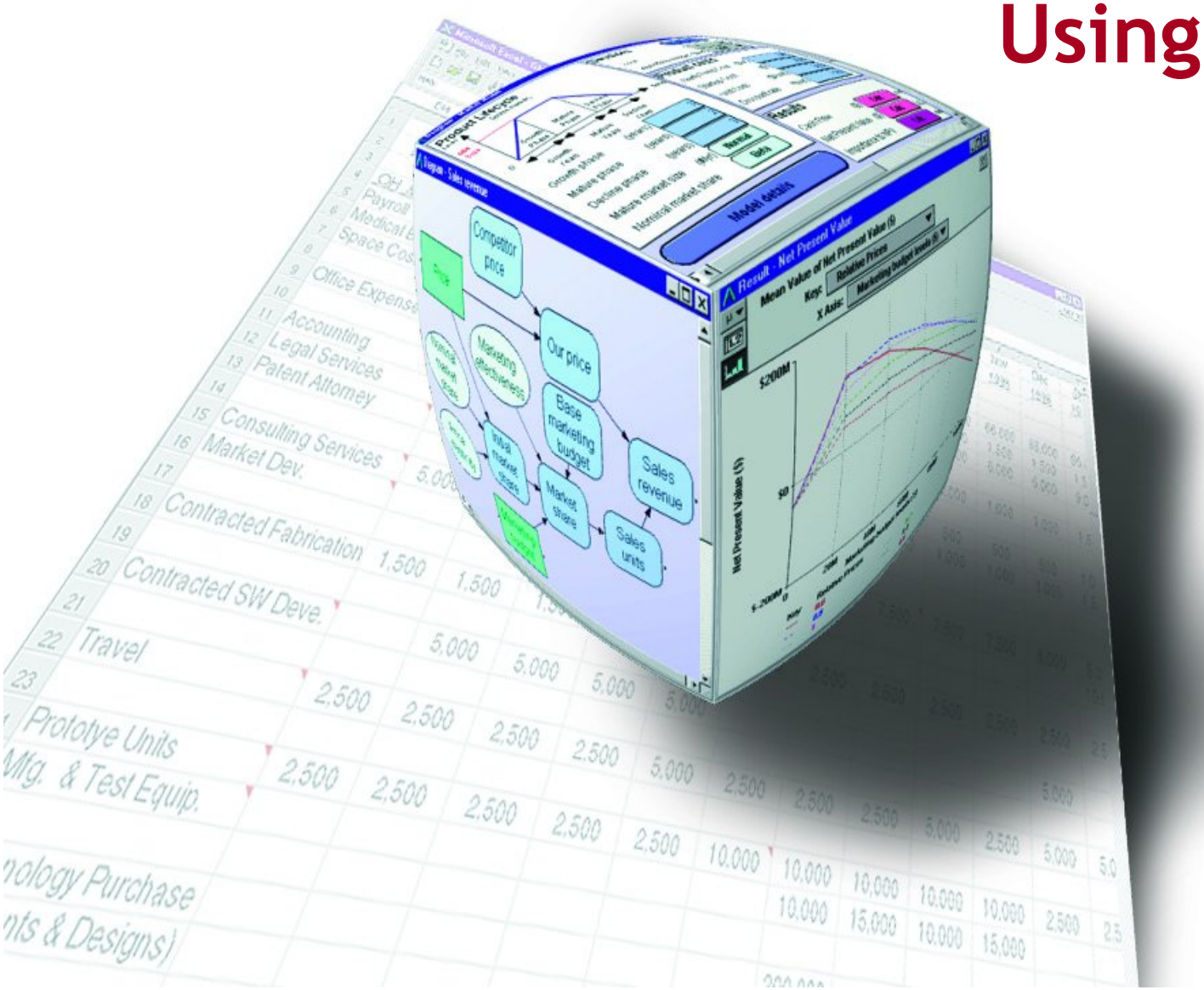
Transparency and Uncertainty in Quantitative Models: Using Analytica

Max Henrion



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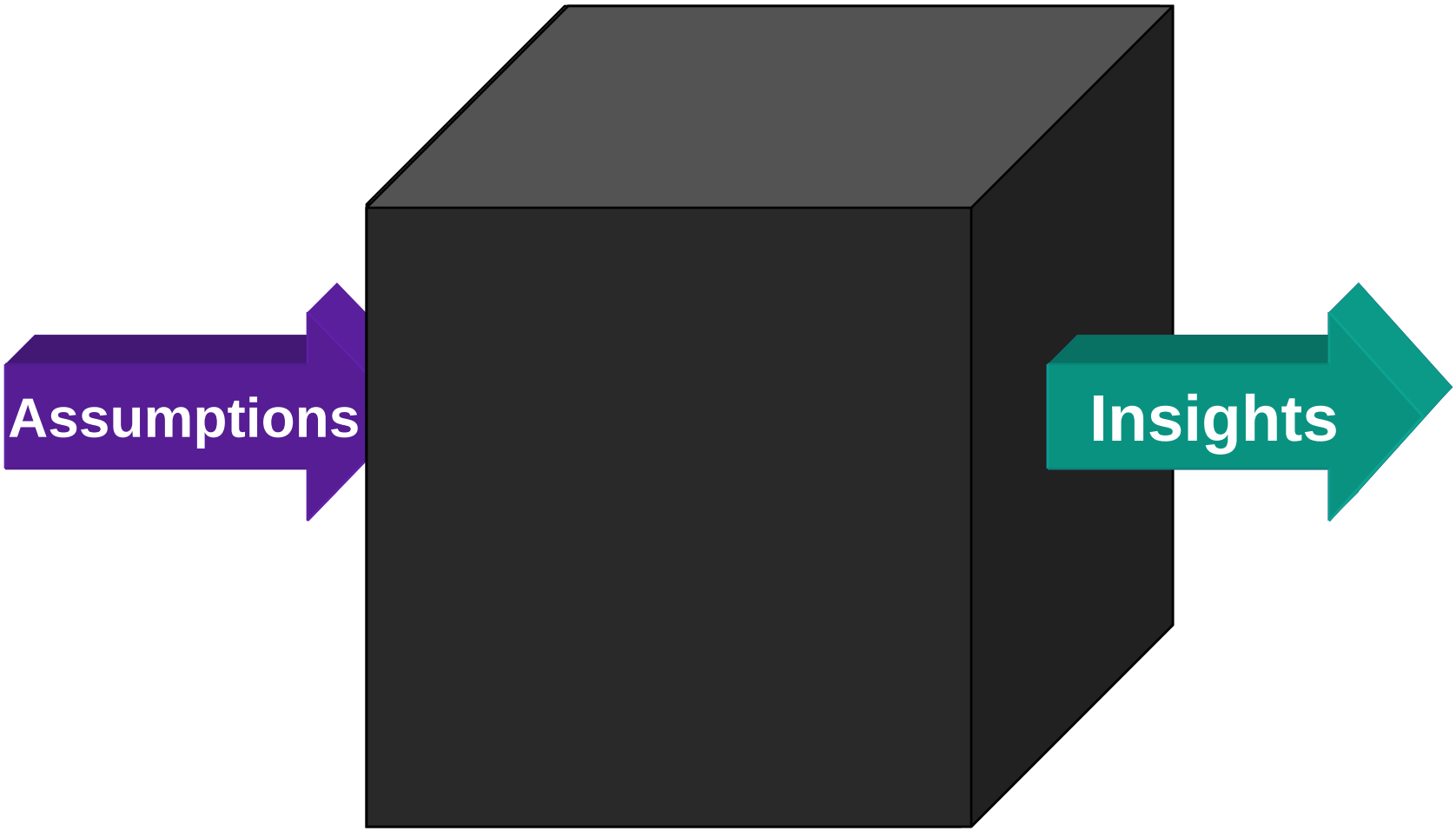
Opening the Black Box: How to make models more



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Overview

- How I got interested in transparency and uncertainty
- Tools to make models more transparent
- Analytica: A demo of Cost-benefit analysis of daylighting
- Open-source policy modeling

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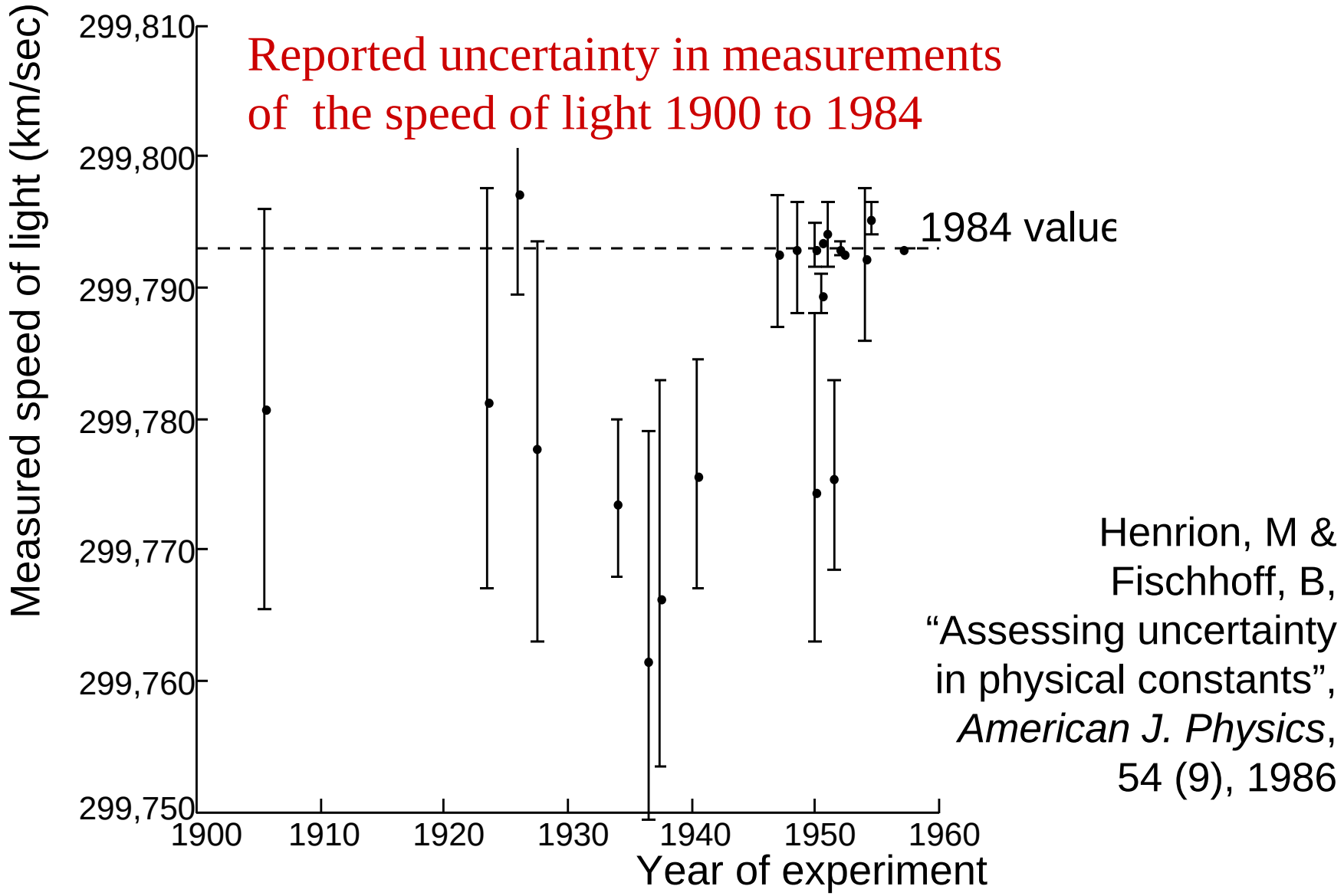
Reported uncertainty in measurements
of the speed of light 1900 to 1984
Measured speed of light (km/sec)
299,810
299,800
299,790
299,780
299,770
299,760
299,750
1984 value
1900
1910
1920
1930
1940
1950
1960
Year of experiment
Henrion, M &
Fischhoff, B,
"Assessing uncertainty
in physical constants",
American J. Physics,
54 (9), 1986

Guidance from OMB:

How to conduct regulatory analysis

- "For major rules … you should present a formal quantitative analysis of the relevant **uncertainties** about benefits and costs."
- "A good analysis is **transparent**. It should be possible for a qualified third party reading the report to see clearly how you arrived at your estimates and conclusions."
- assessments should be capable of being substantially **reproduced**. … independent reanalysis …using the same methods would generate similar analytical results."
  [Emphases added]

OMB Circular A-4, John Graham, OIRA Administrator, 17 Sep 2003

http://www.whitehouse.gov/omb/circulars/a004/a-4.html

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Why should we care about model transparency?

- To improve communication within the modeling and analysis team
- To facilitate improve scrutiny by outside model reviewers, including peer reviewers, industry, NGOs, and more.
- To help decision makers and stakeholders understand the assumptions, implications, limitations and insights of the analysis
- To aid debugging and verification
  - Studies show that over 50% of operational spreadsheets have serious (>10%) errors

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Errors in operational spreadsheets

Study	Number of spreadsheets	Criterion	% Models with Errors
Davies & Ikin [1987]	19	14 had qualitative errors. Methodology unspecified.	21%
Butler [1992]	273	Audited by 143 UK tax inspectors. Only "material" errors.	10.70%
Cragg & King [1993]	20	150 to 10,000 cells, serious errors	25%
Coopers & Lybrand [1997]	23	Results off by at least 5%	91%
KPMG [1997]	22	Containing major errors.	91%
Butler [2000]	7	Tax spreadsheets audited by human and automated checker.	86%
Total	**367**	**Weighted average**	**24%**
Since 1997	**54**	**Weighted average**	**91%**

From Raymond Panko [2000],
What We Know About Spreadsheet Errors

http://panko.cba.hawaii.edu/ssr/Mypapers/whatknow.htm

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A historical perspective

"Professional standards … are non-existent.
The documentation of model and source data is in an unbelievably primitive state.
This goes even (and sometimes especially) for models actively consulted by policy makers.
Poor documentation makes it next to impossible for anyone but the modeler to reproduce the modeling results and to probe the effects of changes to the model.
Sometimes a model is kept proprietary by its builder for commercial reasons. The customer is allowed to see only the results, not the assumptions."

Greenberger, Grensen, and Crissey (1976)

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How can modeling software encourage transparency?

- Integrate documentation into the computational model
- Visual modeling: Modular influence diagrams
- Features of a modeling language:
  - Declarative — not imperative
  - Purely functional — no side-effects
  - Probabilistic — to express and propagate uncertainties
  - Array abstraction: Work with arrays as elements
- Make it easy to express, propagate, and analyze uncertainties using probability distributions

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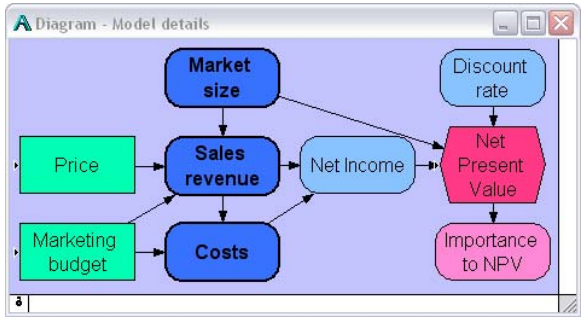
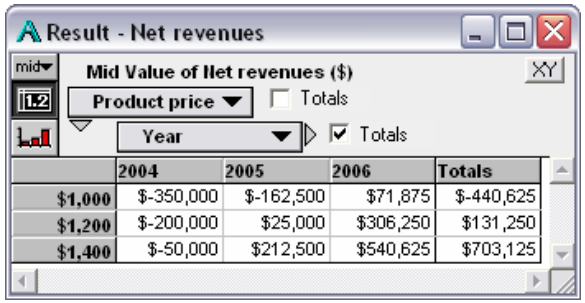
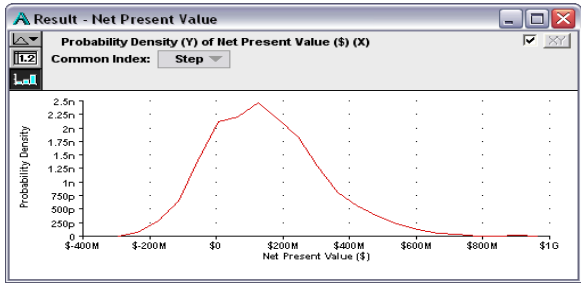
Introducing Analytica

Analytica is a visual tool for building and deploying analytic applications. It offers:

- **Transparency:** Visual influence diagrams make models easier to create, understand, and audit.
- **Flexibility:** Intelligent Arrays™ make it easy to build and extend multi-dimensional models (data cubes)
- **Risk analysis:** Integrated Monte Carlo simulation enables fast evaluation of risk and uncertainty
- **Scalability:** Hierarchical modules, Intelligent Arrays, and ultra-compact code let you manage and run models much larger than is practical with spreadsheets.







"Everything that's wrong with the common PC spreadsheet is fixed in Analytica", *PC Week*

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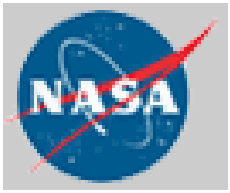
Sample Analytica applications

Tool to prioritize and manage a portfolio of R&D projects

Global market analysis of business case for a $13 billion satellite-based broadband system

Analysis of warranty costs led to savings of over $900 million per year (a major US auto maker)

Engine for online consumer advisor to help customers select credit cards, >100,000 users (VISA)



Schedule and cost risk-analysis tool for refurbishing space shuttle (NASA Kennedy Space Center)

For more, see
http://www.lumina.com/casestudies/

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Sample Analytica applications in public policy

TAF: Integrated Assessment Framework for Clean Air Act in North America (NAPAP, US EPA, DoE)

APHEBA: Benefits of cleaner air in cities in the developing world (China, Chile, India, Mexico) Cifuentes, et al., U. Catolica Santiago, Chile)

ICAM: Integrated Climate Assessment Model looking at human dimensions of global climate change (Hadi Dowlatabadi, et al. Carnegie Mellon, UBC)

Lifecycle cost risk analysis of the $50+ billion planned repository for high level radioactive waste in Yucca Mountain, Nevada (Bechtel SAIC/DoE)

Arctic whale hunting: Risks to beluga whale populations from traditional Inuit whale hunting (Oceans & Fisheries, Canada)

Farmed salmon: Comparing risks of eating farmed vs. wild salmon vs. meat (KTL - National Public Health Institute, Finland). *Science*

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An Analytica example: Cost/benefit analysis of daylighting

Analysis
Cost/Ben
adapted
M. Gabe
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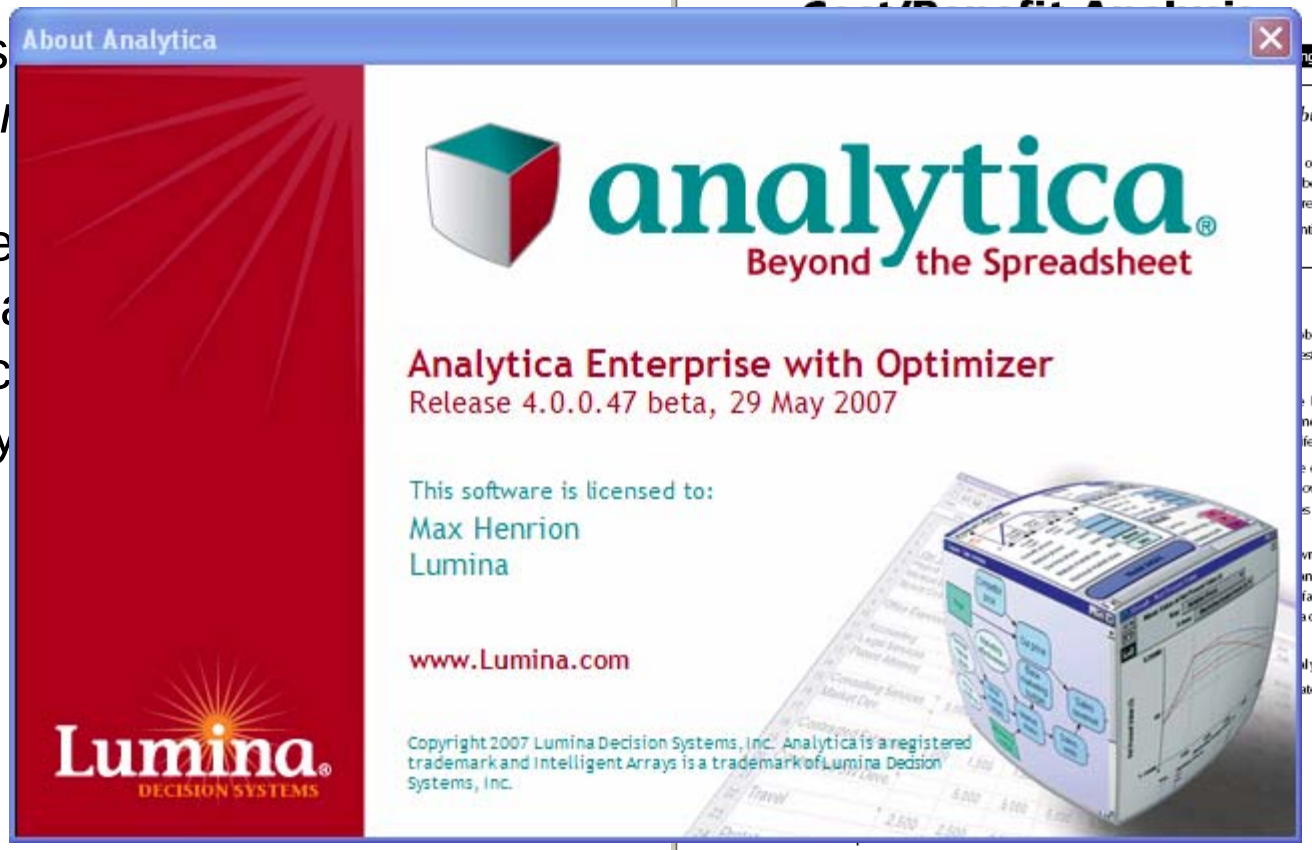
Lawrenc
Berkeley



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Integrating a model and its explanation

- Typically, documentation is written
  - after the initial model is nearly complete,
  - often not by the modeler builder, and
  - in a different "medium" - a word processor, not the modeling tool
- So
  - Documentation isn't available to help the model builders communicate
  - Model and documentation have different structures
  - Omissions and inconsistencies creep in, and are hard to spot and eradicate
- *Integrated documentation* reduces these problems by combining model and explanation into the same electronic document
  - readable by human *and* computer

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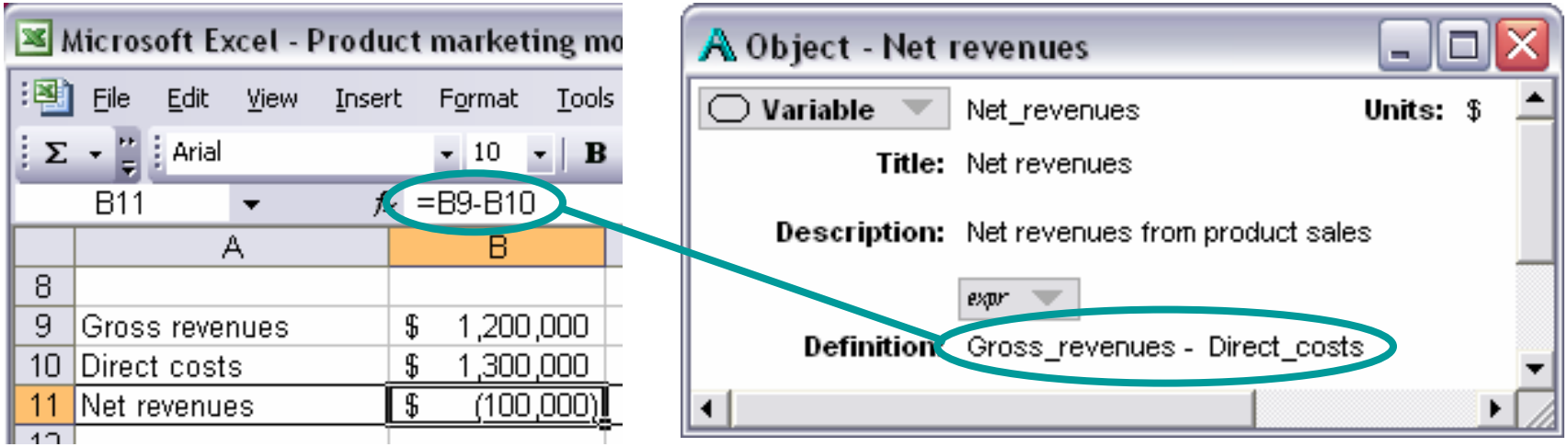
Meaningful variable names & structured documentation



- Use meaningful variable names not obscure cell references
- Use structured model documentation, integrated with the model

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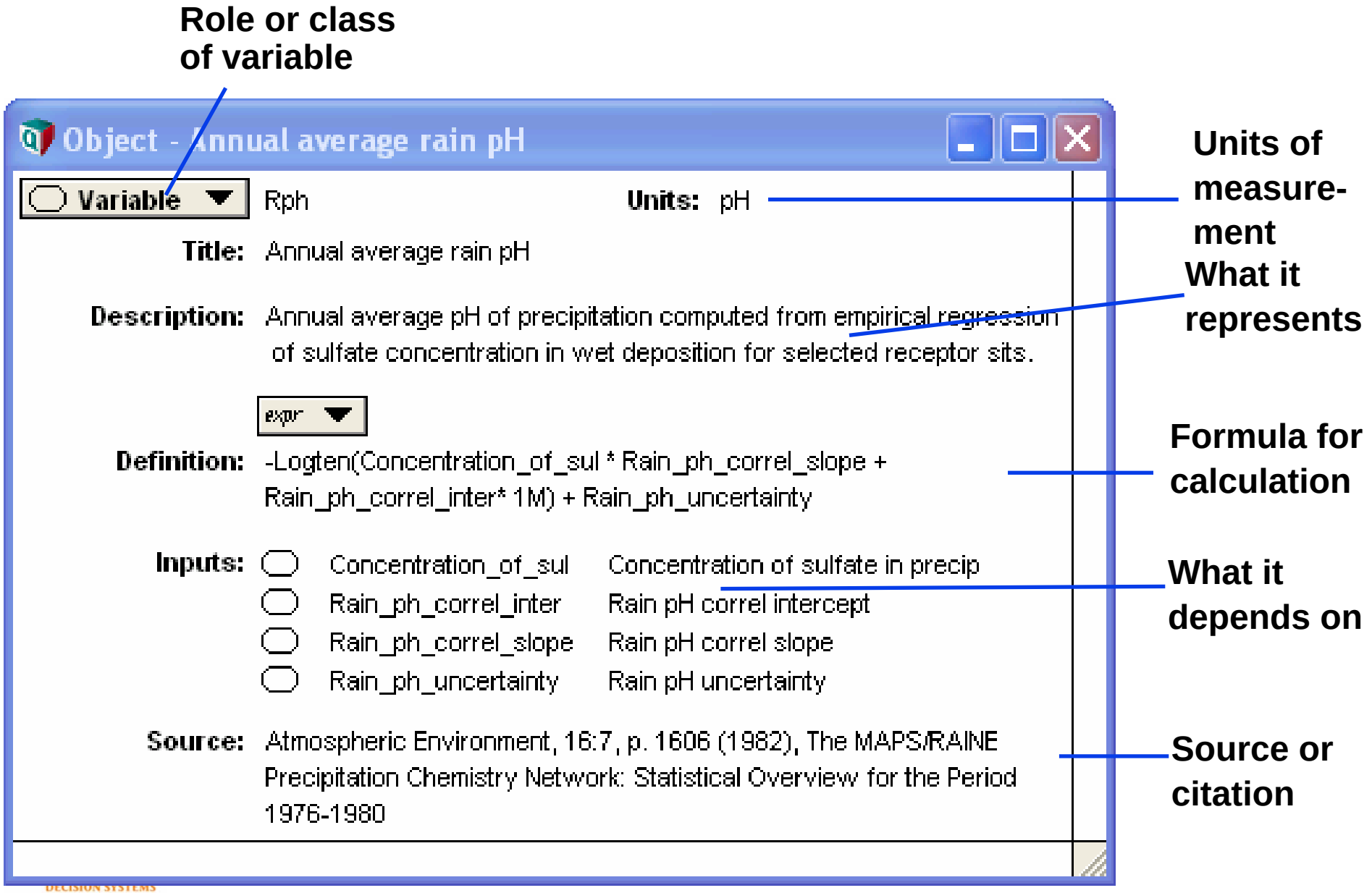
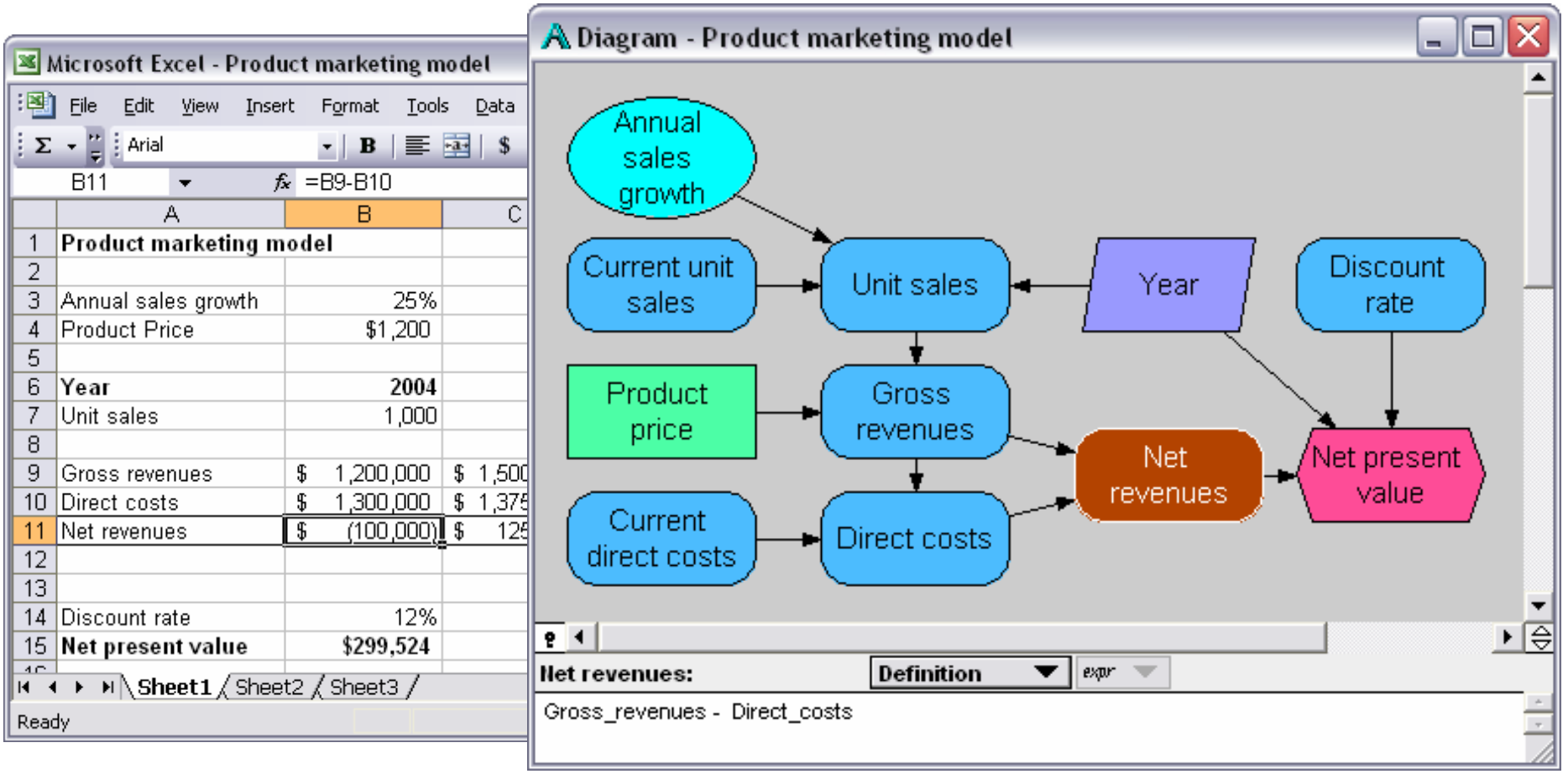
Structured documention



A visual modeling language



- Identify the *role* of each variable: Certain or probabilistic, decision or objective, input or output.
- Visualize dependencies between variables

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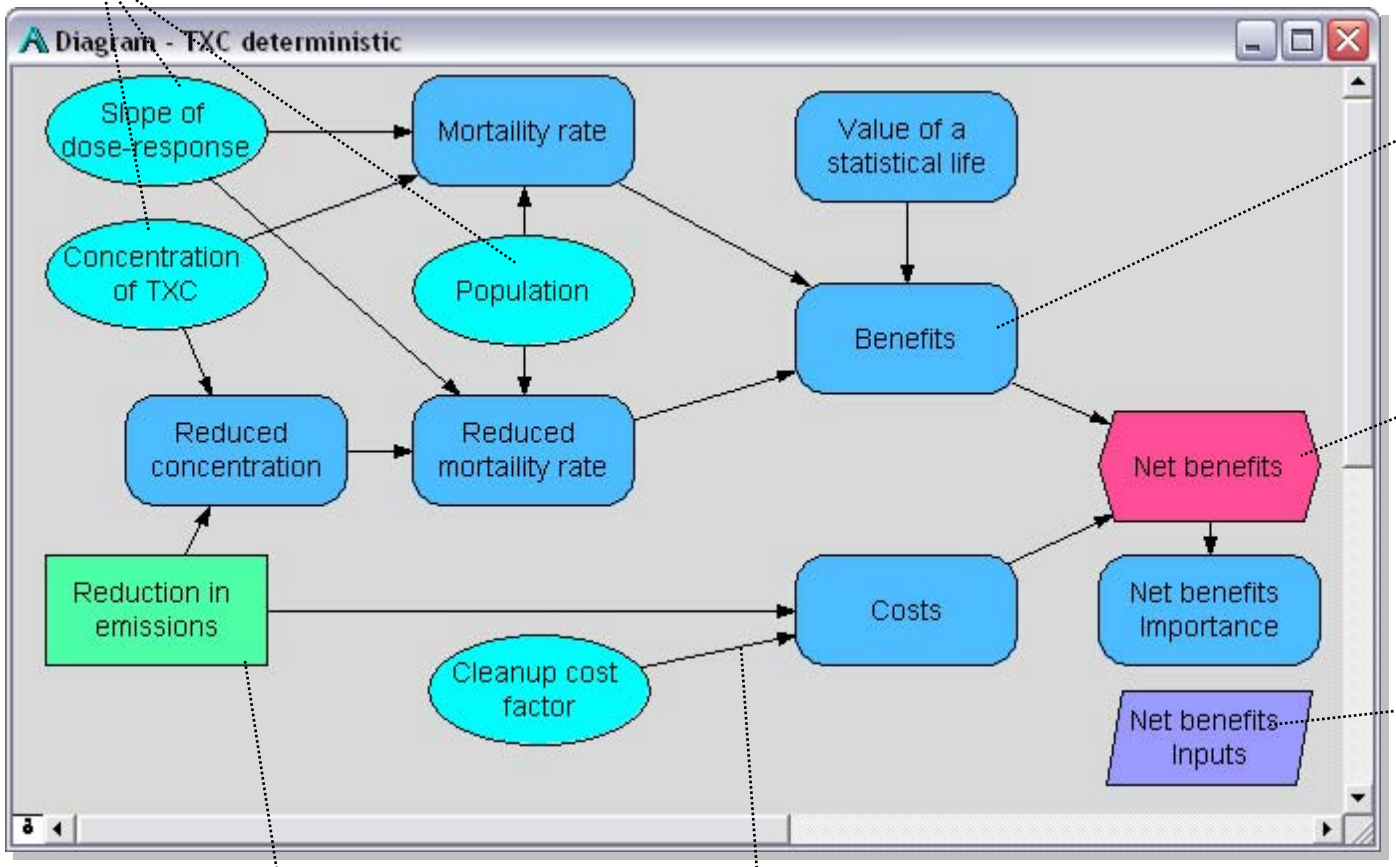
An influence diagram

Chance variables



Simple variable

Objective

Index

Decision

Arrows show *influences* between variables

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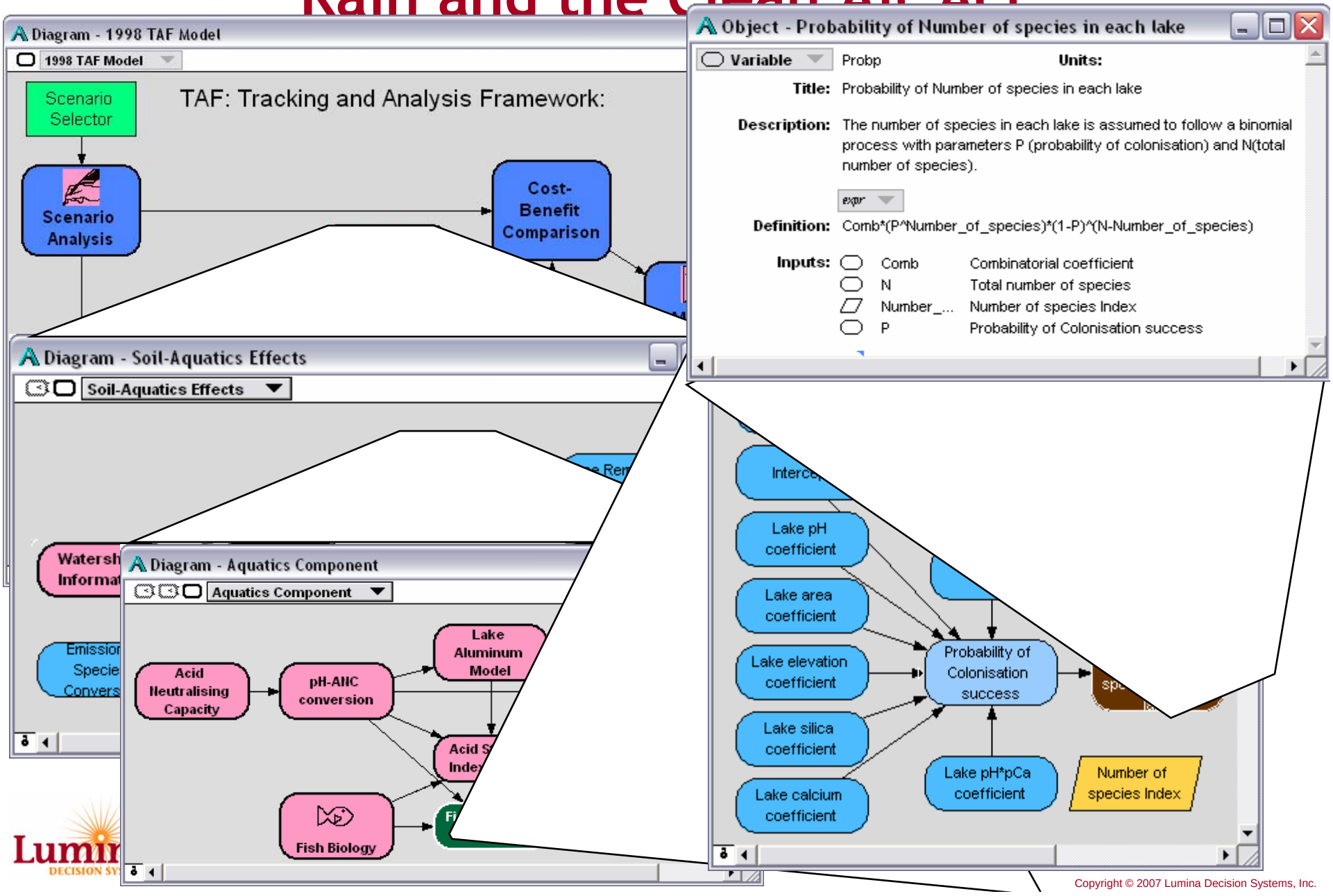
TAF: Integrated Assessment of Acid Rain and the Clean Air Act



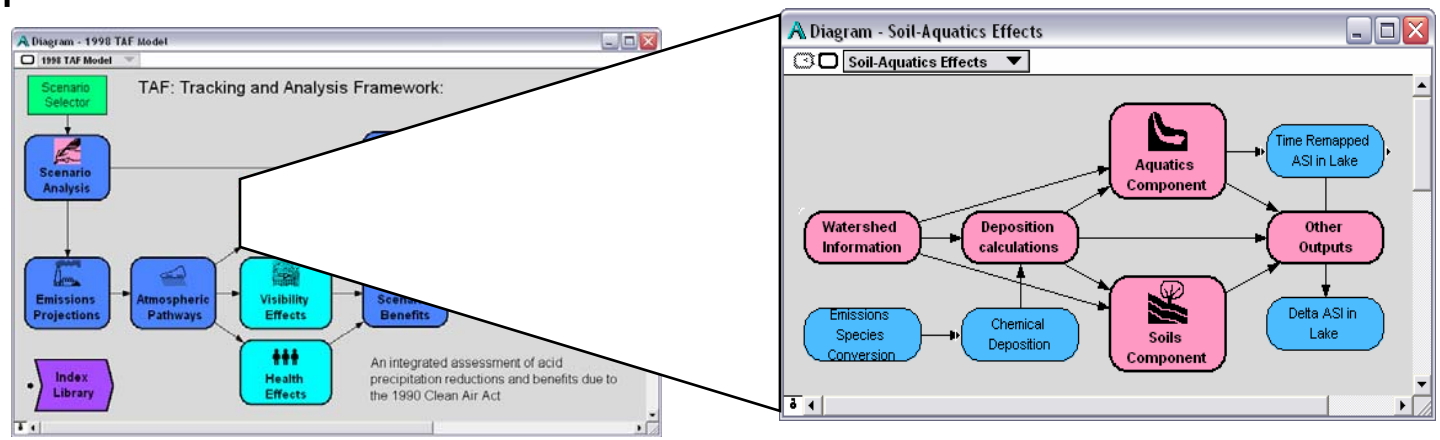
How hierarchical influence diagrams support transparency

Influence diagrams

- Facilitate collaborative sketching of concepts
- Identify role of each variable by node shape: decision, chance, objective, etc.
- Document model structure accurately
- Show influences as arrows, which automatically reflect dependencies in formulas

Module hierarchies

- Organize complex model into comprehensible pieces
- Enable intuitive navigation and drill down to details
- Support collaborative development by distributed developers
- Encourage creation of reusable modules and libraries



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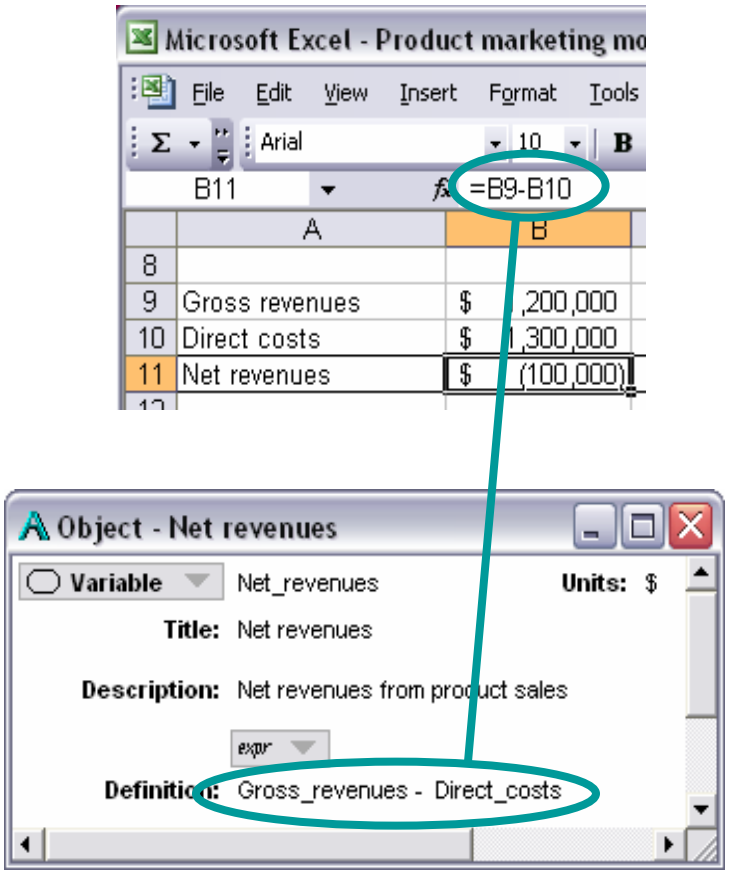
Analytica as a programming language

Analytica (like a spreadsheet) is

- **Declarative** (not imperative): A model is an unsequenced set of variables and functions. Analytica, not the modeler determines sequence of execution
- **Functional** (not procedural): Execution has no side-effects
- So, you can write and understand each variable or function as an independent unit. This makes models much easier to build, understand, and verify.

Unlike a spreadsheet, Analytica supports:

- **Probabilistic computation**: Any value can be a distribution, with Monte Carlo simulation.
- **Array abstraction** (Intelligent Arrays™): It operates on multidimensional arrays, just like on scalar values. This reduces complexity by orders of magnitude relative to spreadsheets.



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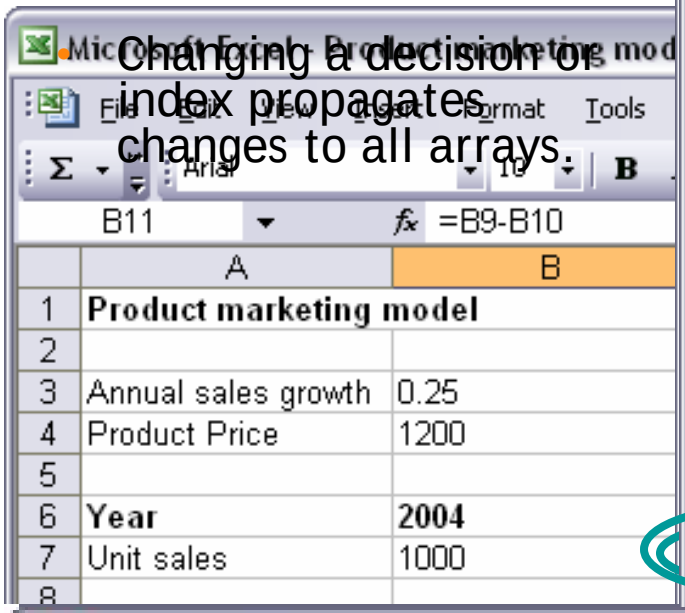
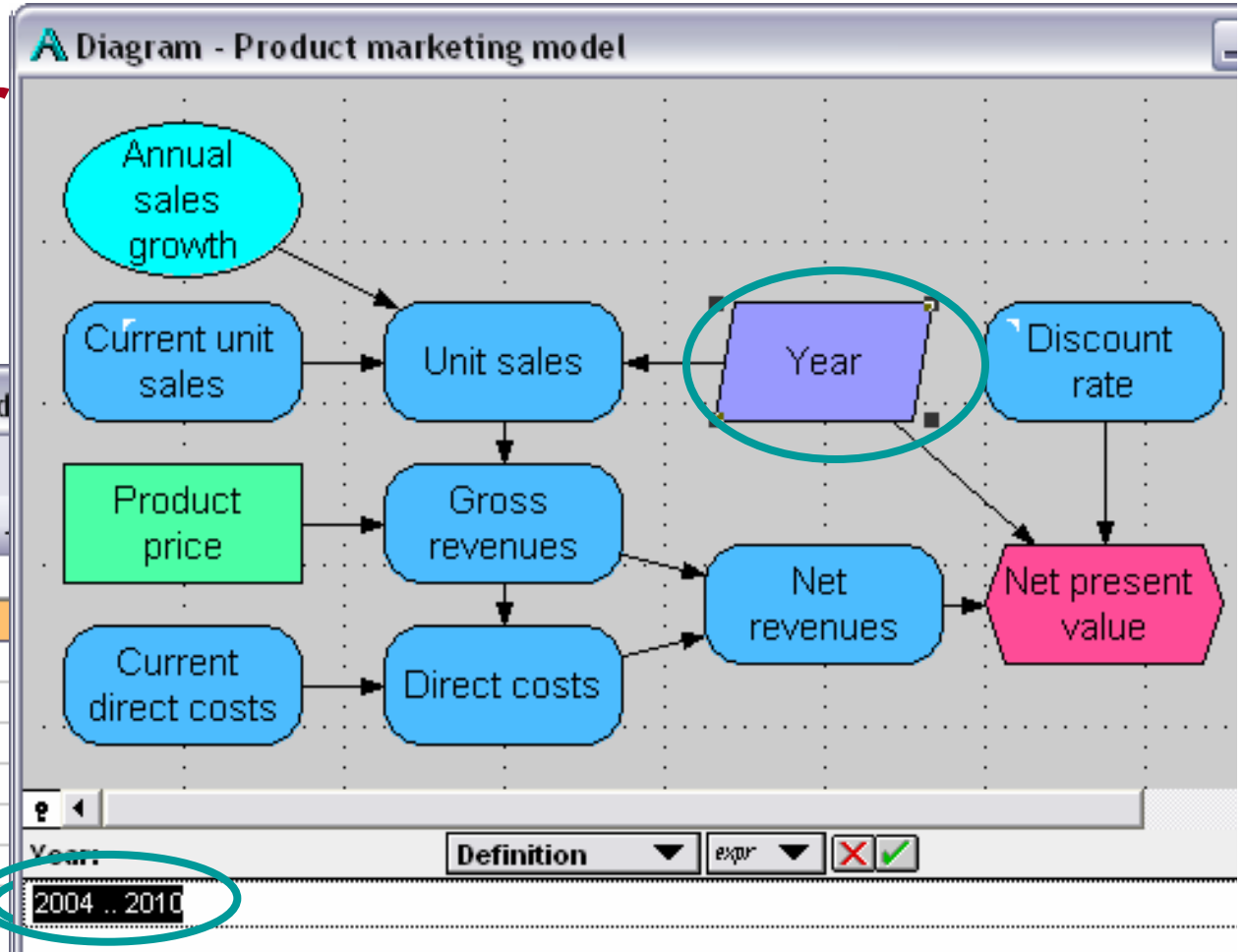
Ar

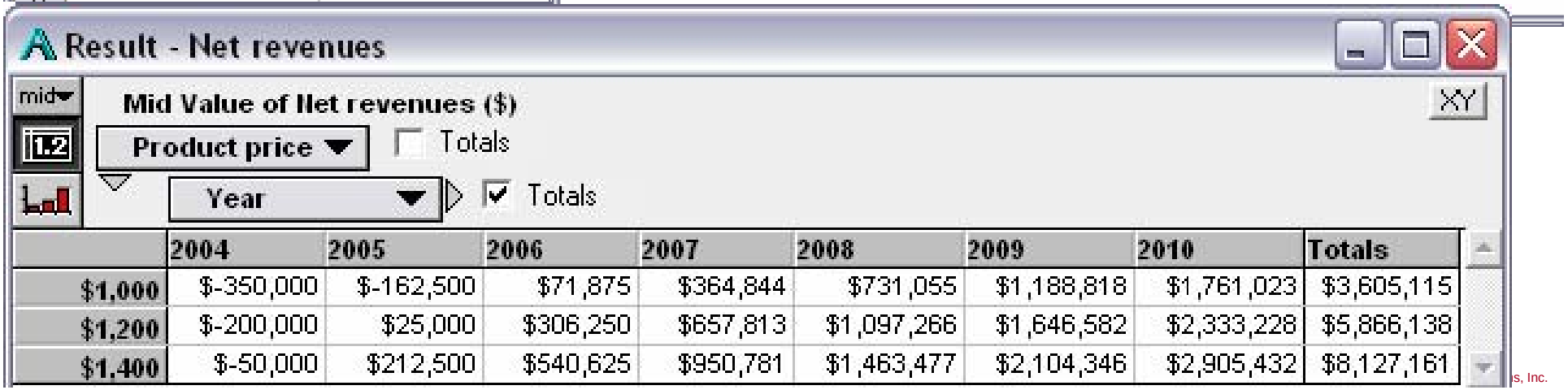
- Where a spreadsheet has a formula in each cell of a table, Analytica uses just one per array

Changing a decision or index propagates changes to all arrays.



	A	B
1	**Product marketing model**	
2		
3	Annual sales growth	0.25
4	Product Price	1200
5		
6	**Year**	**2004**
7	Unit sales	1000
8		





	2004	2005	2006	2007	2008	2009	2010	Totals
$1,000	$-350,000	$-162,500	$71,875	$364,844	$731,055	$1,188,818	$1,761,023	$3,605,115
$1,200	$-200,000	$25,000	$306,250	$657,813	$1,097,266	$1,646,582	$2,333,228	$5,866,138
$1,400	$-50,000	$212,500	$540,625	$950,781	$1,463,477	$2,104,346	$2,905,432	$8,127,161

Why should we quantify uncertainty explicitly?

- We know it's there – let's be explicit (and transparent) about how much
- It's standard scientific method – policy analysts should do the same
- With multiple sources of data or calculations, knowing their uncertainty helps us combine them
  - E.g. model predictions vs. monitoring results of air quality
- Uncertainty analysis guides us in deciding where and how much further research is worthwhile

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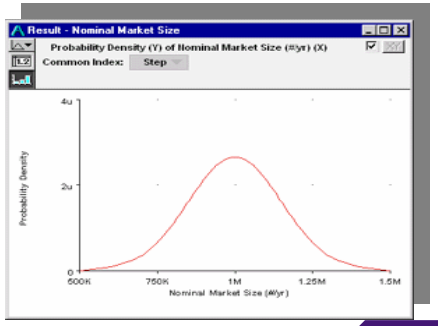
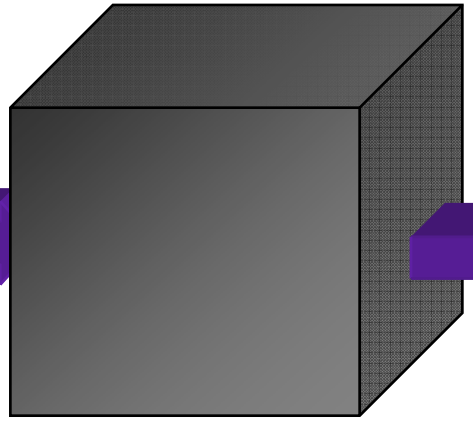
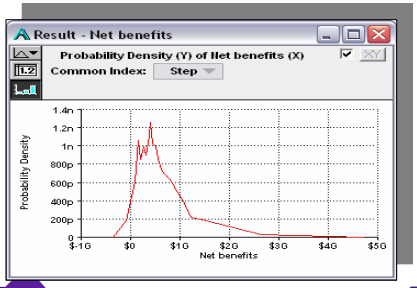
How does one assess uncertainty in quantitative policy models?



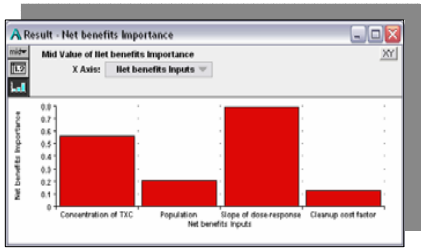
1. Express uncertainty by eliciting **probability distributions** from experts



2. Use **Monte Carlo** simulation to propagate probability distributions through the model.



3. View uncertainty on key results



4. Use **sensitivity analysis** to compare effects of uncertain assumptions on results

5. Make a decision: e.g. maximize expected value (net benefits)

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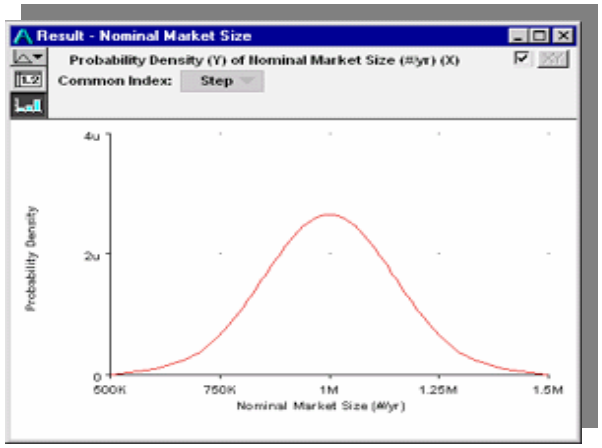
1. How to express uncertainty as probability distributions



- Probability is the clearest, most widely used language for expressing uncertainty
- Statistics helps us understand the uncertainty in data
- Where science is uncertain, eliciting probability distributions from a range of experts is a way to quantify the current state of scientific knowledge

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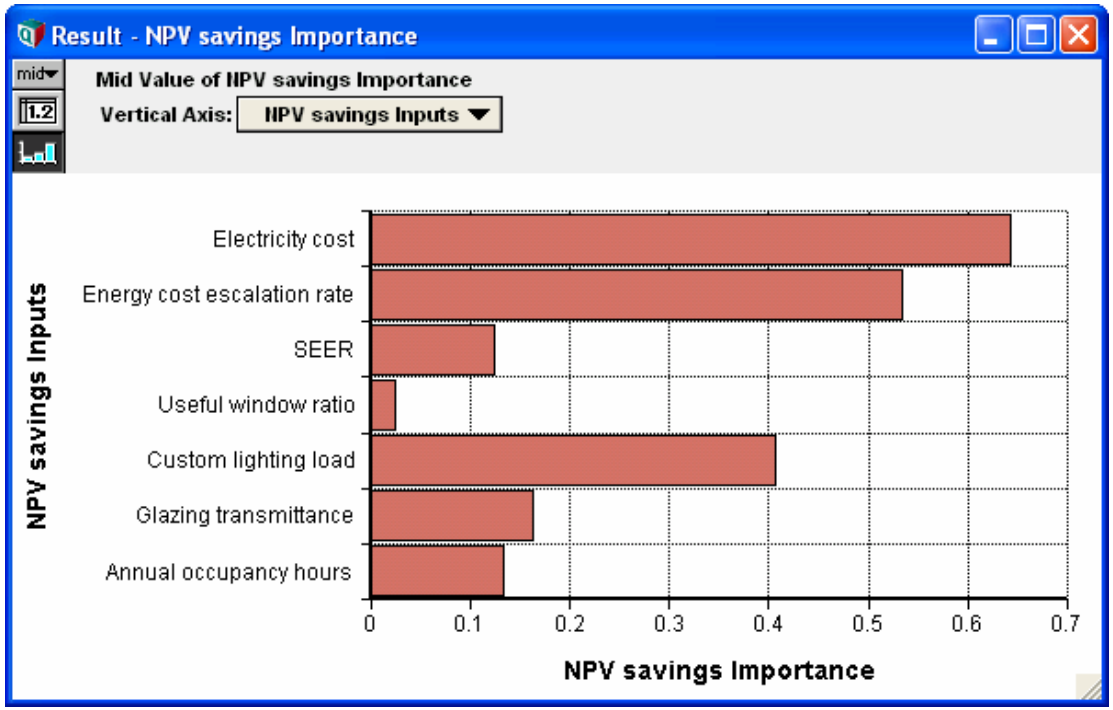
4. Sensitivity analysis: Which uncertainties matter most?



- Sensitivity and uncertainty analysis quantify relative contribution of each input to uncertainty in output
- A potent source of insights.
- Suggests priorities for further research

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5. Making decisions under uncertainty

- Virtually, *all* important decisions are made under uncertainty – whether we acknowledge it or not.
- Usually, we select the decision with the maximum *expected* value (net social benefit)
- If net benefits are large relative to the uncertainty, we can act now
- If not, we can weigh expected benefits of awaiting better information
- We can assess the value of more research using the expected value of information

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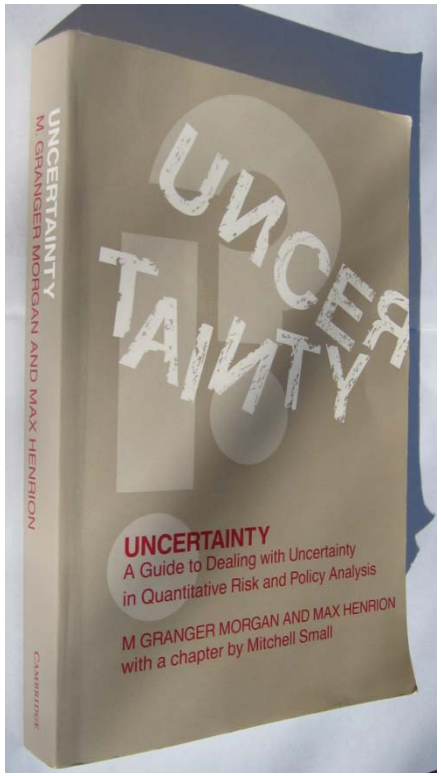
Isn't it too difficult to quantify uncertainty?

- Arguably, it may have been impractical 25 years ago.
- Nowadays, there are widely agreed methods, convenient software, detailed guide books, good examples, and experienced practitioners.



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How big should a model be?

A theory [model] should be as simple as possible, but no simpler.

Albert Einstein

Work expands to fill the time available for its completion.

Cecil Northcote Parkinson

Models expand to exhaust the computational — and human — resources available

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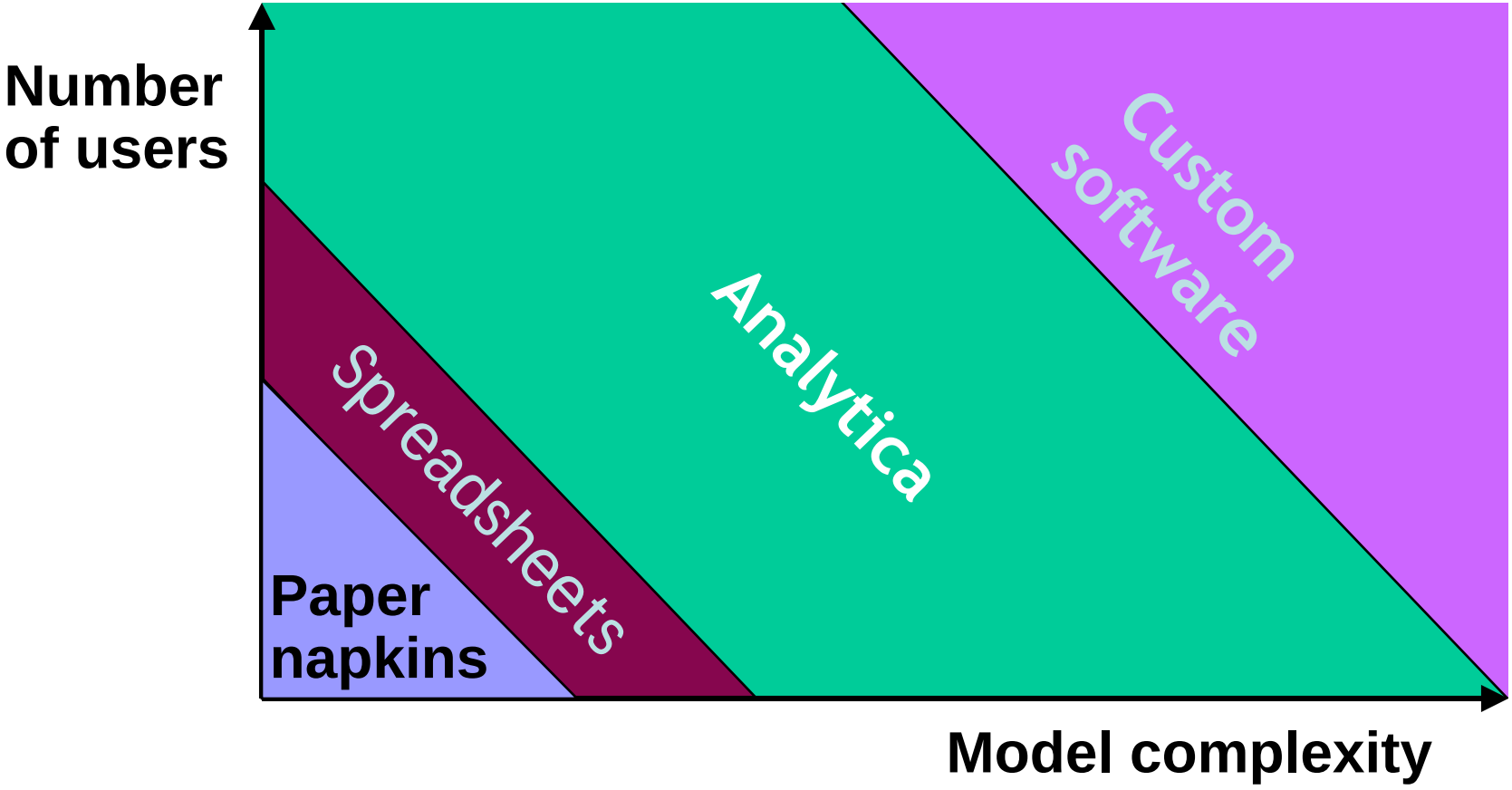
Choosing a modeling tool to suit the application



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Explanation, not "documentation"

- Documentation sounds like a tedious duty for the unknown reader
- An effective explanation is tailored to the knowledge, interests, and goals of audience
- The most effective explanation is an interactive process, between explainer and explainee

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Open-source policy modeling:
A modest proposal

All computer models used by government to evaluate or justify public policy should be *open source*

That is, the source program code in which the models are written should be publicly available for anyone to download, review, run, and modify.

Does this mean we may only use open-source tools?

No. We can still use proprietary software, like Microsoft Excel, or Analytica — as long as the model code is public and the tool is easily available.

Max Henrion, Open-Source Policy Modeling: A Commentary, *I/S, J. of Law and Policy for the Information Society*, (in press)

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Why open-source policy models?

- Anyone — policy analysts, industry, NGOs, students, public, other agencies — should be able to review and critique assumptions, analyze sensitivity to alternatives.
- Inspired by open-source software
  - Linux runs 30% of servers, Apache 70% of web servers, My SQL 44% of database systems, Firefox 16% of web browsers in US.
- And open-source content, notably Wikipedia
- Detect and fix errors:
  - "Given enough eyeballs, all bugs are shallow.'' *Linus's Law*, (*The Cathedral and the Bazaar*, Eric Raymond, 1996).
- Imagine a growing community of open-source policy modelers checking, comparing, building open, recombining, each others models, in selected domains of energy, environment, public health, criminal justice, defense analysis….

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Challenges for open-source policy modeling

- Maintaining data confidentiality
- Intellectual property and proprietary models
- Tracking responsibility and credit:
  - "Encouraging lots of improvement is a good thing, but users have a right to know who is responsible for the software they are using. Authors and maintainers have reciprocal right to know what they're being asked to support and to protect their reputations." (Open Source Definition)
  - Integrity of Author's code. Editing vs. patch releases.
  - Pedigree and version management
- Controversy: Would Wikipedia's *Neutral Point of View* (NPOV) work for policy modeling?

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Open source ≠ transparency, but they support each other

- Transparency helps make open source work, so that others can understand, extend, and reuse models
- Open source improves transparency
  - Modelers may try to be clearer when their code will be scrutinized by peers
  - If the code is a mess anyway, others can clean it up — or replace it

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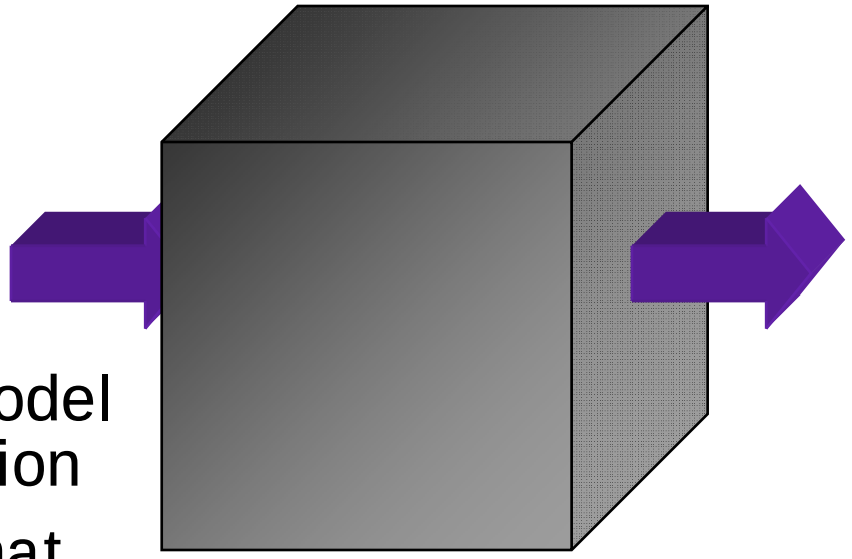
Summary: How can we open up the black box?



- Integrate explanation and model into a combined representation
- Use a visual modeling tool that encourages transparency: Modular structure, integrated docs, probabilistic, declarative, functional language, array abstraction.
- Treat uncertainty explicitly
- Explain – don't "document"
- Practice open-source modeling

- If we do all this, are we guaranteed transparent models?

No. But it will sure help!

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Comparing Analytica with other modeling software

	Benefits:	Transparency and clarity	Managing risk and uncertainty	Flexibility and scalability
Product categories:	Features:	**Visual modeling**	**Probabilistic simulation**	**Multiple dimensions**
Spreadsheets	E.g. MS Excel	**No**	**No**	**No**
Risk add-ins to Excel	E.g. Crystal Ball, @Risk	**No**	**Yes**	**No**
Visual simulation	E.g. Stella/iThink, Extend	**Yes**	**Some**	**No**
Decision Analysis	E.g. DecisionAdvisor, DPL, TreeAge DATA	**Yes**	**Yes**	**No**
OLAP **Business Intelligence**	E.g. Business Objects, Hyperion, Microsoft Analysis Services	**No**	**No**	**Yes**
Lumina DECISION SYSTEMS	analytica	**Yes** Influence diagrams	**Yes** Monte Carlo	**Yes** Intelligent Arrays™

Editions of Analytica

- Analytica Trial: Free for 15 days
  - Provides full functionality of Analytica Professional
- Analytica Player: Free
  - View and run, change inputs, but not save model:
- Analytica Professional: $1295
- Analytica Enterprise: $2495
  - ODBC database access, Huge Arrays, saves models as Browse-only, encrypts sensitive data and models.
- Analytica Enterprise with Optimizer: $3995
- Analytica Decision Engine (ADE): $5000
- Analytica Web Publisher (AWP): Coming soon!

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Support and consulting

- Free Webinar with live demo every week
- QuickStart Coaching
  - Four hours of personalized coaching via web-conference
- Two-day Analytica Training
  - **Boston, Mass, Jan 17 - 18th 2007**
  - Los Gatos, California, Washington DC, or your site
- Conversion of spreadsheets into Analytica
- Spreadsheet audit and verification
  - Guaranteed verification of mission-critical spreadsheets by conversion into Analytica
- Consulting on modeling and decision analysis
- Co-development of analytic applications

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Analytica 4.0: Key enhancements

- Completely new graphing & charting
- Auto save
- Weighted sampling for greater precision with Monte Carlo
- Node coloring for sensitivity analysis
- Improved speed
- Expected release Q1 2007

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Announcing:
Spreadsheet verification service

- We convert your mission-critical spreadsheet into Analytica
- We test both with extensive sensitivity and scenario analysis
- We fix any spreadsheet errors we find, so that both versions give identical results
- The cost is comparable to a conventional audit, but this process is far more rigorous.
- **Guarantee:** No errors, or price refunded
- **The result:** Justified confidence in the results of your spreadsheet

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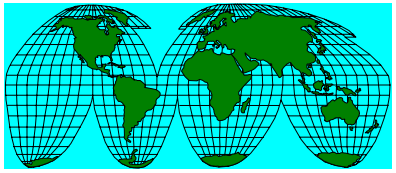
Some Analytica users:

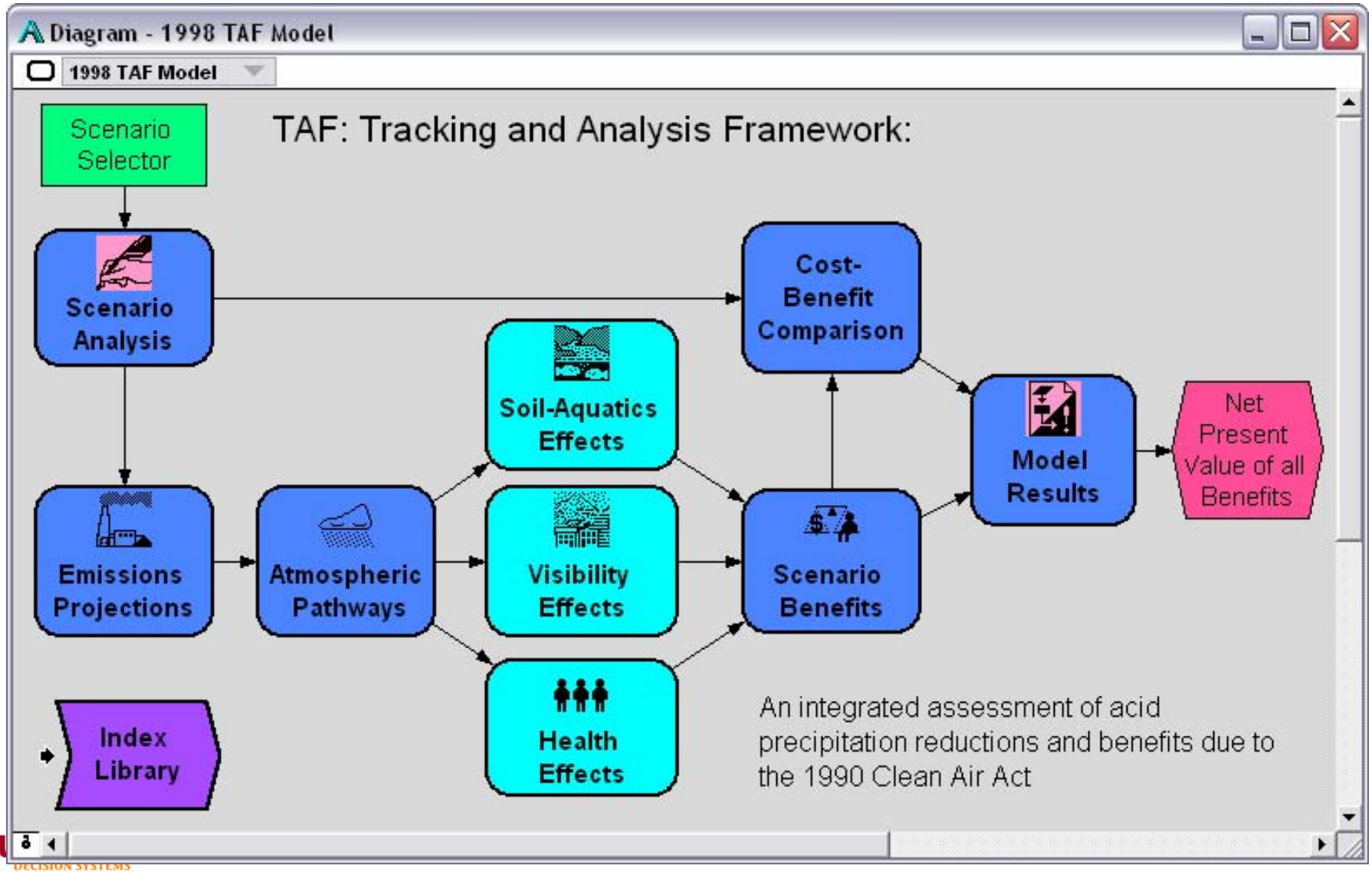
Aerospace/defense:	Army Corps of Engineers, Boeing, DARPA, FAA, Hughes, JPL, Lockheed Martin, Los Alamos, NASA, Northwest Airlines, USN/NOSC, USAF
Automotive:	Daimler-Chrysler, General Motors, Ford
Consulting	Accenture, Battelle, Bechtel, Deloitte & Touche, Ernst & Young, McKinsey, SAIC, PWC, Mitre, RAND Corporation
Energy/environment:	ARCO, Ballard, BP-Amoco, Chevron, Conoco, DoE, EPA, Environment Canada, EPRI, NRC, NREL, Quebec Hydro, Schlumberger, S Cal Edison, South Africa Power, Westinghouse
Financial services:	Guy-Carpenter, Merrill Lynch, MBNA, JPMorgan Chase, Morningstar, Warburg Pincus, Marsh & McLennan, VISA
Consumer:	Nike, Procter & Gamble, Unilever, WL Gore
Health & pharma:	Bayer, Blue Cross, CDC, Eli Lilly, FDA, Health Canada, NIOSH, Novartis, Partners Boston, Roche, USDA, Veterans Admin
High Tech:	3M, ALCOA, AT&T, Canon, Cisco, Eastman Kodak, Ask Jeeves, HP, Lucent, MCI, Microsoft, Motorola, Seagate, Siemens, TRW, US West, Xerox
Universities	Cambridge, Carnegie Mellon, Georgia Tech, Harvard, MIT, Oxford, Penn State, Stanford, UC Berkeley, UNC, USC

40% of customers are outside the United States

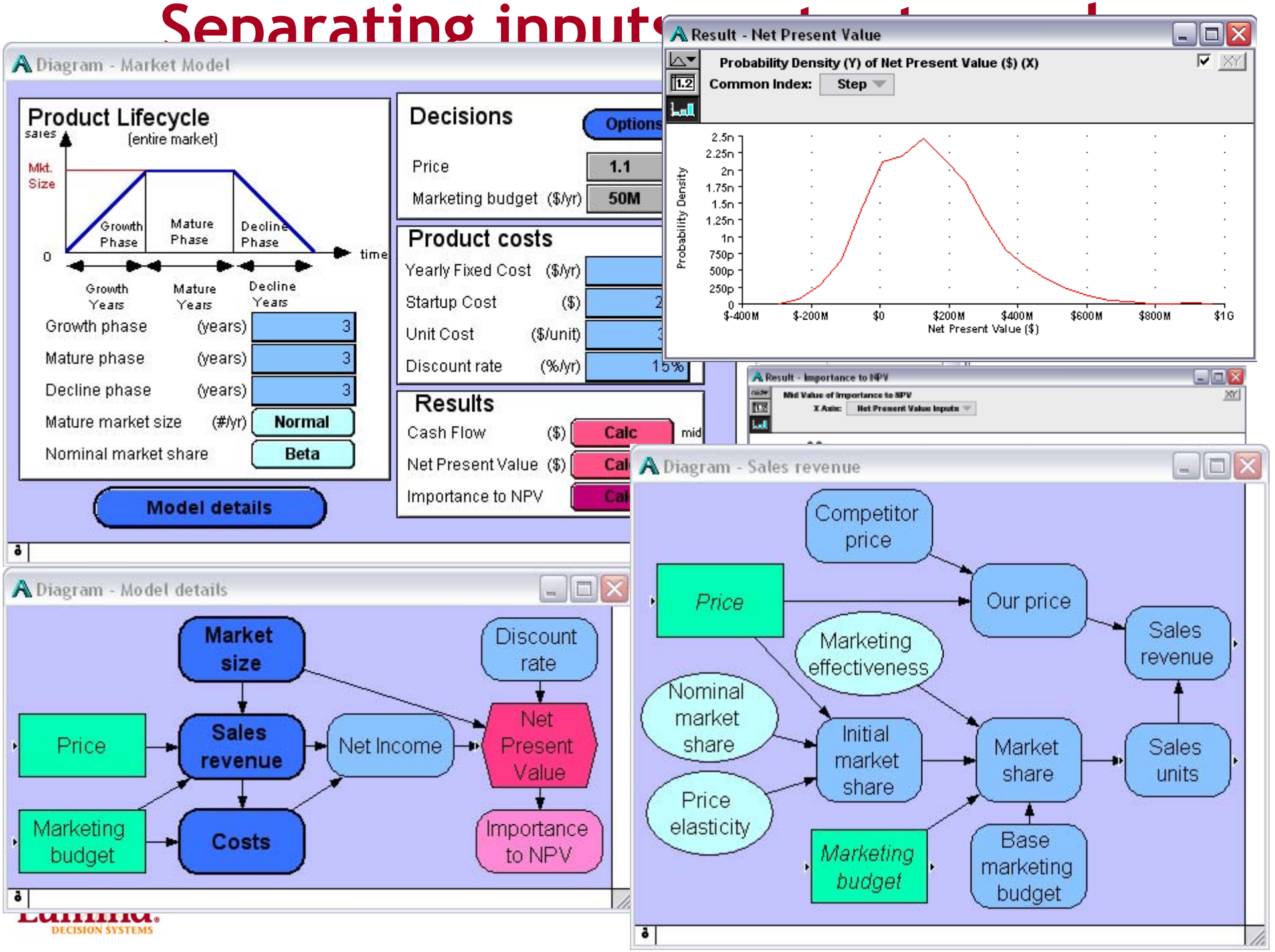


Lumina DECISION SYSTEMS

TAF: Integrated Assessment of Acid Rain and the Clean Air Act



Separating inputs



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TAF: An Integrated Assessment of Acid Rain and the Clean Air Act

- **The "Grand Experiment":** Congress tasked NAPAP (the National Acid Precipitation Program) to evaluate the costs and benefits of the US Clean Air Act (1990)
- **Distributed development:** Ten groups of scientists, analysts and modelers around the USA, at universities, government labs, nonprofit groups, and companies
- **A tractable model:** TAF was small and easy enough to run on a personal computer, freely distributable and extensible, and in the public domain
- **Reduced-form models:** Develop a relatively small and fast model that can be explored interactively and run many times for different simulations and scenarios.

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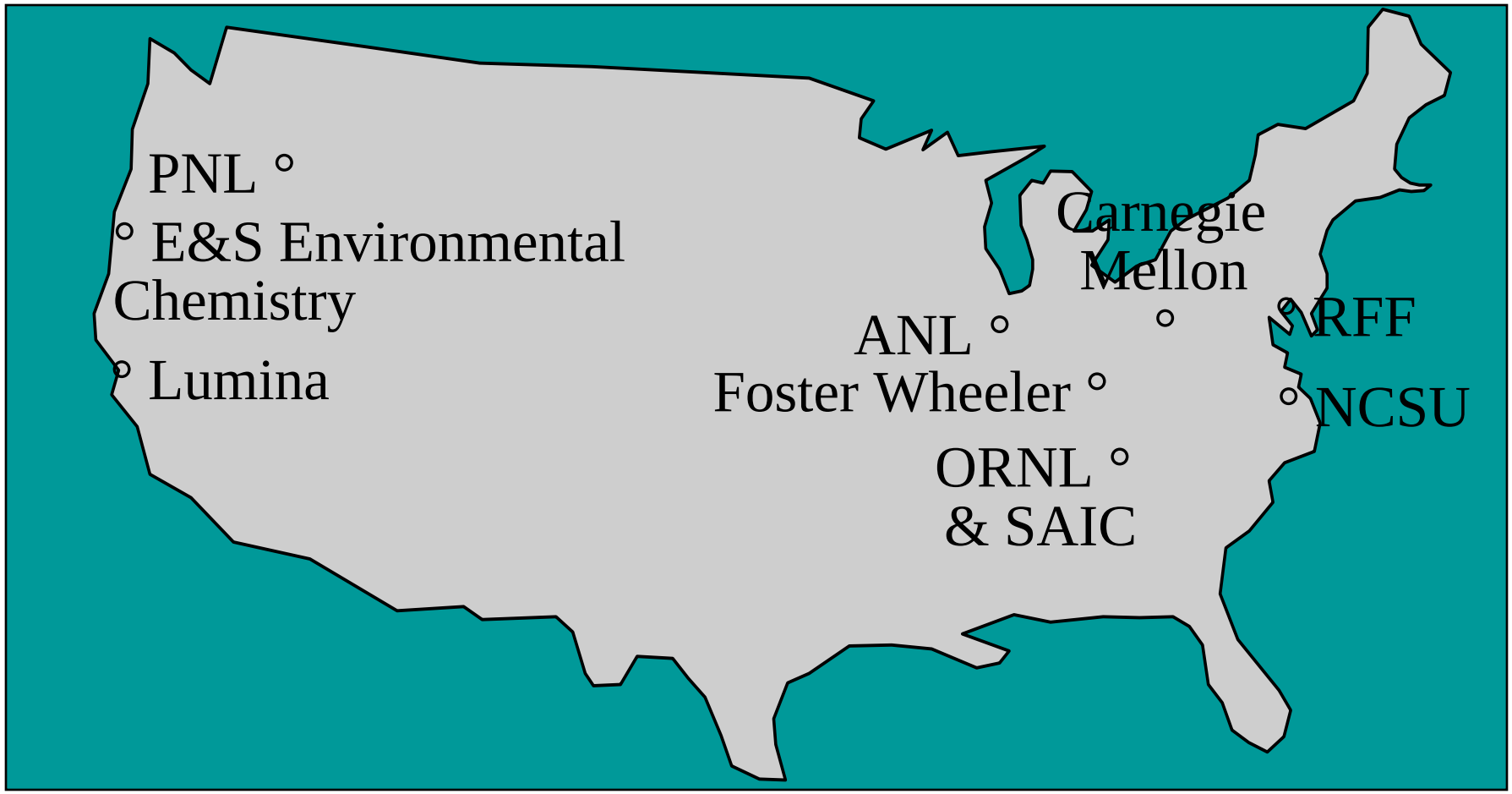
TAF: A Nationwide Collaboration



Ten groups involving 35+ scientists and economists, modelers, policy analysts created Analytica modules integrated into TAF

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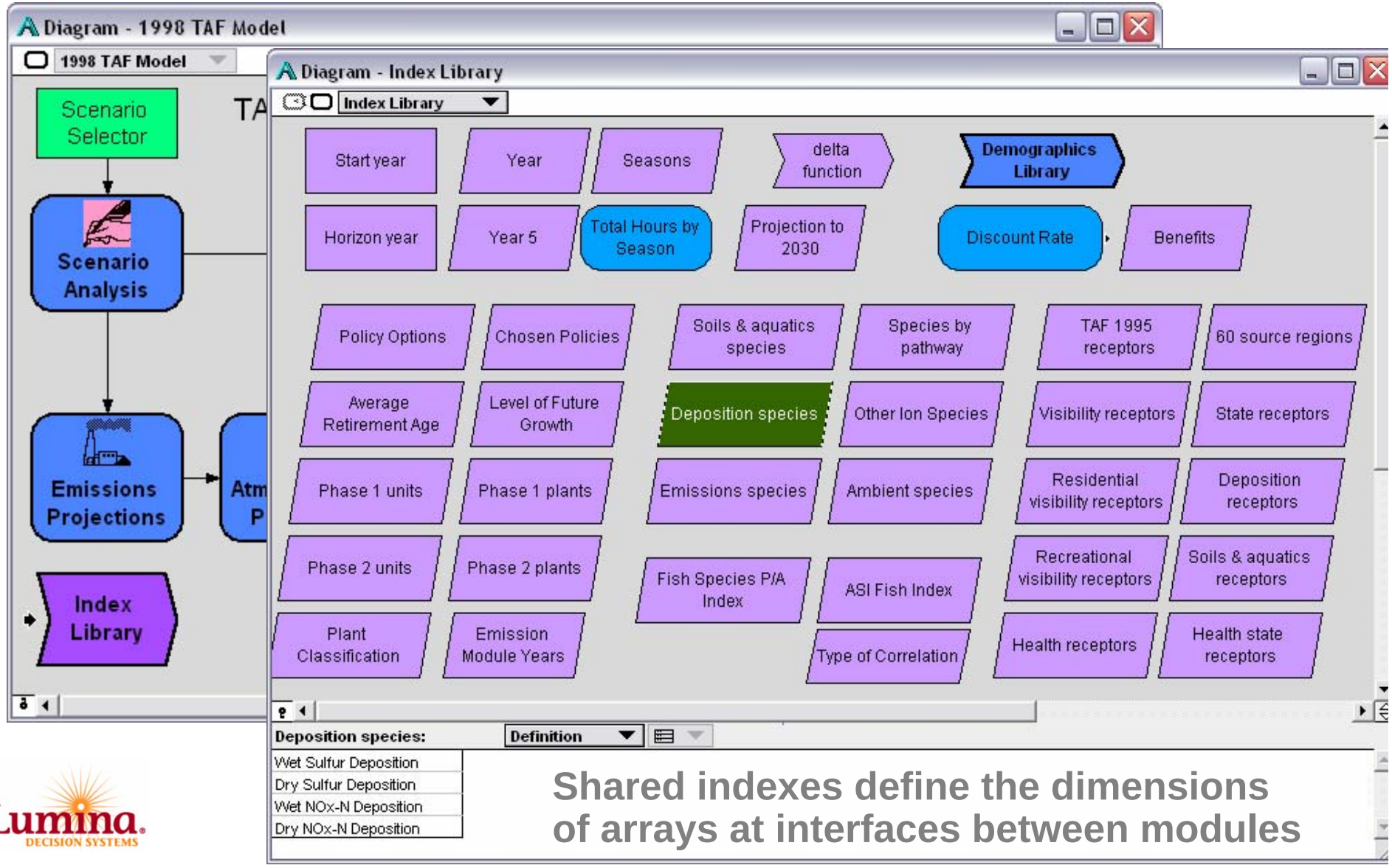
Collaborative modeling with intelligent arrays



Shared indexes define the dimensions of arrays at interfaces between modules

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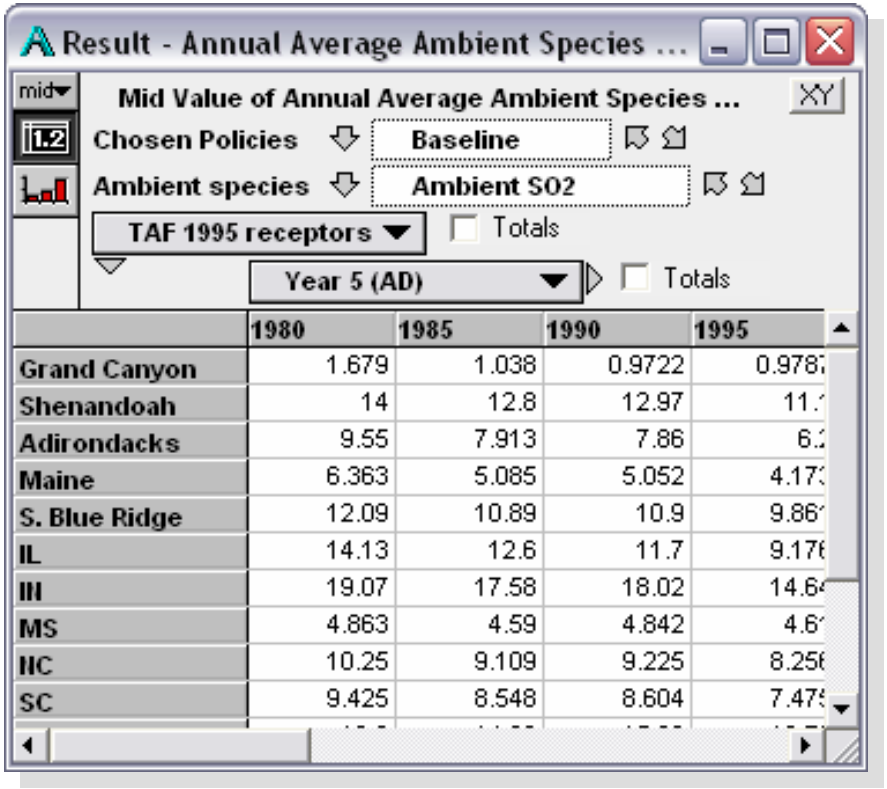
Array abstraction
or Intelligent Arrays



Ann_av_ambient_conc:=
Average(ambient_conc, Seasons)

- Expressions (formulas) do not mention indexes for array dimensions, except when they're relevant
- Editing, adding, removing indexes (dimensions) requires no changes to formulas, except where they refer to that index
- Avoiding redundant repetitions of formulas in all the cells of a spreadsheet table can reduce model size by one or two orders of magnitude.
- This hugely simplifies writing, verifying, and maintaining models
- It makes it practical to analyze sensitivity to level of detail

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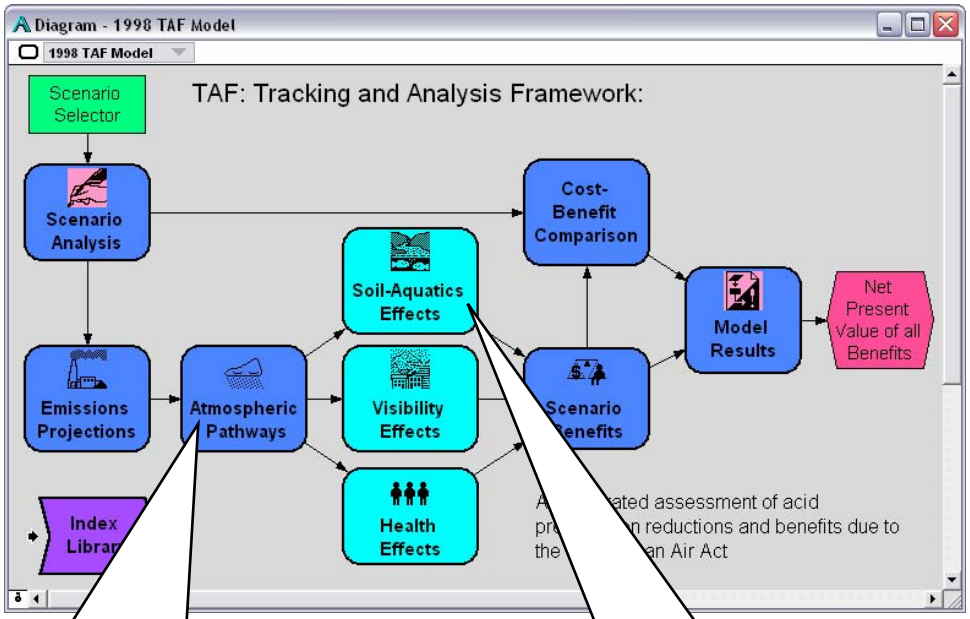
Reduced-form models: Keeping things simple



The **Atmospheric pathways** module used **source-receptor matrices** by chemical species (SOx, NOx) and season, generated by a large Eulerian transport model, **ASTRAP** (ANL)

Stream and lake acidification module based on a statistical fit to results from **MAGIC**, a detailed model from UNC.

- **Reduced-form models** are simple response-surfaces or models fitted statistically or calibrated against complex models.
- They make it practical to create integrated models linking multiple components
- Their simplicity improves transparency, and allows easy exploration of scenarios, sensitivities, and uncertainties on a laptop computer.
- Their accuracy is comparable to the detailed models against which they are calibrated