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Decision Making Under Deep Uncertainty: Theoretical Background

Prof. Dr. Warren E. Walker
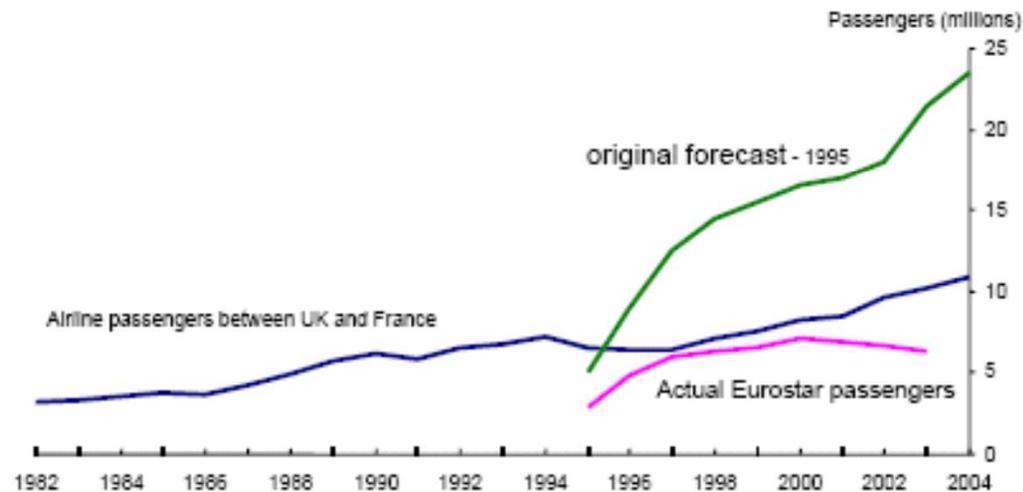**Delft University of Technology**

NMDC

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The Problem: How to make policy in a deeply uncertain world

- "There are things that we know that we know; there are things that we know that we don't know; there are things that we don't know that we don't know."
  - Donald Rumsfeld, 2/12/2002

- The challenge: to <u>make policy</u> taking into account the things that we know that we don't know, and <u>safeguarding against/preparing for</u> the things that we don't know that we don't know.

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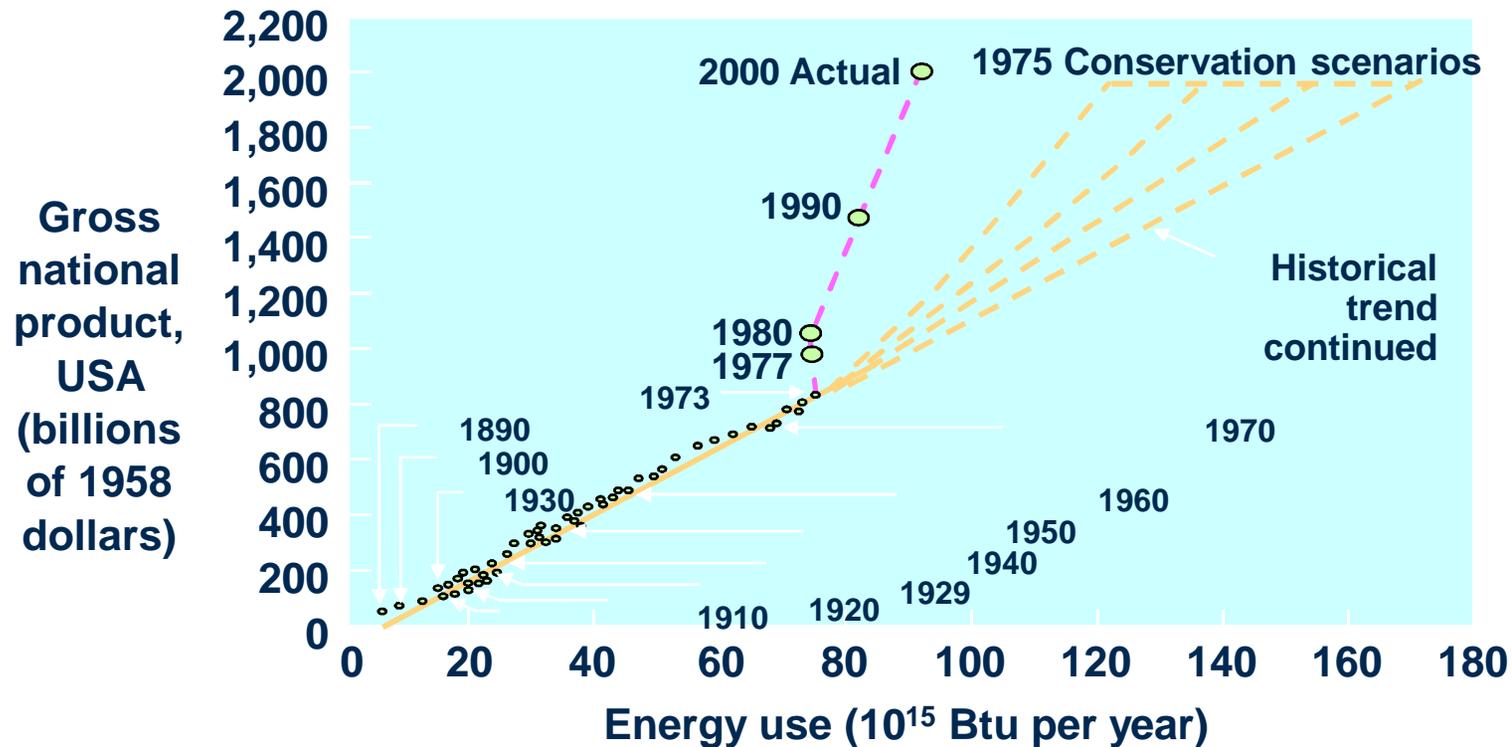
Large Losses Possible if Take Action Based on Wrong Predictions

Project optimism
Eurostar passenger numbers and forecasts.

Passengers (millions)

original forecast - 1995

Airline passengers between UK and France

Actual Eurostar passengers

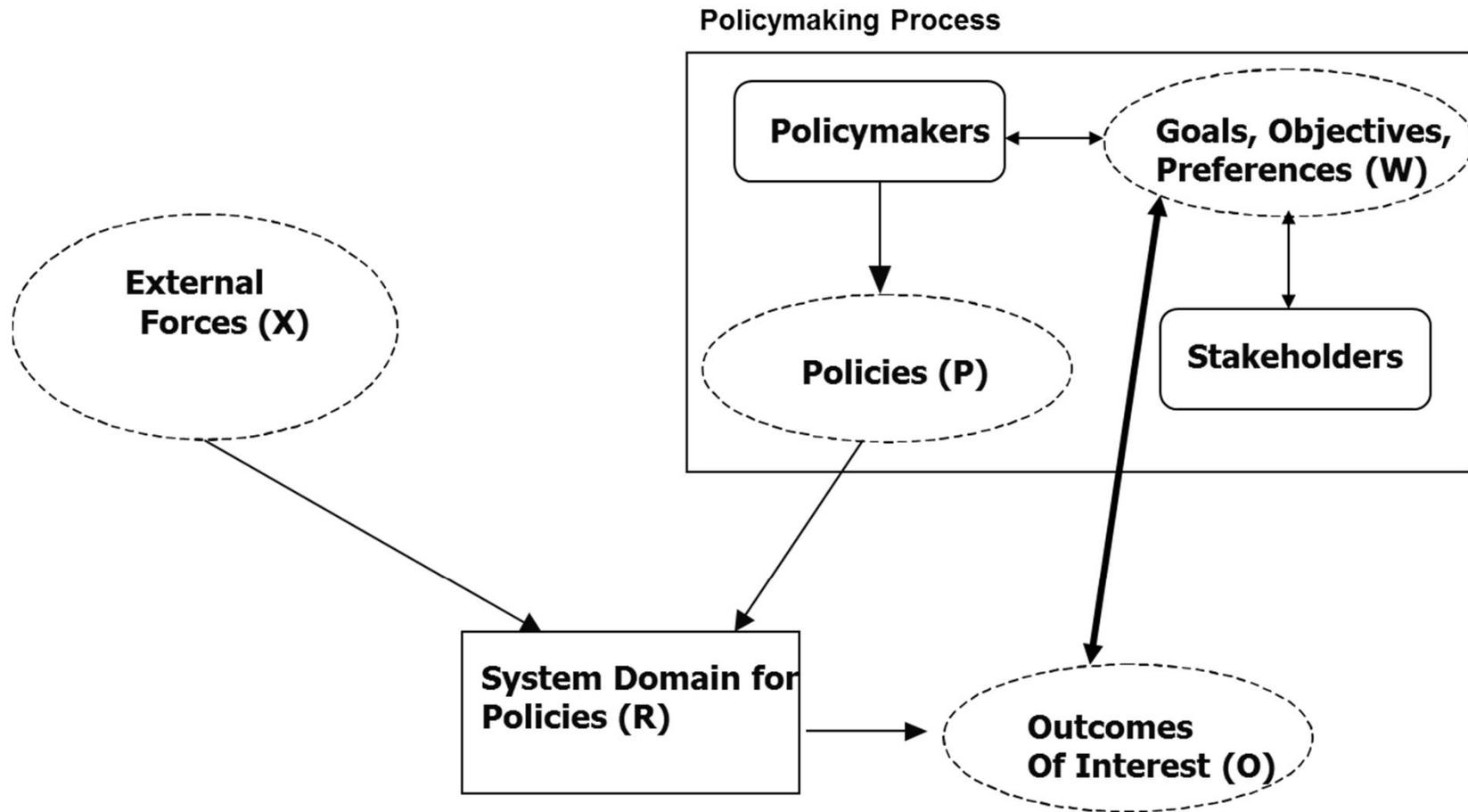1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004

Sources: LCR and CAA

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Large Needless Expenditures Possible if Take Action Based on Wrong Predictions

Gross national product, USA (billions of 1958 dollars) vs **Energy use (10^{15} Btu per year)**

2000 Actual — 1975 Conservation scenarios — 1990 — 1980 — 1977 — 1973 — Historical trend continued — 1890 — 1900 — 1930 — 1970 — 1960 — 1950 — 1940 — 1929 — 1910 — 1920
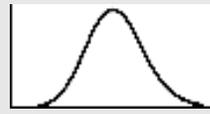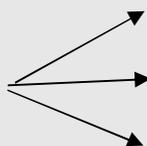
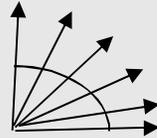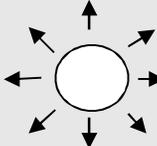**[Implementing a policy that assumes the future will be a continuation of the past is like driving a car while looking only into the rear view mirror.]**

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A Framework for Traditional Policy Analysis

Policymaking Process

Policymakers ↔ Goals, Objectives, Preferences (W)

External Forces (X)

Policies (P)

Stakeholders

System Domain for Policies (R)

Outcomes Of Interest (O)

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Model-Based Decision Support Must Deal With Several Levels of Uncertainty at Each of the Locations

	Complete determinism	Level 1	Level 2	Level 3	Level 4 (Deep Uncertainty)		Total ignorance
					Level 4a	Level 4b	
Context (X)		A clear enough future	Alternate futures (with probabilities)	A few plausible futures	Many plausible futures	Unknown future	
System Model (R)		A single (deterministic) system model	A single (stochastic) system model	A few alternative system models	Many alternative system models	Unknown system model; know we don't know	
System Outcomes (O)		A point estimate for each outcome	A confidence interval for each outcome	A limited range of outcomes	A wide range of outcomes	Unknown outcomes; know we don't know	
Weights (W)		A single set of weights	Several sets of weights, with a probability attached to each set	A limited range weights	A wide range of weights	Unknown weights; know we don't know	
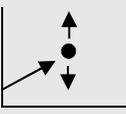
Traditional Approaches for Dealing with Uncertainty about the Future (X) are Problematic

- Ignore uncertainty

- Assume the future is knowable ('predict-and-act' ➔ "optimal" policy) (Level 1)

- Assume the future will (probabilistically) look like the past (driving while looking only through rear-view mirror) (➔ 'trend-based' policy)(Level 2)

- Look for a policy that will do well in a few scenarios (➔ 'static robust' policy) (Level 3)

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- Look for a policy that will do well in a few scenarios (➔ 'static robust' policy) (Level 3)

- What if the experts do not know and /or stakeholders can not agree on what the future might bring (Level 4) = "**deep uncertainty**" (➔ 'adaptive' policy)

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Definition of Deep Uncertainty*

A situation in which the relevant actors do not know, or cannot agree upon:
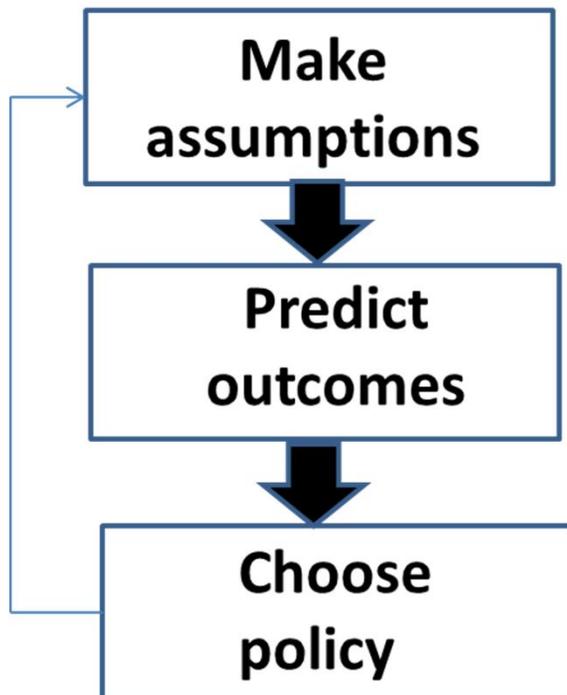
- how likely or plausible various future states are (X)
- how the system works (or would work) (R & O)
- how to value the various outcomes of interest (W)

* Walker, Warren E., Robert J. Lempert, and Jan H. Kwakkel (2013). "Deep Uncertainty", entry (pp. 395-402) in Saul I. Gass and Michael C. Fu (eds.), *Encyclopedia of Operations Research and Management Science.,* 3rd Edition*,* New York: Springer.

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The Adaptive Approach Conducts the Analysis Backwards

- Traditional Approaches
  (Level 1-3 Uncertainty)

- Adaptive Approach
  (Level 4 Uncertainty)

Make assumptions → **Predict outcomes** → **Choose policy** (loops back to Make assumptions)

Propose policy → **Identify vulnerabilities** → **Assess options for reducing vulnerabilities** (loops back to Propose policy)

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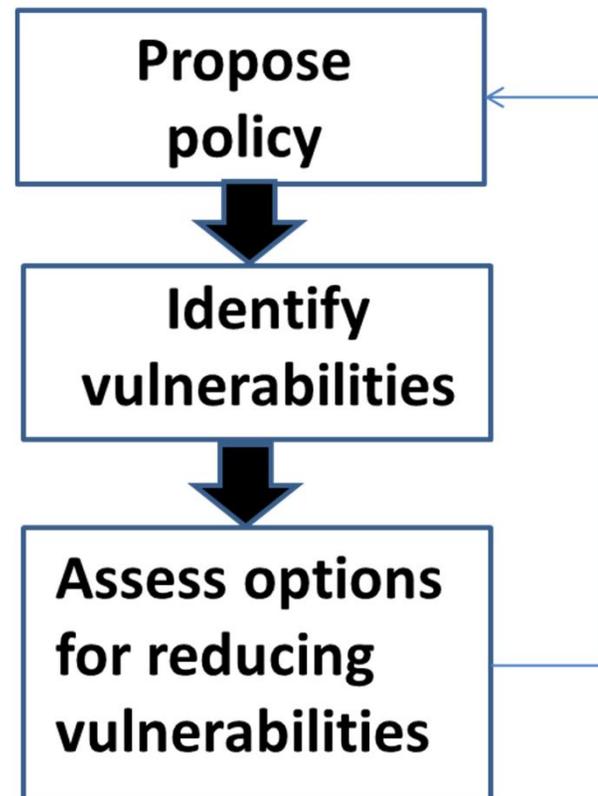
The Adaptive Approach

- Determine a set of goals

- Identify a promising basic policy and conditions for its success

- Identify vulnerabilities of the policy (how it could fail) and ways of protecting it

- Monitor progress toward the goals

- Adapt the policy as exogenous and endogenous conditions change over time

we cannot direct the wind but we can adjust the sails

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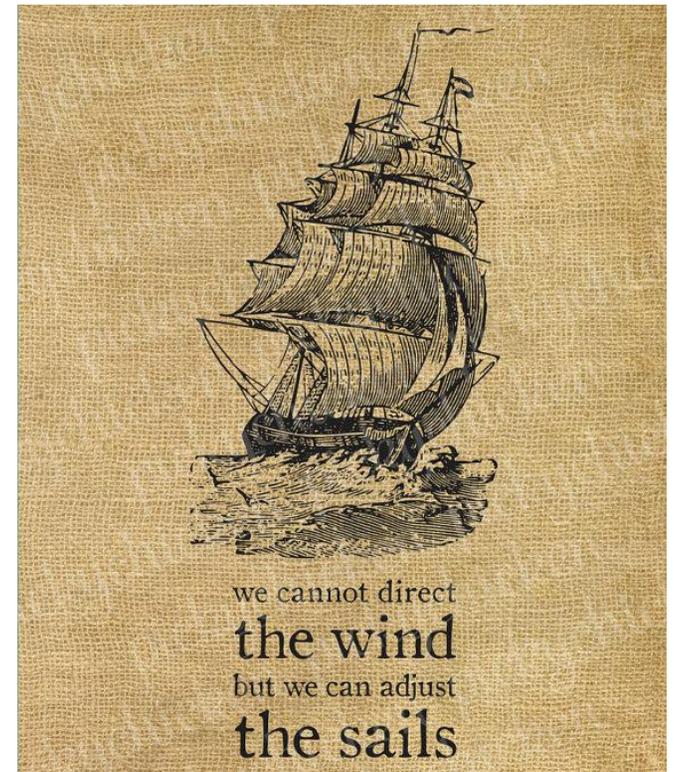
Identifying Vulnerabilities: Use Non-Predictive Models ('Exploratory Modeling')

- Model is used to explore ("what if . . .")

- Simultaneously takes into account context uncertainty, model uncertainty, and uncertainty about weights (multi-dimensional sensitivity analysis)

- The objective is to reason about system behavior: under what circumstances would a policy succeed or fail ('Scenario Discovery')

- May require a huge number of computer runs

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'Consolidative' vs. 'Exploratory' Modeling

Consolidative Modeling

- Model is used to predict

- The objective is to predict   system behavior (predict whether a policy will succeed or fail)

Exploratory Modeling

- Model is used to explore

- The objective is to reason about system behavior (under what circumstances would a policy succeed or fail)
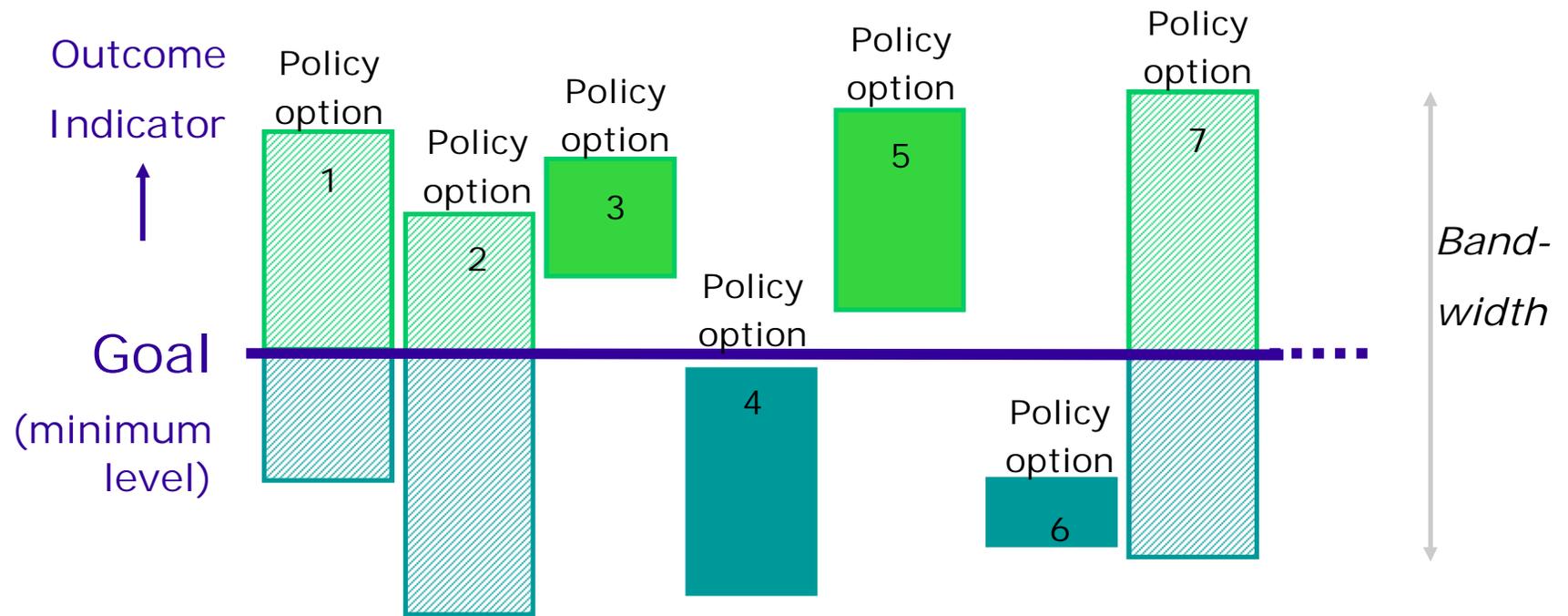
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Exploratory Modeling: Approach

1. Develop a fast and simple model (FSM*) of the system of interest

2. Specify the assumptions underlying the 'experiments' to be run

3. Specify alternative policy options

4. Do the experiments (i.e., calculate the performance of the options for the various assumptions using the FSM**)

5. Analyze the performance of the policy options across the experiments
   − Perhaps iterating over Steps 4 & 5 using screening and multi-resolution modeling

* FSMs are sometimes called meta-models, compact models, repro models, surrogate models, emulation models, computationally efficient models, low fidelity models, or screening models.

** It is necessary to carefully design the experiments in order to restrict the number of experiments that are run.

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Scenario Discovery (Vulnerability Analysis)

Outcome Indicator

Goal (minimum level)

Band-width

Policy option 1

Policy option 2

Policy option 3

Policy option 4

Policy option 5

Policy option 6

Policy option 7

= Good option, regardless of circumstances

= Bad option, regardless of circumstances

= Potentially good (but vulnerable → monitoring + action)

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Key Element of Adaptive Policies:
A monitoring system, with related contingency actions to keep the policy on track
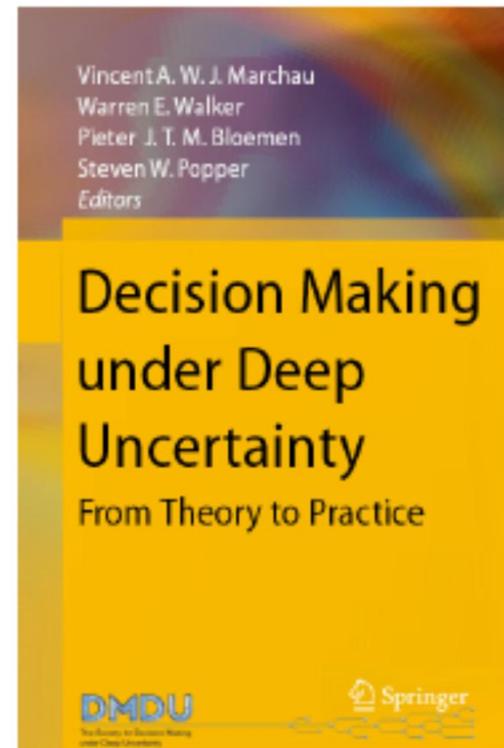

MONITORING SYSTEM:

- **Signposts and trigger values**
- **Are we still on track?**
- **Are corrective actions needed?**
- **Do we need to implement actions earlier or later?**
- **Is reassessment needed?**

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Conclusions

- Uncertainty is always present in strategic policymaking
- Ignoring uncertainty is a <u>terrible</u> idea
- Adaptive policies are good ways of dealing with deep uncertainty
  - Get implementation under way
  - Allow adaptations of policy over time as new solutions are developed, values change, and other external events take place
  - Enable learning from experience over time
- Exploratory Modeling and Scenario Discovery are useful tools for identifying good adaptive policies
- Motto: 'Be Prepared'

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Decision Making under Deep Uncertainty

From Theory to Practice

DMDU

Springer

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Some Relevant References

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Questions for Discussion

1. Transitioning from 'predict and act' to 'monitor and adapt' requires a change in mind-set. Are the decisionmakers in your organization ready (and willing) to change their mind-set?

2. Exploratory Modeling and Multi-resolution modeling requires modelers to change the way they build and use models. Are the modelers in your organization prepared to build and apply models in these new ways?

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