitivity analysis
• Take Action (or iterate)
Sensitivity Analysis - briefly

• Modern methods allow global sensitivity analysis on probabilistic non-linear non-monotonic models
• We use gradient boosting, but have tested various other methods
• We are working on a method using discretized Bayes nets
• See presentation at WM2015
Some research needs

• Effective probabilistic modeling
  • Input distributions – scaling – correlation (otherwise GIGO)
  • Effect of simulation time steps
  • Bayesian spatio-temporal modeling
  • Bayesian updating for model calibration
• Effect of computer tools on elicitation bias
• Using global sensitivity analysis directly in a value of information analysis (hence Bayes nets)
• Applying sensitivity analysis across the time frame of a dynamic model (hence Bayes nets)
Some research needs

- Model abstraction – inputs to “systems-level” models sometimes come from “process-level” models
- Merging decision analysis tools with traditional fate and transport modeling and HH and eco risk assessment tools
- Visualization of sensitivity analysis and other aspects of PA modeling

*We don’t need a bigger sledgehammer, we need smarter tools*
DA for PA – Summary

*Decision Analysis provides the appropriate paradigm for evaluating cost-benefit of alternative options*

This approach is achievable with current technology for PA-related decisions, and has been implemented for other complex environmental decision problems

*It can (should) be stakeholder driven*

*Decision models should be based on “reasonable realism” coupled with uncertainty*

*It is fine to make conservative decisions, but not to make important decisions based on conservative models*

*We need this approach to help optimize decision making for the nuclear industry*
The intent today was to introduce decision analysis concepts.

We have examples as indicated, and will present some at WM2015 (turn abstract into concrete).

We will also conduct an interactive panel session on Thursday afternoon at WM2015 as an initial (simplified) demonstration of how this decision analysis process works.

Watch for us at WM2015.
Technical needs

• Complex projects such as PA require multi-disciplinary approaches to problem solving
• Typically PA involves modelers, scientists, engineers
• PA following a decision analysis path also needs:
  • statisticians, decision analysts, economists,
  • computer scientists,
  • elicitation experts,
  • stakeholder involvement experts
• All with a common vision!
In Summary...

Performance Assessment can serve Structured Decision Making in the presence of Values and Uncertainty.