VALUE-OF-INFORMATION: A DECISION-CENTRIC PERSPECTIVE ON EMERGING SCIENCE

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• Ideas from *Science & Decisions (NRC, 2009)*
• Value-of-Information
  • *Formal vs. Informal*
  • *Value of Methods, Value of Information Systems*
• Altered Decision Outcome Pathways
• Mapping Decision Contexts
• Model-based Reasoning
I D E A S  F R O M  S C I E N C E  A N D  D E C I S I O N S

• Enhanced Role of Problem Formulation
• Need for Up-front Identification of Decision-making Options
• Need for Stopping Criteria in Risk Assessment
• VOI and VOI-Lite: Informal Value of Information
• Value of Methods
Stage 1: Planning
• For the given decision-context, what are the attributes of assessments necessary to characterize risks of existing conditions and the effects on risk of proposed options? What level of uncertainty and variability analysis is appropriate?

Stage 2: Risk Assessment
• Hazard Identification
  What adverse health or environmental effects are associated with the agents of concern?
• Dose-Response Assessment
  For each determining adverse effect, what is the relationship between dose and the probability of the occurrence of the adverse effects in the range of doses identified in the exposure assessment?
• Exposure Assessment
  What exposures/doses are incurred by each population of interest under existing conditions?
  How does each option affect existing conditions and resulting exposures/doses?
  What risk decreases (benefits) are associated with each of the options?
  Are any risks increased? What are the significant uncertainties?
• Risk Characterization
  What is the nature and magnitude of risk associated with existing conditions?
  What risk decreases (benefits) are associated with each of the options?
  Are any risks increased? What are the significant uncertainties?

Stage 3: Confirmation of Utility
• Does the assessment have the attributes called for in planning?
• Does the assessment provide sufficient information to discriminate among risk management options?
• Has the assessment been satisfactorily peer reviewed?

FORMAL PROVISIONS FOR INTERNAL AND EXTERNAL STAKEHOLDER INVOLVEMENT AT ALL STAGES
• The involvement of decision-makers, technical specialists, and other stakeholders in all phases of the processes leading to decisions should in no way compromise the technical assessment of risk, which is carried out under its own standards and guidelines.
Maintaining a Constant Focus on Decision-making Options

PHASE I: PROBLEM FORMULATION AND SCOPING

- What problem(s) are associated with existing environmental conditions?
- If existing conditions appear to pose a threat to human or environmental health, what options exist for altering those conditions?
- Under the given decision context: what risk and other technical assessments are necessary to evaluate the possible risk management options?

PHASE II: PLANNING AND CONDUCT OF RISK ASSESSMENT

Stage 1: Planning
- For the given decision context, what are the attributes of assessments necessary to characterize risks of existing conditions and the effects on risk of proposed options? What level of uncertainty and variability analysis is appropriate?

Stage 2: Risk Assessment
- Hazard Identification
  - What adverse health or environmental effects are associated with the identified hazards?
- Dose Response Assessment
  - For each determining adverse effect, what is the relationship between dose and the probability of the occurrence of the adverse effects in the exposed population?
- Exposure Assessment
  - What exposures/ doses are incurred by each population of interest under existing conditions?
  - How does each option affect existing conditions and resulting exposures?

Stage 3: Confirmation of Utility
- Does the assessment have the attributes utilized in planning?
- Does the assessment provide sufficient information to discriminate among risk management options?
- Has the assessment been satisfactorily peer reviewed?

PHASE III: RISK MANAGEMENT

- What are the relative health or environmental benefits of the proposed options?
- How are other decision analytic factors (technologies, costs) affected by the proposed options?
- What is the decision, and its justification, in light of benefits, costs, and uncertainties in each?
- How will the decision be announced?
- Is it necessary to evaluate the relative values of the decision?
- If so, how should this be done?

FORMAL PROVISIONS FOR INTERNAL AND EXTERNAL STAKEHOLDER INVOLVEMENT AT ALL STAGES

- The involvement of decision-makers, technical specialists, and other stakeholders in all phases of the process leading to decisions should in no way compromise the technical assessment of risk, which is carried out under its own standards and guidelines.
SELF-VALUATION OF THE IMPORTANCE OF OUR WORK TO DECISION-MAKING

“I think you should be more explicit here in step two.”
• Decision-centric valuation of the benefit of new information that would reduce uncertainty.
• How does new information generate benefit?
• Information reduces the *likelihood* and *severity* of *adverse* outcomes from decisions.
WHAT VOI IS NOT

• VOI ≠ Interesting or Publishable

• VOI ≠ Scientific Importance

• Transferable to other decisions contexts, times
PROPERTIES OF VOI ANALYSIS

• Dynamic
  • Which information came first
  • Information A can make Information B more or less valuable

• Often Counter-Intuitive
  • A 50-person survey on use of consumer products
  • A two-generation primate study
FORMAL VOI

• Calculates the difference between the expected benefit given new information and that same decision without additional info.

\[ EVSI = \int_{t \in T} \max_{s \in S} \left( \int u(a, s)p(s \mid t)ds \right) h(t)dt - \max_{s \in S} \left( \int u(a, s)f(s)ds \right) \]

• Excellent review articles and application to toxicity testing by Yokota et al., *Risk Analysis*
Decision-Maker's Valuation of Attributes of Quality in Public Decision-Making

Stakeholder Involvement

Peer Review Approach

Methods to Achieve Timeliness

Quality of Risk and Cost Assessment Process

Baseline Design of Risk Assessment Process and Product

Uncertainty Characterization

Variability Characterization

Dose-Response Methods

Exposure Modeling Methods

Quality of Risk and Cost Measurement

Quality of Decision Support

Baseline Assessment of Decision-Support

Enhancement Opportunities

Detailed Analysis of Susceptible Population

Expand Scope to Include Risks of Substitutes

Enhanced Stakeholder Consultation

Expanded Uncertainty Quantification

Multi-Stage Public and Peer Review

More Complex Exposure Assessment Model

Communication Methods

Value-of-Methods Analysis

Expected Benefit to DM Process

Projected Impact of Enhancement on Quality of Decision Support

Expected Detriments to DM Process

Net Impact of Enhancement

Direct Resource Costs of Enhancement
The same concept extends naturally to information systems

- Information \(\rightarrow\) Information Systems
  - Resolution, Timeliness, Quality

- Decision \(\rightarrow\) Class or Series of Decisions
CHALLENGES IN ESTIMATING THE IMPACT OF INFORMATION

• Formal VOI Analysis is difficult when:
  • you don’t know what options the decision-makers is contemplating
  • you don’t know how the decision-maker chooses among the options
  • you are unwilling to describe your current state of uncertainty
  • You are unwilling to characterize the predictive quality and therefore the weight to ascribe to new knowledge
FROM FORMAL TO INFORMAL

• Silver Book Committee recommended increased application of informal VOI
  • Requiring a clear causal link between a particular piece of information, the magnitude of uncertainty reduction, and the reason why the decision-maker is likely to make a better and different choice.

• The Goal: stopping criteria for risk assessment
VOI: A RISK ASSESSMENT
OF A DECISION MADE UNDER UNCERTAINTY

• Hazard: the lack of information to reduce uncertainties in a decision
• Pathway perturbation: the effect of information on beliefs that alter estimates of risk and other decision-relevant variables
• Adverse Outcome: losses (health, economic) that would be avoided had the information been available
## ANALOGIES TO SYSTEMS BIOLOGY

### Chemical Risk/Benefit Assessment
- Source and Emission
- Pathway to Receptor
  - *Complex Mixtures*
- Other Health Determinants
- Intake Route
- Pharmacokinetics
- Molecular events
- Network response
- Biological system effect
- System Response
- Adverse or Beneficial Effect
- Risk = f(Likelihood, Severity of Effect)
- Repeat for next individual

### Information Impact Assessment
- Source and Transmission
- Pathway to Receiver
  - *Channel Noise and Bandwidth*
- Decision Context
- Information Portal
- Information Processing
- Updated belief or estimate
- Integration of evidence
- Updated key measure
- Application of Decision Rules
- Δ Decision --> Δ System
- VOI = Likelihood and Severity of Δ System
- Repeat for next decision-maker
“There are significant health and economic consequences associated with communication failures. ... As result, one should no more release an untested communication than an untested drug.” (Fischhoff, 1998)
### PUBLIC RISK COMMUNICATIONS

#### Information Impact Assessment
- Source and Transmission
- Pathway to Receiver
  - *Channel Noise and Bandwidth*
- Decision Context
- Information Portal
- Information Processing
- Updated belief or estimate
- Integration of evidence
- Updated key measure
- Application of Decision Rules
- $\Delta$ Decision $\rightarrow$ $\Delta$ System
- $\text{VOI} = \text{Likelihood and Severity of } \Delta \text{ System}$
- Repeat for next decision-maker

#### Air Quality Advisory
- Health authority issues smog alert
- Multi-media exposure
  - *Complex, noisy media*
- Age, Health, Lifestyle, Access to AC
- Radio, TV, Internet, Mobile Device
- Cognitive Processing
- Altered Level of Concern
- Consideration of Options
- Behavior Change Preference
- Decision to Adapt
- Altered Exposure(s)
- $\text{VOI} = \text{Likelihood and Severity of } \Delta \text{ Exposure}$
- Repeat for next decision-maker
THE MISSING ‘OMIC

- Genomics
- Proteomics
- Metabolomics
- Toxicogenomics
- Microbiomics
- Exposomics
It is (equally) critical to map out the Environmental Health *Decisiome*.

*Decisiome*: the totality of processes that interact with new information to reduce or affect uncertainty in decision-making and the consequences of the change in uncertainty for decision-making that affects public health and other societally valued outcomes.
**U N D E R S T A N D I N G D E C I S I O N S Y S T E M S**

- **Systems Biology**: an interconnected network of events predictive of emerging properties.

- **Decision Systems Analysis**: an interconnected network of processes and decisions that convert knowledge and information into decisions and their impacts.

- **Risk Governance**: the totality of actors, rules, conventions, processes, and mechanisms concerned with how relevant risk information is collected, analysed and communicated and management decisions are taken. (IRGC, 2005).
Distinct Decision Contexts

- Two-sided dose-response curve
- Decisions regarding biomonitoring
- Decisions regarding *in vivo* toxicity testing
- Decisions regarding product formulation or substitution
- Decisions regarding site clean-ups
VOI FOR TOXICITY AS A FUNCTION OF EXPOSURE
A PROPOSED SOLUTION:
MODEL-BASED REASONING

• Construction of a class of Decision-Context Models which serve as a sandbox for exploring the value of information, the value of complex model components, and the impact of risk assessment processes and the decision-maker.

• At the onset of a Risk Assessment
  • Choose the right decision context model
  • Tune it with crude approximations
  • See what is truly necessary to support the decision-maker
SUMMARY

• Value Of Information (VOI)
  • Informal VOI (Causality)
  • “Altered Decision-Outcome Pathway”

• Need to focus some analysis on the systems of processing information and decision-making
  • Mapping the “Decisiome”
  • If we invest 0.1% of the cost of producing information in analyzing the downstream use, the effort would make the other 99.9% more useful