Technical and non-technical uncertainties in operational energy performance

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CIBSE BSG Event
London South Bank University
27th April 2012

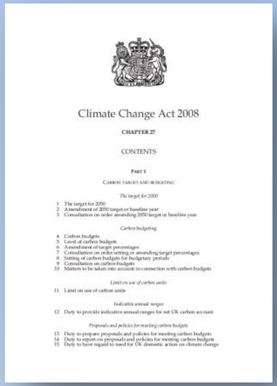
Overview

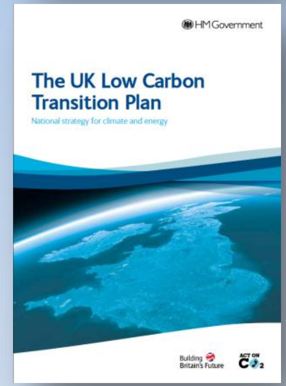
- Quick summary of the problem
- Identifying the key issues:
  - Improving simulation techniques
  - Accounting for uncertainty
  - Incorporating non-technical factors
- Proposing a way forward:

  A due diligence framework for energy performance risk management

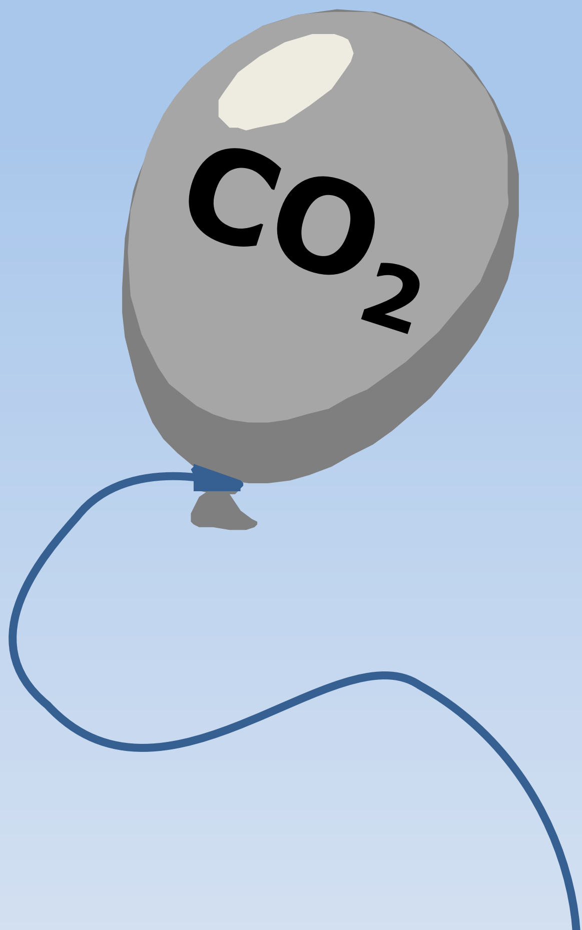
Drivers

- Climate Change Act 2008
  - Net 80% reduction on 1990 emissions by 2050
  - At least 26% reduction on 1990 emissions by 2020
- Low Carbon Transition Plan 2009
  - Emission cuts of 18% on 2008 levels by 2020
  - Over a one third reduction on 1990 levels
- Zero carbon new non-domestic construction by 2019
- Changes to Building Regulations





The big picture

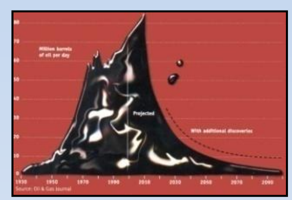


Opposition to Generation

Security of Supply

Environmental Pollution

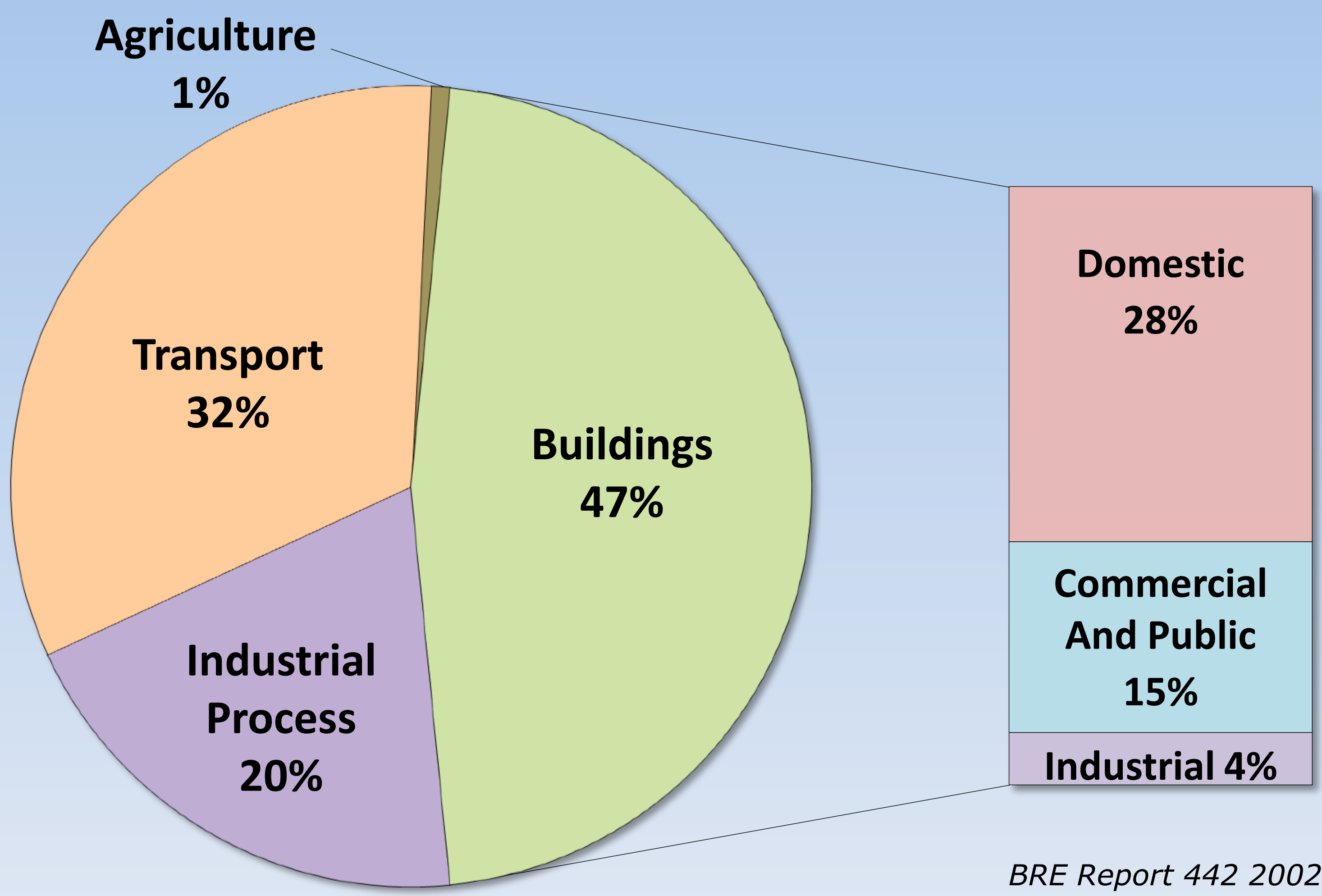
Resource Depletion



Cost

Energy Consumption

CO_2 emissions by end use



BRE Report 442 2002

Energy benchmarks

ECON19	Office Type 1		Office Type 2		Office Type 3		Office Type 4	
	G.P.	Typ.	G.P.	Typ.	G.P.	Typ.	G.P.	Typ.
Non-electric (kWh/m^2.yr)	79	151	79	151	97	178	114	210
Electricity (kWh/m^2.yr)	33	54	54	85	128	226	234	358
Total CO_2 (kgCO_2/m^2.yr)	32	57	43	73	85	151	143	226

EEBP Energy Consumption Guide 19 1998

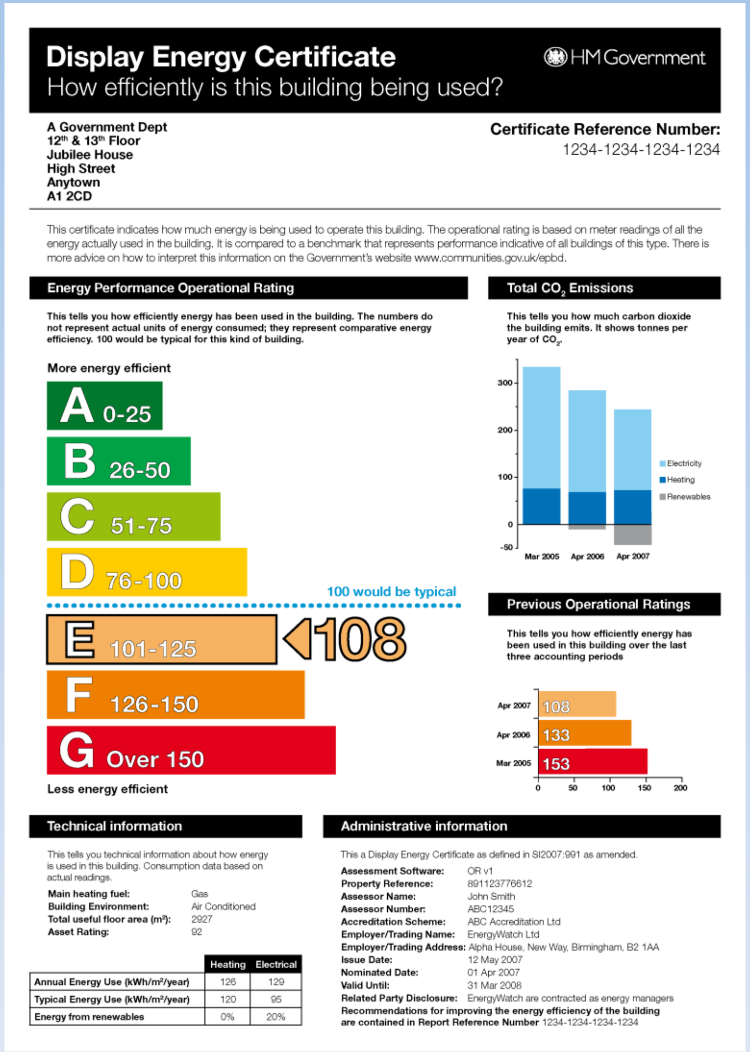
National Trust	Good Practice	Best Practice	Innovative	Pioneering
Non-electric (kWh/m^2.yr)	79	47	30	20
Electricity (kWh/m^2.yr)	54	43	35	25
Total CO_2 (kgCO_2/m^2.yr)	40	30	15	0

Gething & Bordass 2006

CIBSE	General Office
Non-electric (kWh/m^2.yr)	120
Electricity (kWh/m^2.yr)	95
Total CO_2 (kgCO_2/m^2.yr)	75

CIBSE TM46 2008

DEC data


Display Energy Certificate
How efficiently is this building being used?
HM Government

A Government Dept
12th & 13th Floor
Jubilee House
High Street
Anytown
A1 2CD

Certificate Reference Number:
1234-1234-1234-1234

This certificate indicates how much energy is being used to operate this building. The operational rating is based on meter readings of all the energy actually used in the building. It is compared to a benchmark that represents performance indicative of all buildings of this type. There is more advice on how to interpret this information on the Government's website www.communities.gov.uk/epbd.

Energy Performance Operational Rating

This tells you how efficiently energy has been used in the building. The numbers do not represent actual units of energy consumed; they represent comparative energy efficiency. 100 would be typical for this kind of building.

Total CO_2 Emissions

This tells you how much carbon dioxide the building emits. It shows tonnes per year of CO_2.

Previous Operational Ratings

This tells you how efficiently energy has been used in this building over the last three accounting periods

Technical information

This tells you technical information about how energy is used in this building. Consumption data based on actual readings.

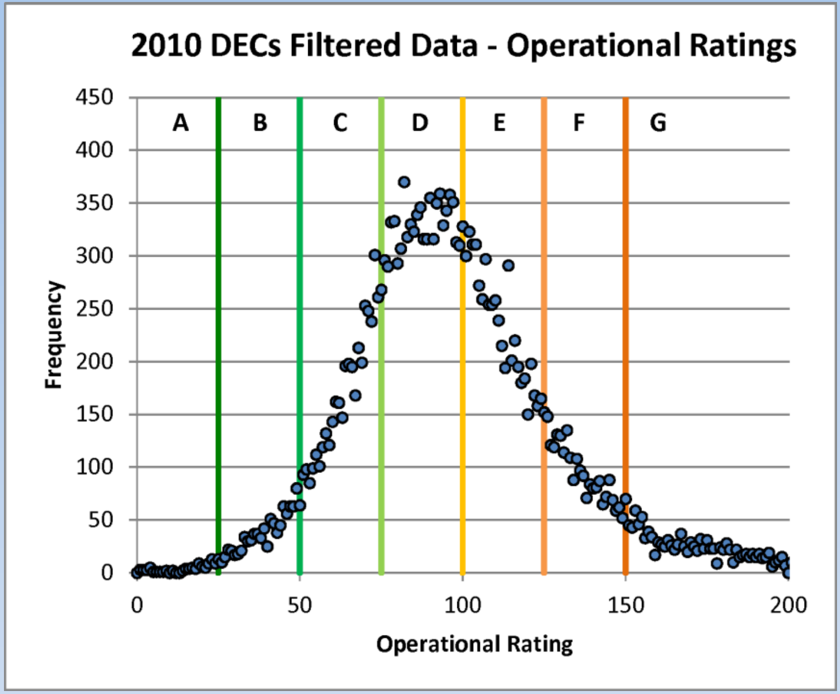
Main heating fuel: Gas
Building Environment: Air Conditioned
Total useful floor area (m^2): 2927
Asset Rating: 92

	Heating	Electrical
Annual Energy Use (kWh/m²/year)	126	129
Typical Energy Use (kWh/m²/year)	120	95
Energy from renewables	0%	20%

Administrative information

This a Display Energy Certificate as defined in SI2007:991 as amended.

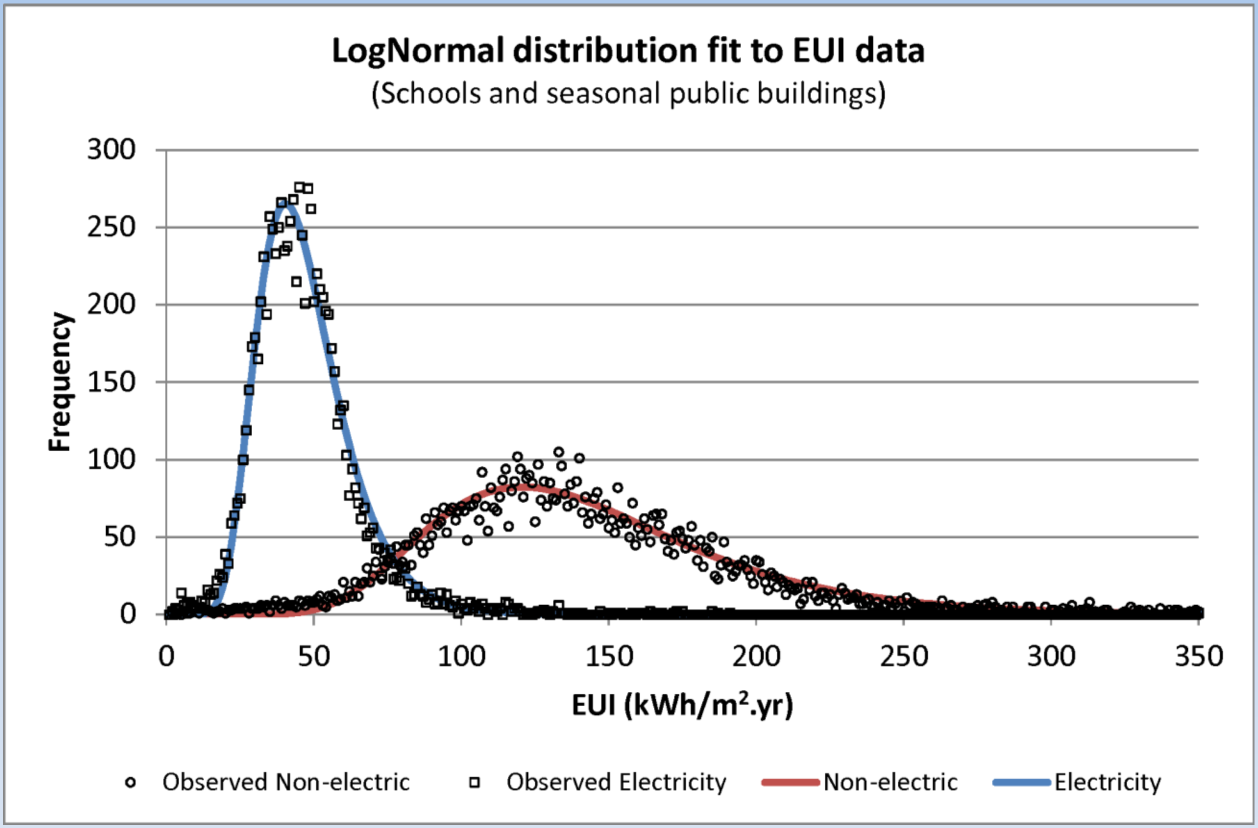
Assessment Software: OR v1
Property Reference: 891123776612
Assessor Name: John Smith
Assessor Number: ABC12345
Accreditation Scheme: ABC Accreditation Ltd
Employer/Trading Name: EnergyWatch Ltd
Employer/Trading Address: Alpha House, New Way, Birmingham, B2 1AA
Issue Date: 12 May 2007
Nominated Date: 01 Apr 2007
Valid Until: 31 Mar 2008
Related Party Disclosure: EnergyWatch are contracted as energy managers
Recommendations for improving the energy efficiency of the building are contained in Report Reference Number 1234-1234-1234-1234



- Operational i.e. 'real'
- Distribution of ratings

Source: [*http://www.cse.org.uk/pages/resources/open-data*](http://www.cse.org.uk/pages/resources/open-data)

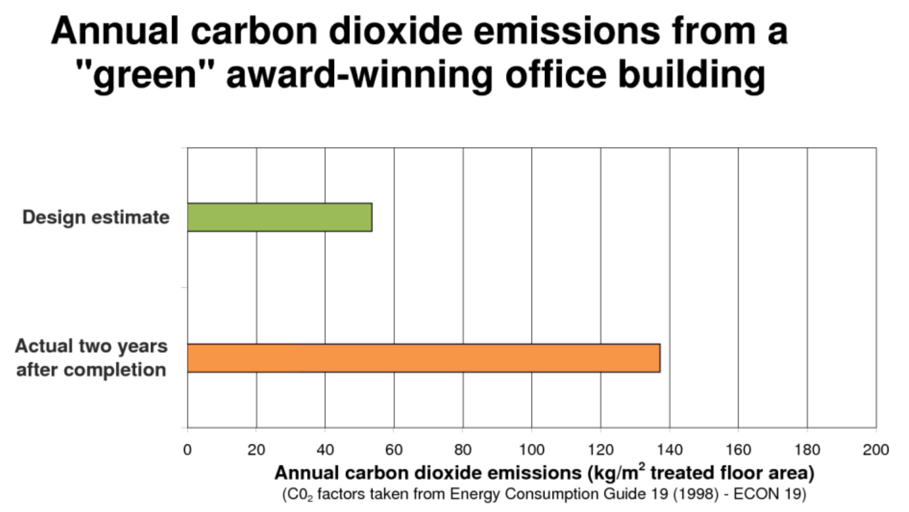
DEC data analysis



CIBSE TM46 Benchmarks (used for DECs)	Schools and seasonal public buildings
Non-electric (kWh/m^2.yr)	40
Electricity (kWh/m^2.yr)	150
Total CO_2 (kgCO_2/m^2.yr)	50.5

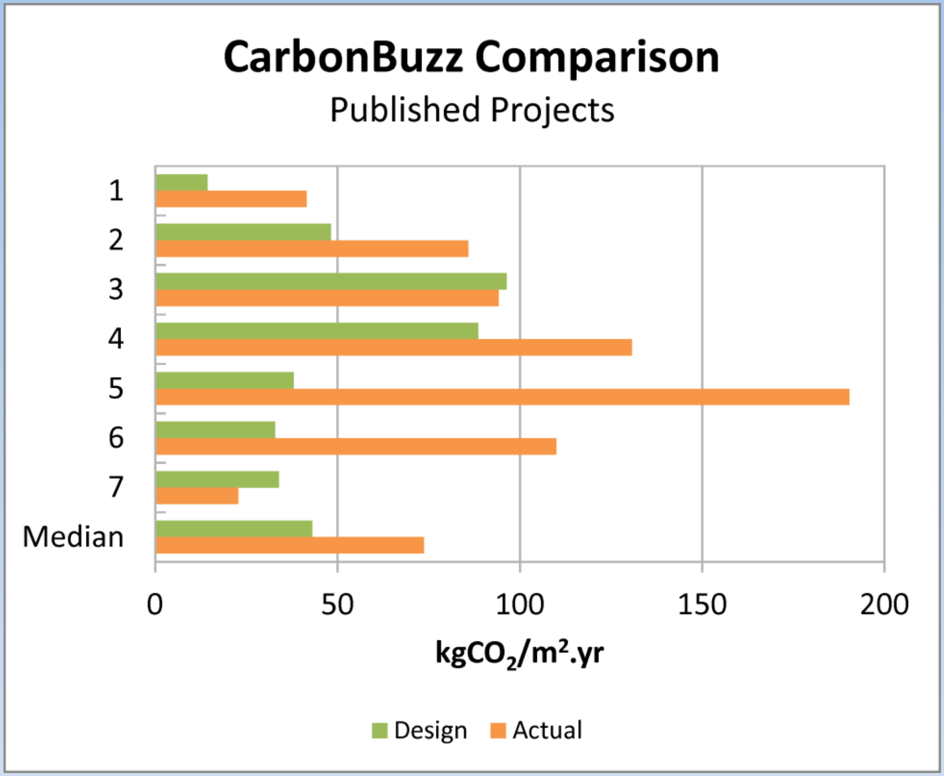
- Wider variation in non-electric than electricity energy use
- Mean electricity use close to benchmark
- Mean non-electric use lower than benchmark

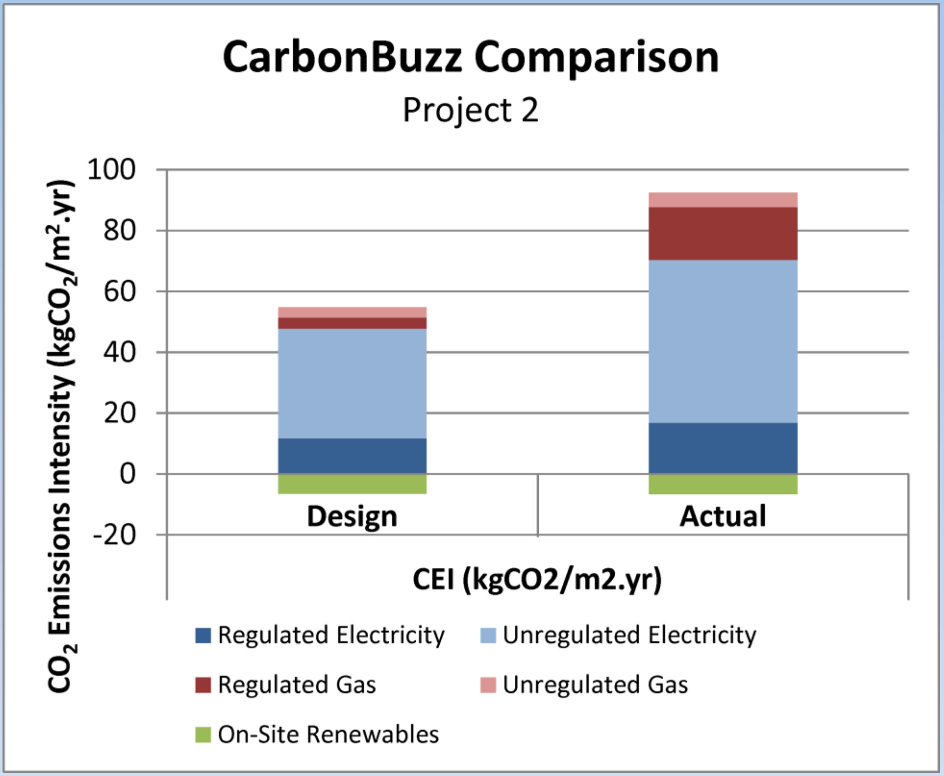
The performance gap



Adapted from Bordass 1999

CarbonBuzz





- Smallest difference: -33%
- Biggest difference: 401%
- Median difference: 71%

Source: http://www.carbonbuzz.org

Context

- Ambitious CO_2 targets for new build
- Demonstrating operational performance
- Use of typical/good practice benchmarks
- DEC dataset illustrates variability
- CarbonBuzz illustrates performance gap

Uses of simulation

- No longer a niche technique
- Part L / EPC NCM calculations
  comparison of design against 'notional' / 'typical' under standard scenarios; no unregulated loads
- Inappropriate for energy prediction
- Does the industry get this?

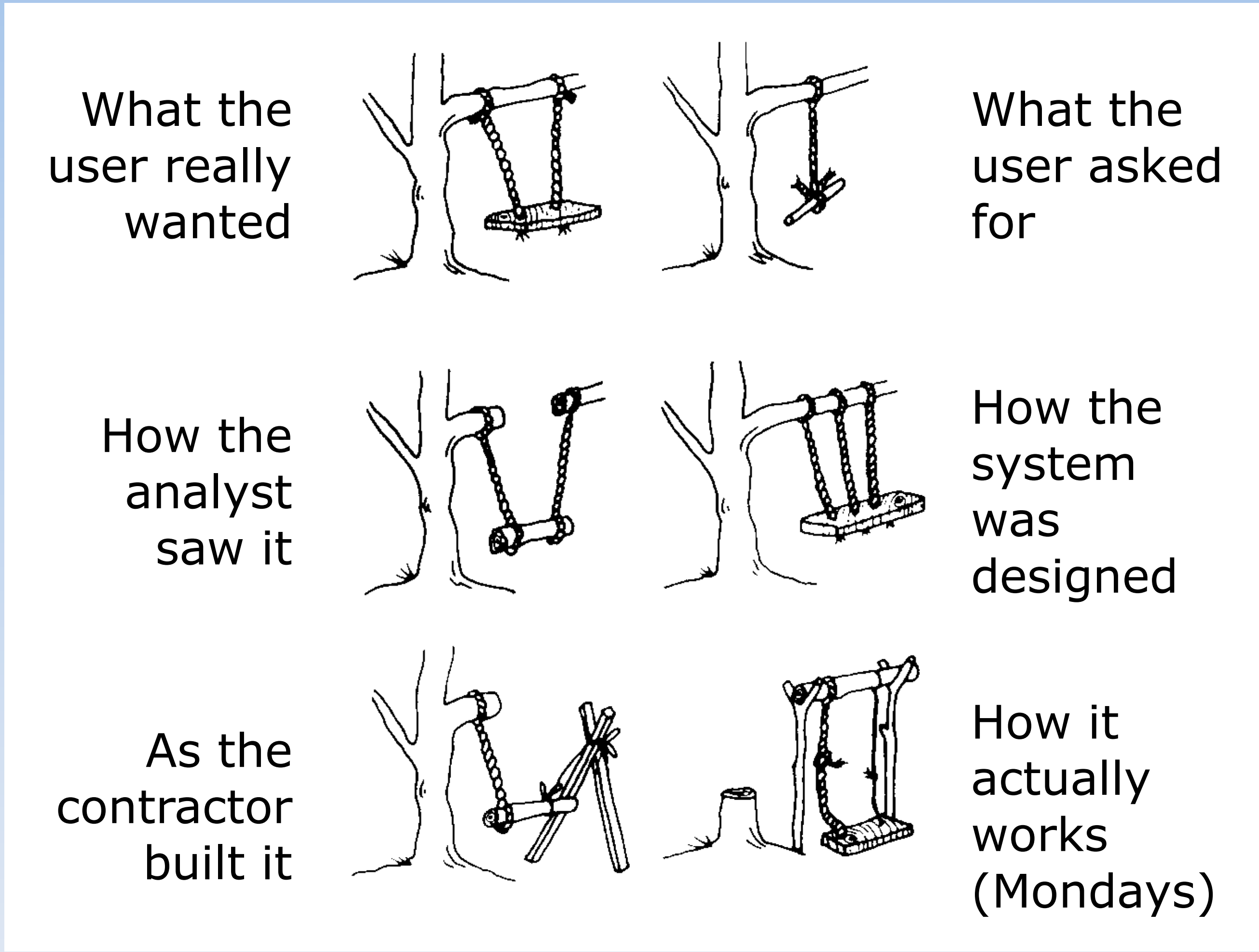
Calibration

- Good results are possible
  ...*for a specific building*
- But what to calibrate against?
- Can improve input data
- Leading to better benchmarks
- Of limited use in improving energy prediction generally

Uncertainty

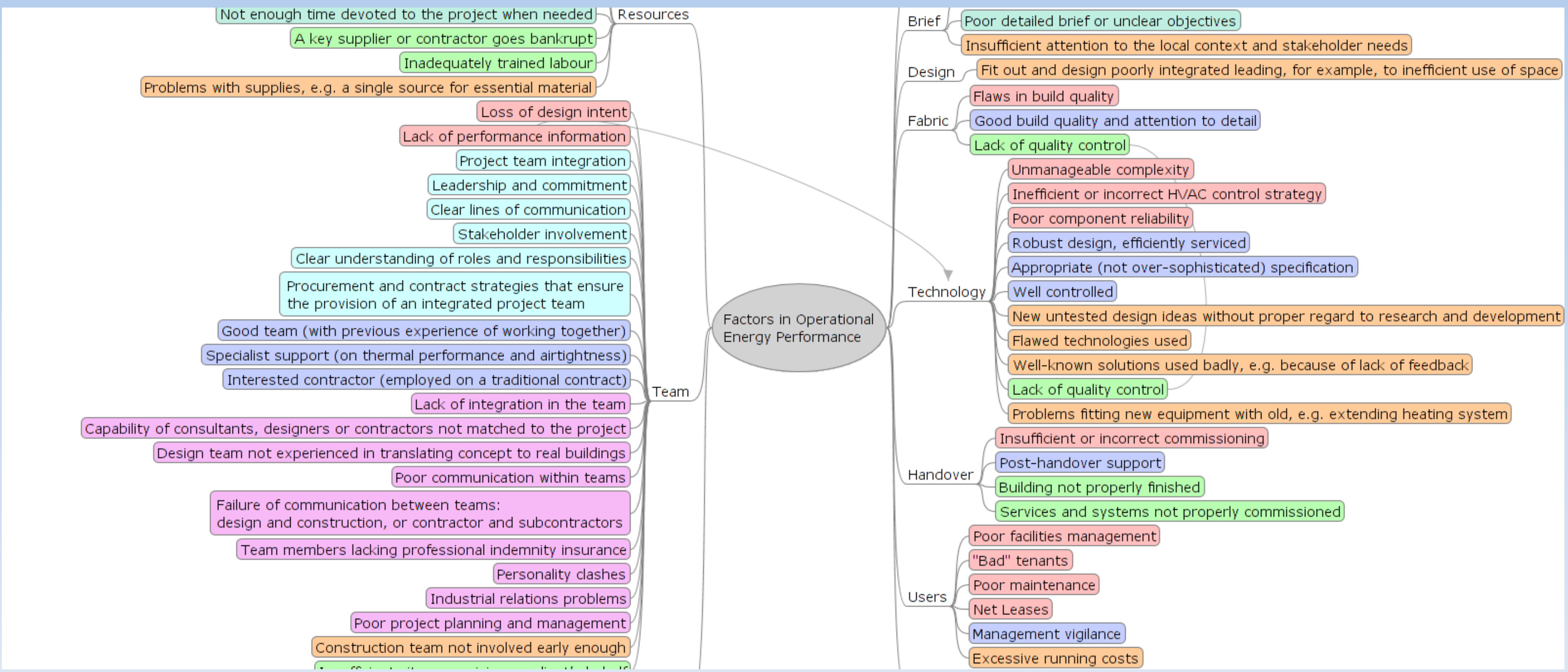
- Do benchmarks reflect future building?
- How do you account for this uncertainty?
  - Sensitivity analysis
    (impact of individual parameters)
  - Monte Carlo analysis
    (repeated simulations using parameter values drawn from probability distributions)
  - Stochastic models
    (probabilistic variation in input data)
- Techniques should become mainstream
  (a plea to tool developers)

What's the problem?



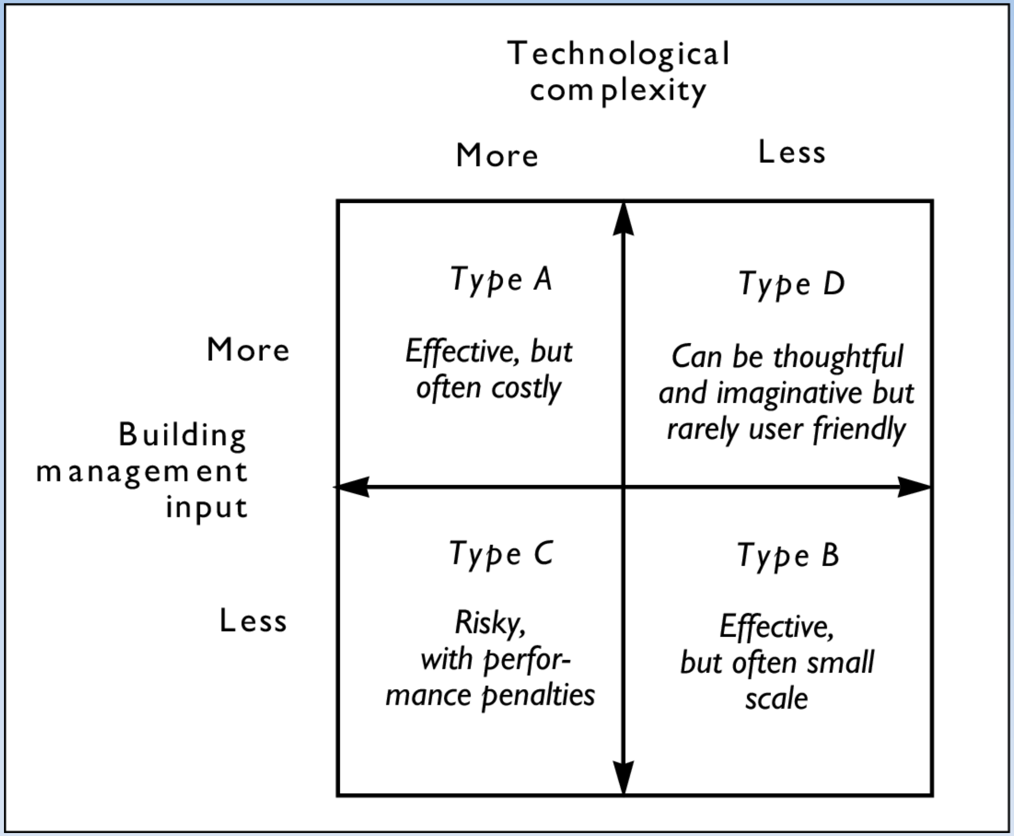
We just can't predict!

- Complex socio-technical systems
- Many non-technical factors:



- How do we account for these?

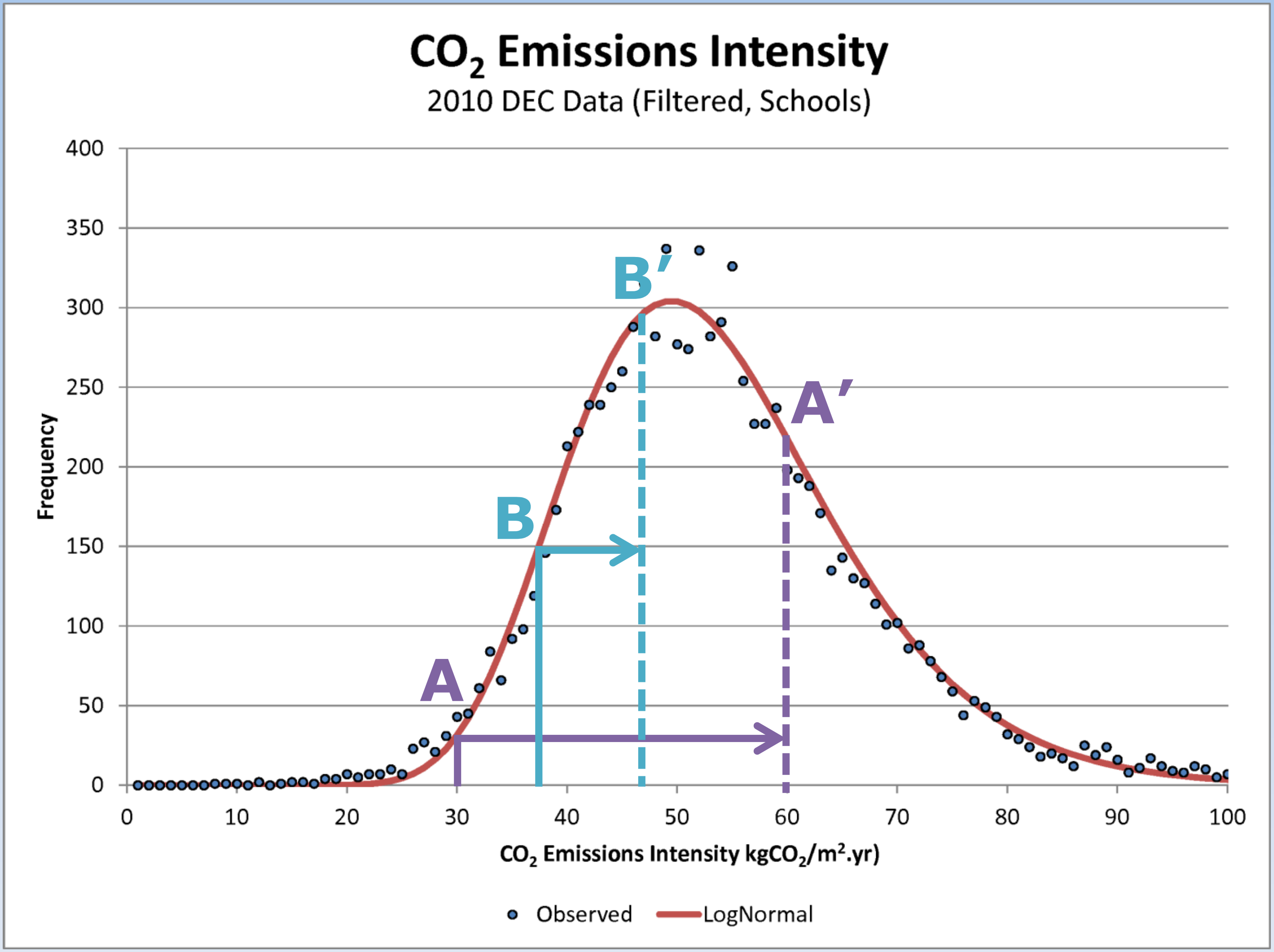
Robust design (1)



Bordass, Leaman, Ruyssevelt 1999

- Technical complexity itself is not the problem
- Needs careful design to ensure robustness
- Vigilance is the price of (technical) complexity
- Robustness can help reduce uncertainty

Robust design (2)



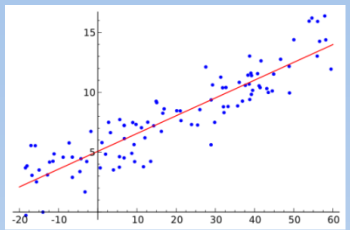
- A outperforms B in theory
- B outperforms A in practice
- Technical sophistication may increase uncertainty
- Robustness can reduce uncertainty

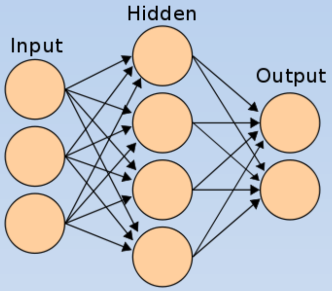
Risk management

- Performance-gap represents risk
- Simulation models need to consider uncertainty
- Also need to integrate non-technical factors
- Compare designs on the basis of performance <u>and</u> risk
- How to evaluate this risk (rigorously)?

What other techniques?

- Regression models
  - Great for predicting the past *(given sufficient data)*
- Neural networks
  - Great given sufficient training
- Bayesian networks
  - Based on probabilistic inference
  - Allow reasoning with incomplete data
  - Integrate quantitative and qualitative data

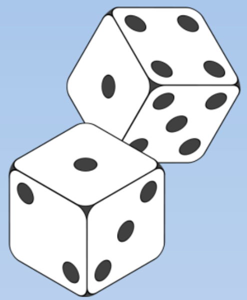




Probability

- Objective (frequentist) probability
  - The long-run or limiting frequency of an event

$$Pr(A) = \lim_{n \to \infty} \frac{n_a}{n}$$



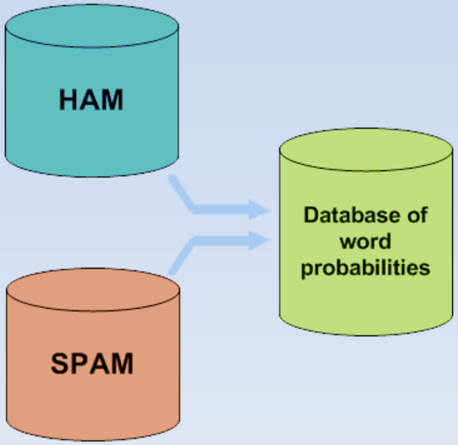
- Subjective (Bayesian) probability
  - Can be used with degrees of belief
  - Derived from Bayes' Rule

$$Pr(A|B) = \frac{Pr(B|A)\,Pr(A)}{Pr(B)}$$

  - Pr(A) represents *prior* probability
  - Pr(A|B) represents *posterior* probability given some evidence B.

Bayesian inference

- Allows reasoning under uncertainty
- Updating initial beliefs in the light of new observations
- Pragmatic approach applicable to real-life problems:
  - Cracking the Enigma
  - Medical diagnosis
  - Spam filtering
  - Reliability prediction

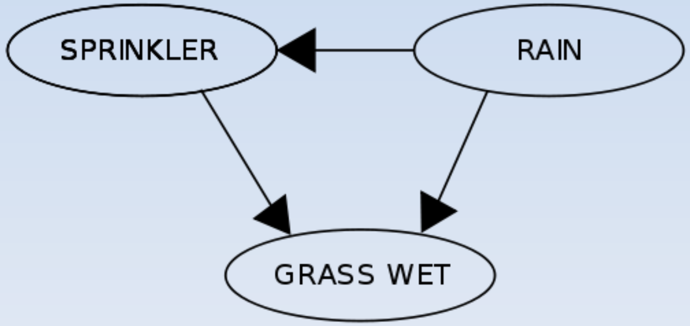


Bayesian networks (1)

- Model cause and effect relationships
- Use Bayesian inference techniques
- Allow reasoning from cause to effect (prognosis) and vice versa (diagnosis)
- Graphical models are transparent and auditable

Bayesian networks (2)

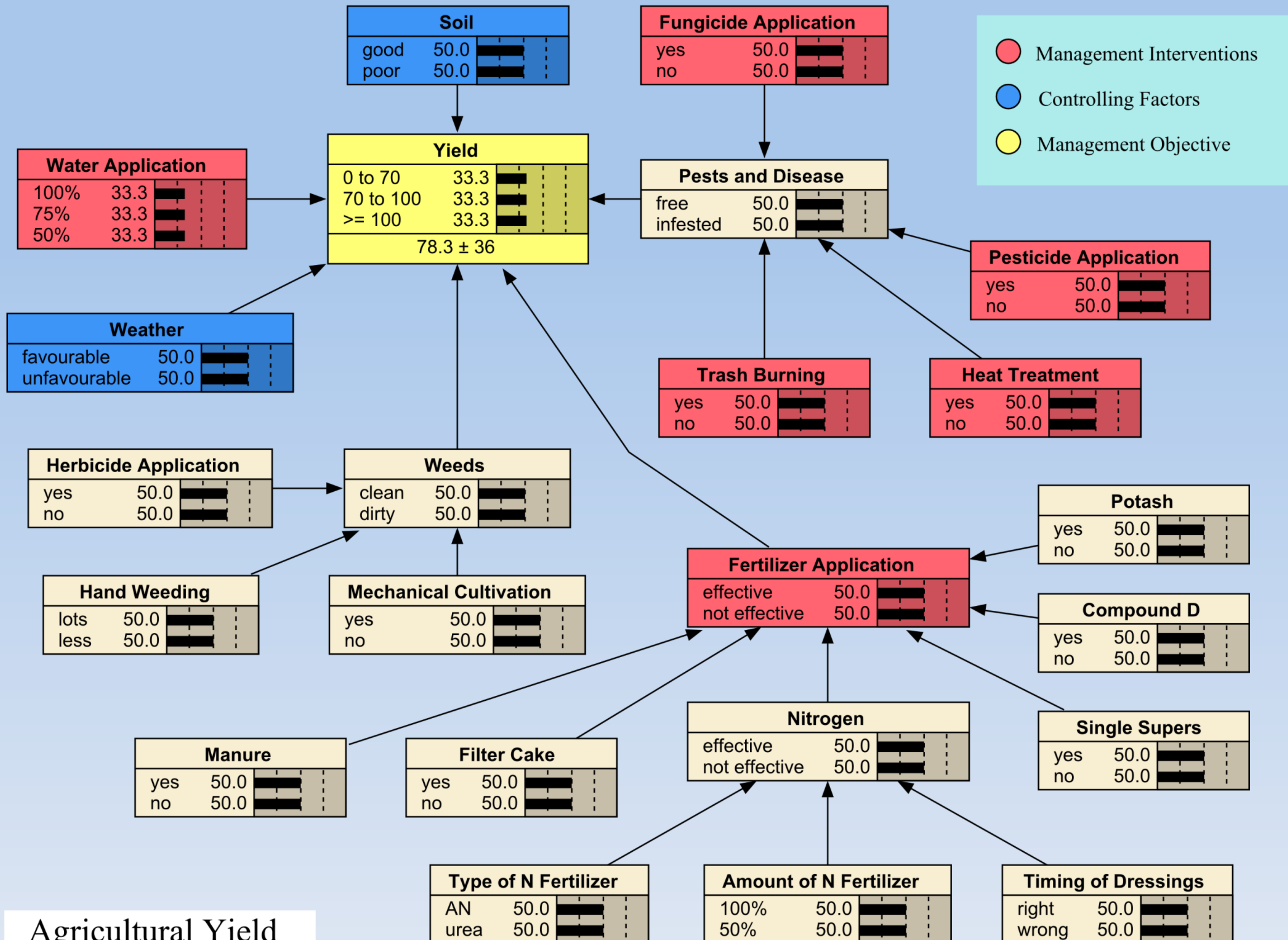
- *"directed acyclic graphs and associated probability tables"*
  - Nodes represent uncertain variables
  - Edges represent causal or influential links
  - Tables describes the probabilistic relationship between parent and child nodes



RAIN	
T	F
0.2	0.8

	SPRINKLER	
RAIN	T	F
F	0.4	0.6
T	0.01	0.99

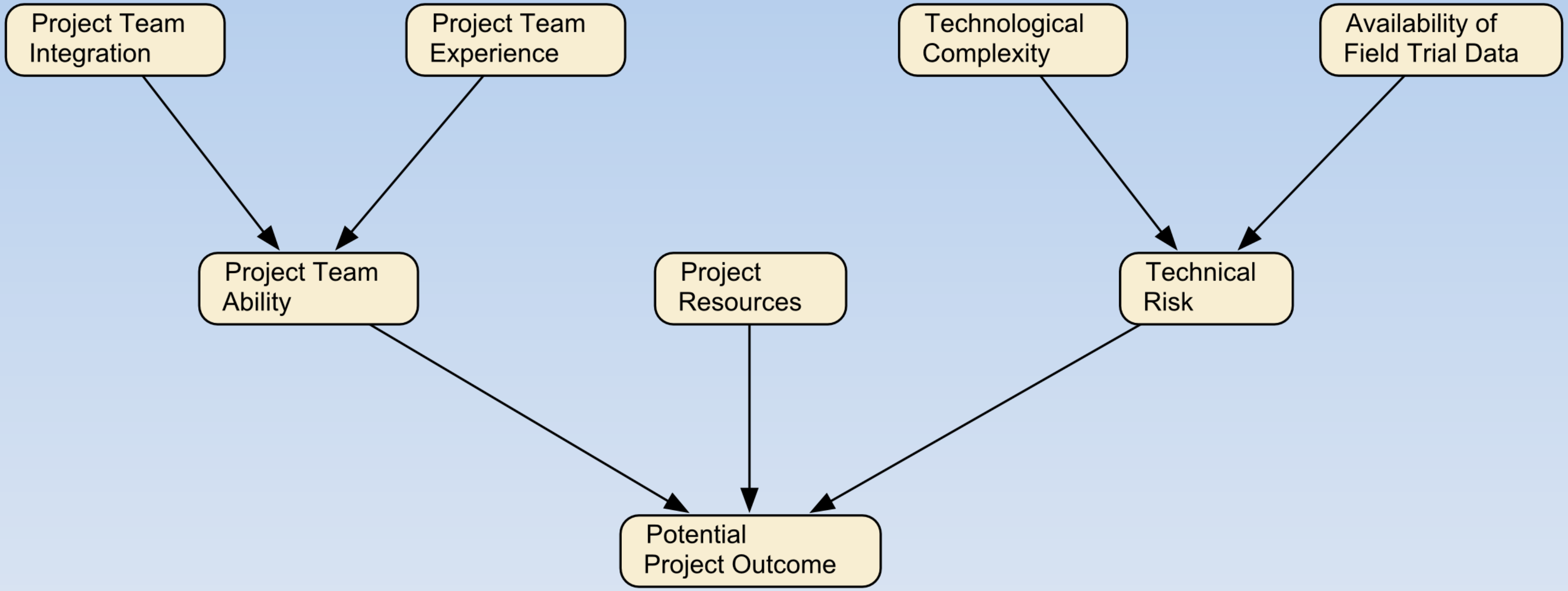
		GRASS WET	
SPRINKLER	RAIN	T	F
F	F	0.0	1.0
F	T	0.8	0.2
T	F	0.9	0.1
T	T	0.99	0.01



Agricultural Yield

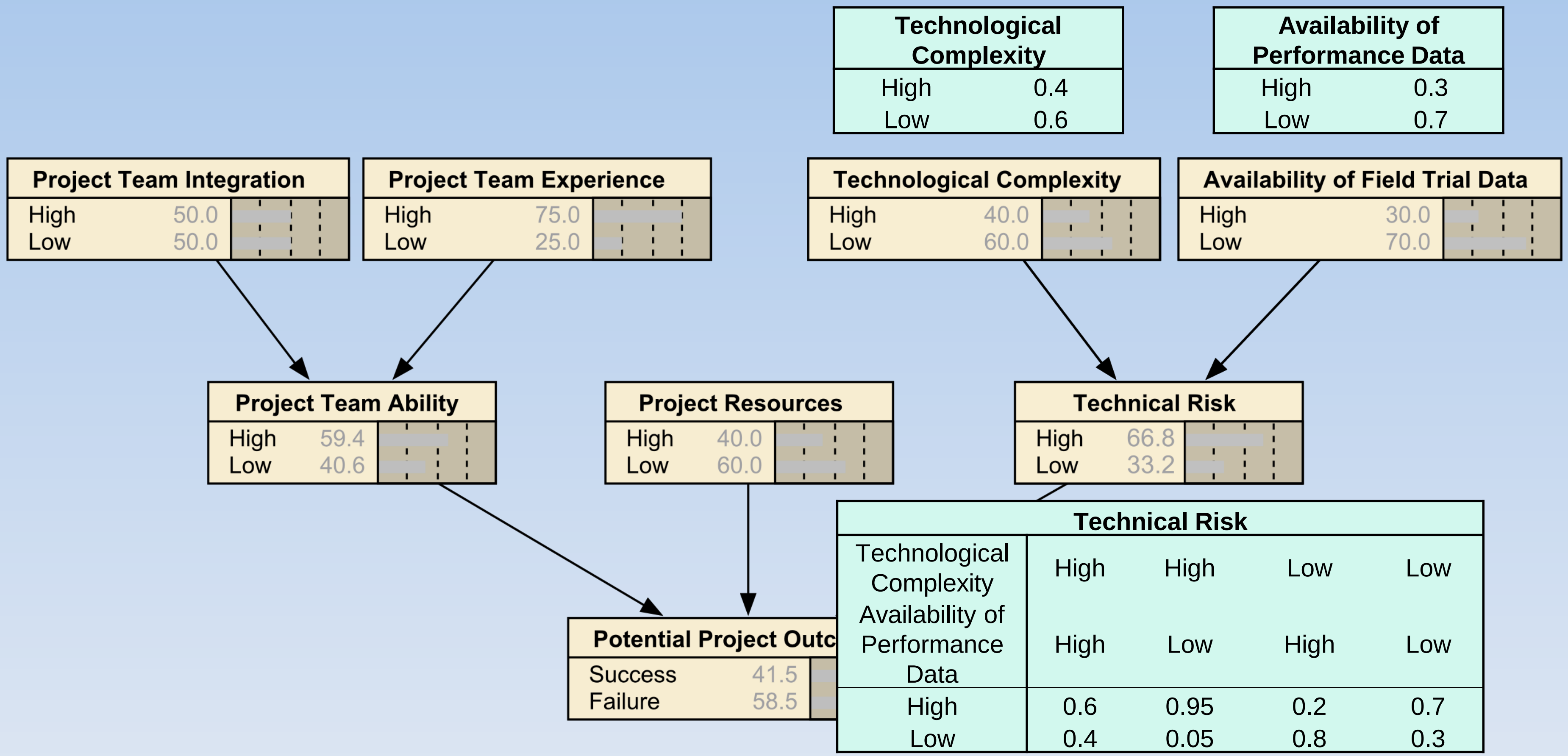
Causal relationships

Example Project Performance Network



Probabilistic relationships

Example Project Performance Network

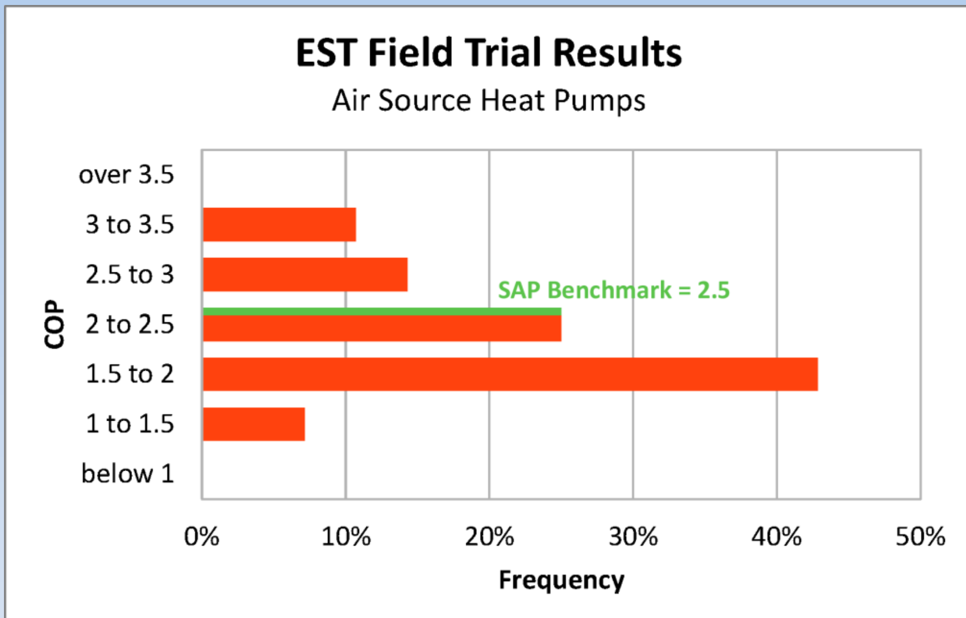


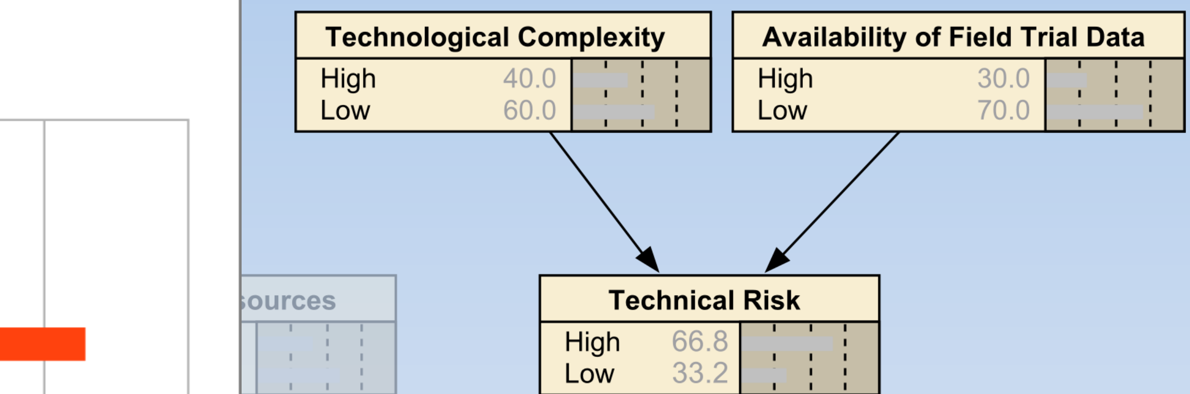
Empirical data

Example Project Performance Network

Technological Complexity	
High	0.4
Low	0.6

Availability of Performance Data	
High	0.3
Low	0.7

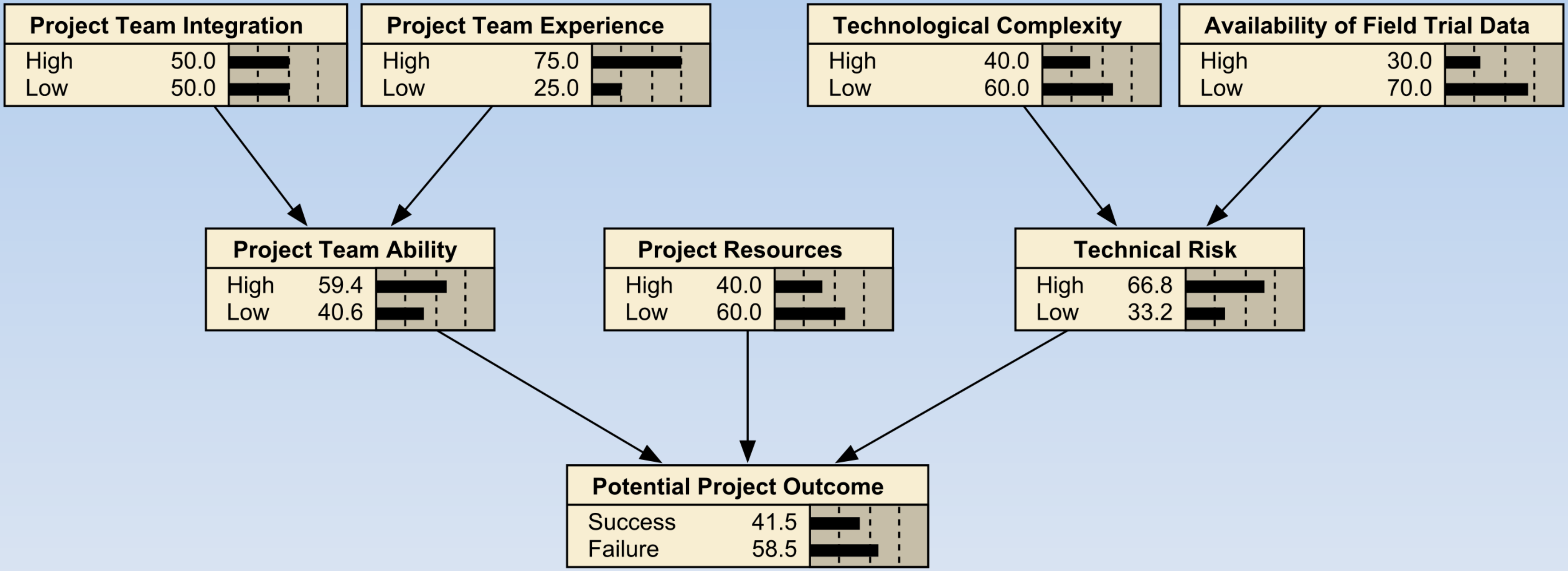




Technical Risk				
Technological Complexity	High	High	Low	Low
Availability of Performance Data	High	Low	High	Low
High	0.6	0.95	0.2	0.7
Low	0.4	0.05	0.8	0.3

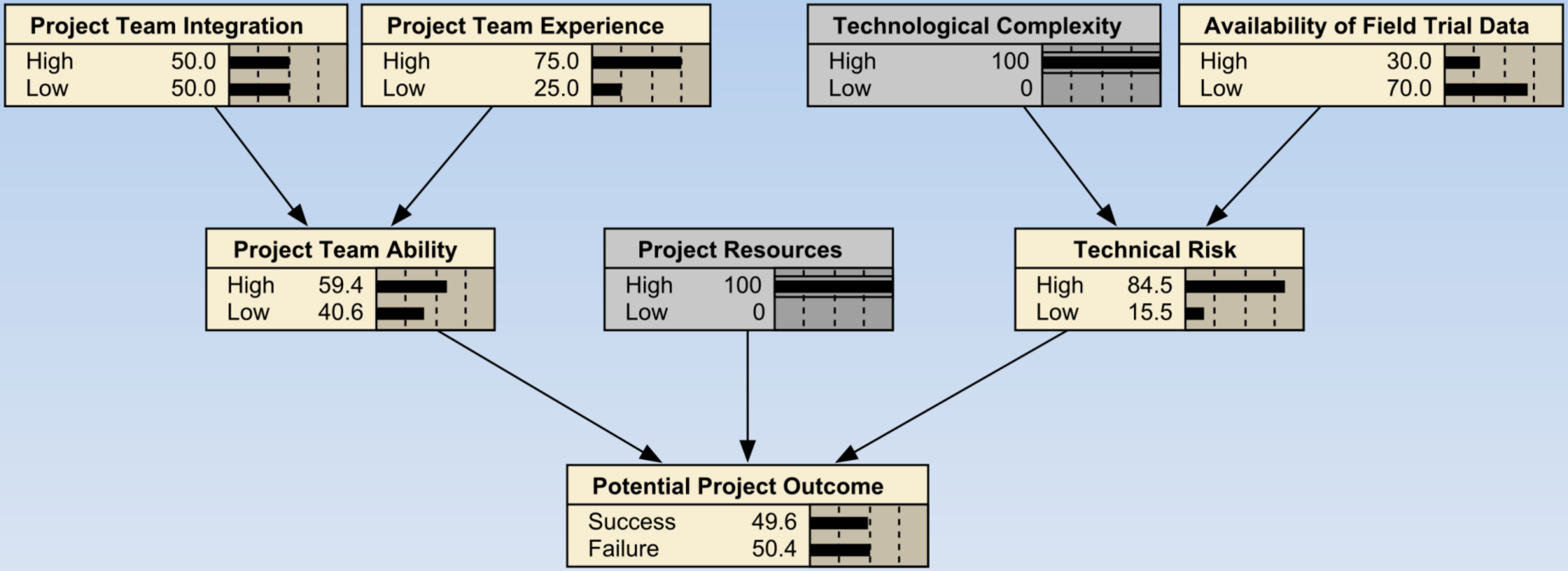
Prognosis (1)

Example Project Performance Network



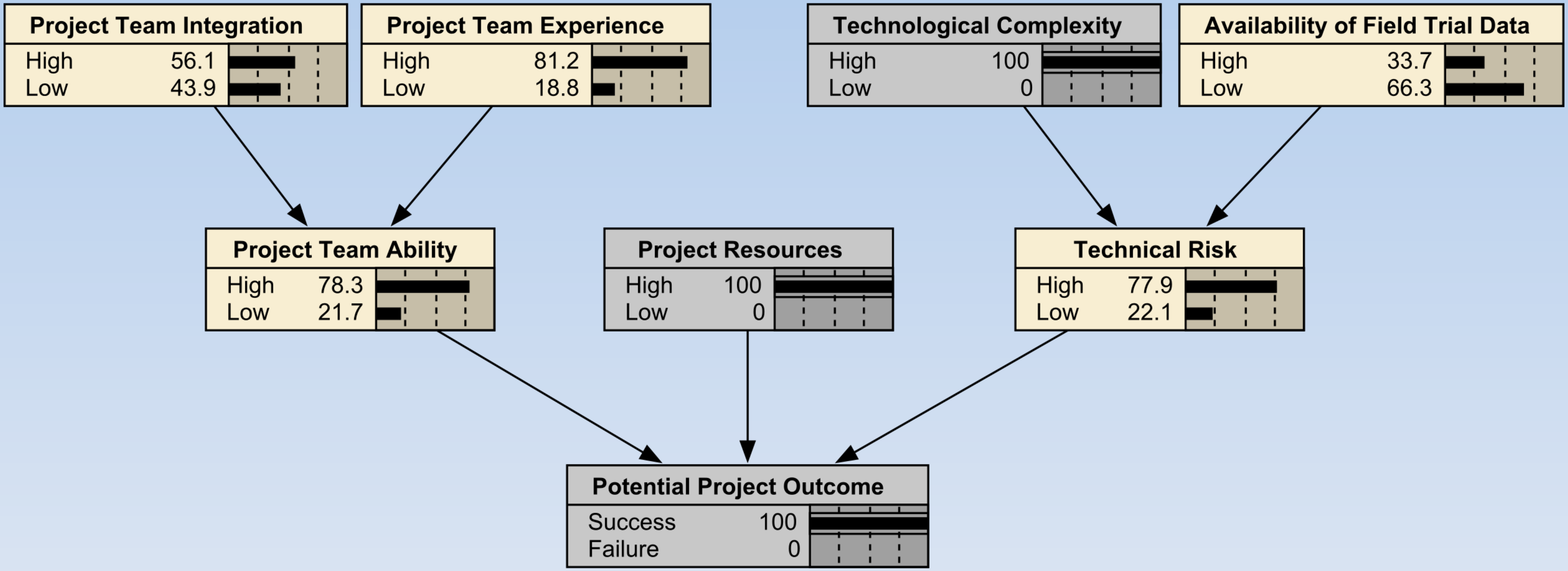
Prognosis (2)

Example Project Performance Network



Diagnosis

Example Project Performance Network



Creating a useful tool

- Data gathering
  - Literature review
  - Semi-structured interviews
- Derivation of causal maps
- Conversion to Bayesian networks
- Probability encoding
  - Empirical data
  - Structured interviews

Nadkarni & Shenoy 2004

Case study building

THE UNIVERSITY OF NORTHAMPTON

Project Part-Financed by the European Union
European Regional Development Fund

- TSB Building Performance Evaluation project
- Wireless energy and environmental monitoring
- Workshops and interviews with design team, tenants and management

Summary

- Simulation isn't the whole story
- Need to consider uncertainty
  - Technical
  - Non-technical
- “Energy Performance Risk Management”

  ...using Bayesian Networks to develop a due-diligence framework for clients and designers

Thank you

For more information:

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