Expert Elicitation and Parametric Decision Analysis

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July 30, 2014
Snowmass, Colorado

Illustrations of the Uses and Limits of Expert Elicitation and Parameterization

- MANPADS Countermeasures
- Bioterrorism Risk Analysis
- Human Intrusion into a Nuclear Waste Repository

DECISION ANALYSIS
Vol. 3, No. 2, June 2006, pp. 63–75
ISSN 1545-8490 | EISSN 1545-8504 | 06 | 0302 | 0063

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DOI 10.1287/deca.1060.0071

Should We Protect Commercial Airplanes Against Surface-to-Air Missile Attacks by Terrorists?

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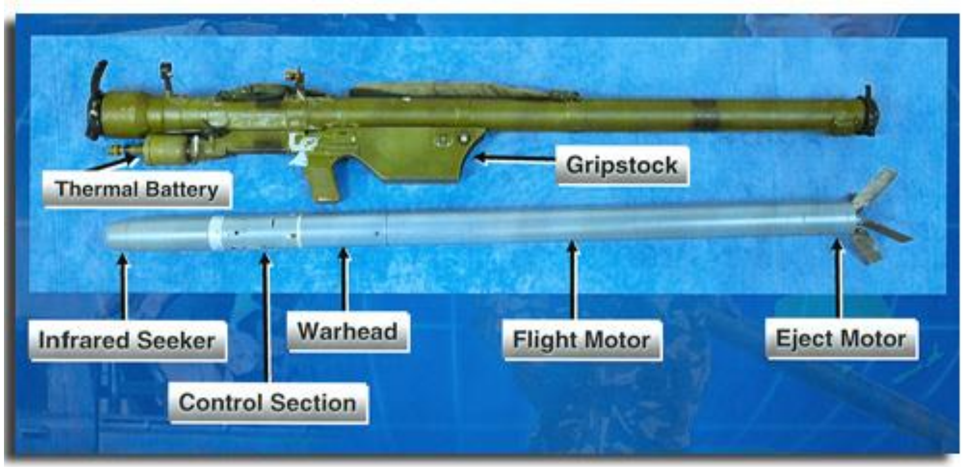
This paper describes a decision tree analysis to assess the cost-effectiveness of MANPADS (Man-Portable Air Defense Systems) countermeasures. These countermeasures are electronic devices that can be installed on commercial airplanes to detect and deflect surface-to-air missiles (SAMs) fired by terrorists. The model considers a terrorist attempt to shoot down a commercial airplane with a heat-seeking SAM, and it evaluates the decision to install countermeasures, taking into account alternative modes of attack, probabilities of success, and consequences to the economy. All model variables were fully parameterized, using reasonable ranges based on open-source literature. Not surprisingly, the probability of an attack, the consequences of an attack to the economy, and the cost of countermeasures are the most important parameters. Surprisingly, some of the hotly disputed parameters, such as the probability of an airplane surviving a successful hit or the probability of a false alarm, have very little impact on the results. The analysis suggests that MANPADS countermeasures installed on planes can be cost-effective if the probability of such an attack is large (greater than about 0.40 in ten years), the economic losses are large (greater than about $75 billion), and the countermeasures are relatively inexpensive (smaller than about $15 billion). An economic analysis conducted as part of this analysis showed that the economic impacts can be as large as $250 billion, thus making countermeasures a possibly cost-effective option. More research is needed to determine the real costs of MANPADS countermeasures and how terrorists may shift their tactics, once countermeasures are installed.

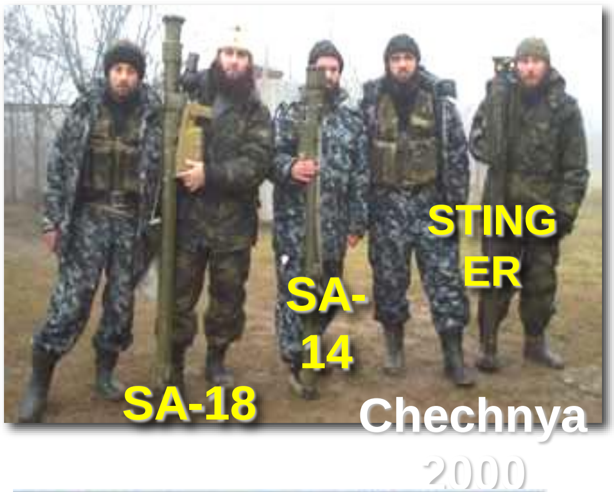
Key words: terrorism risk; aviation system attacks; surface-to-air missiles; MANPADS; risk analysis; MANPADS countermeasures
History: Received on April 23, 2006. Accepted by Robert Clemen on June 21, 2006 after 2 revisions.

MANPADS



This image identifies the main components of a typical MANPADS.

“Bad Guys” with MANPADS



Two insurgents in Iraq with SA-7b and SA-14 MANPADS. (Photo Courtesy: U.S. Department of Homeland Security)

Close Call, Baghdad, 2003


22 11 2003
22 11 2003
22 11 2003

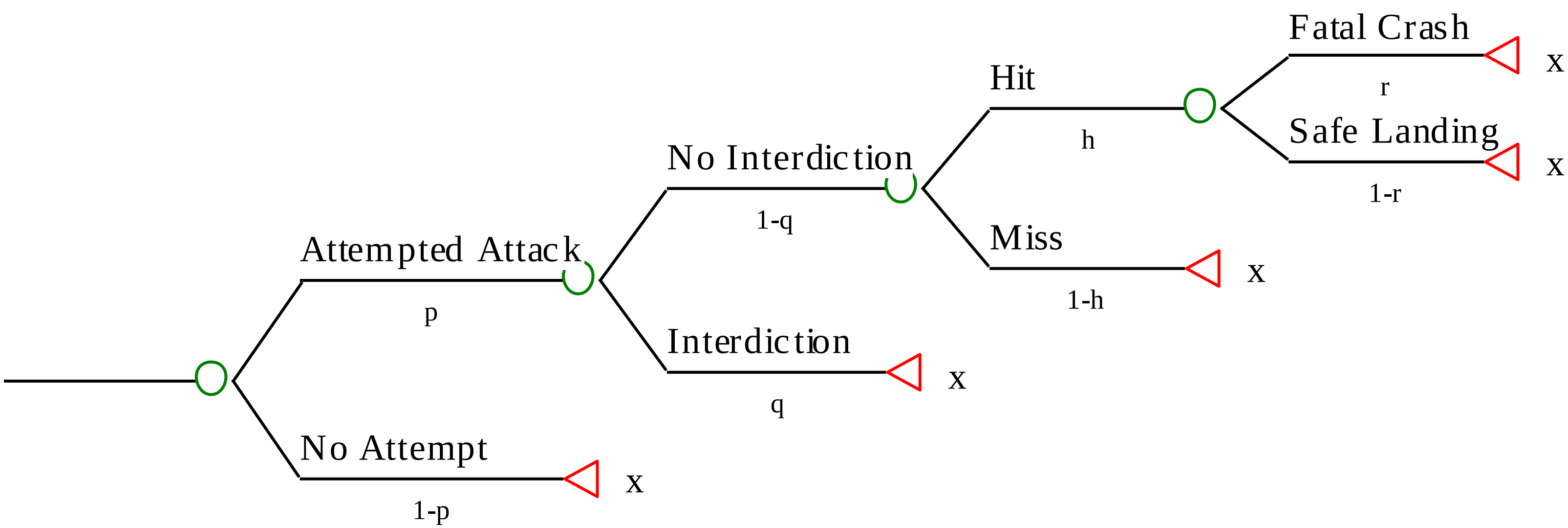

DHL
DHL


DHL

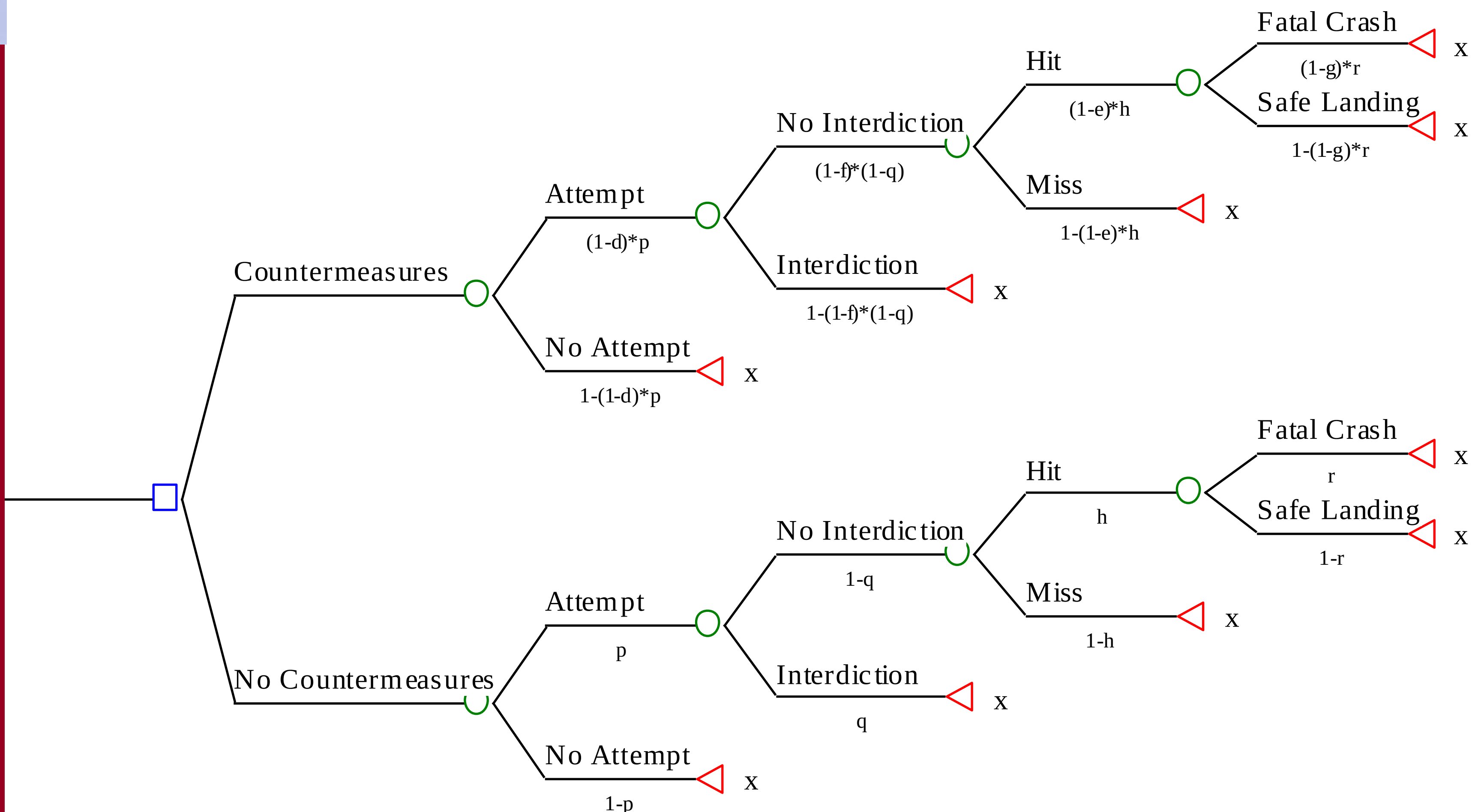
MANPADS – Countermeasures

Number of Planes:	5,000
Capital Cost/Plane:	$2 million
O&M/Plane/Yr.:	$500,000
10-Year Life Cycle Cost:	$35 billion

Some Deep Uncertainties!



Deep Uncertainties Continued



MANPADS Attack – Direct Consequences

- Fatalities
- Injuries
- Loss of Airplane(s)

MANPADS Attack – Indirect Consequences

- Aviation System Shutdown
- Reduced Airline Passenger Volume
- Fears and worries

MANPADS Inputs: Probabilities and Effectiveness Measures

Table 1 Base Case and Ranges of Probabilities and Effectiveness Parameters

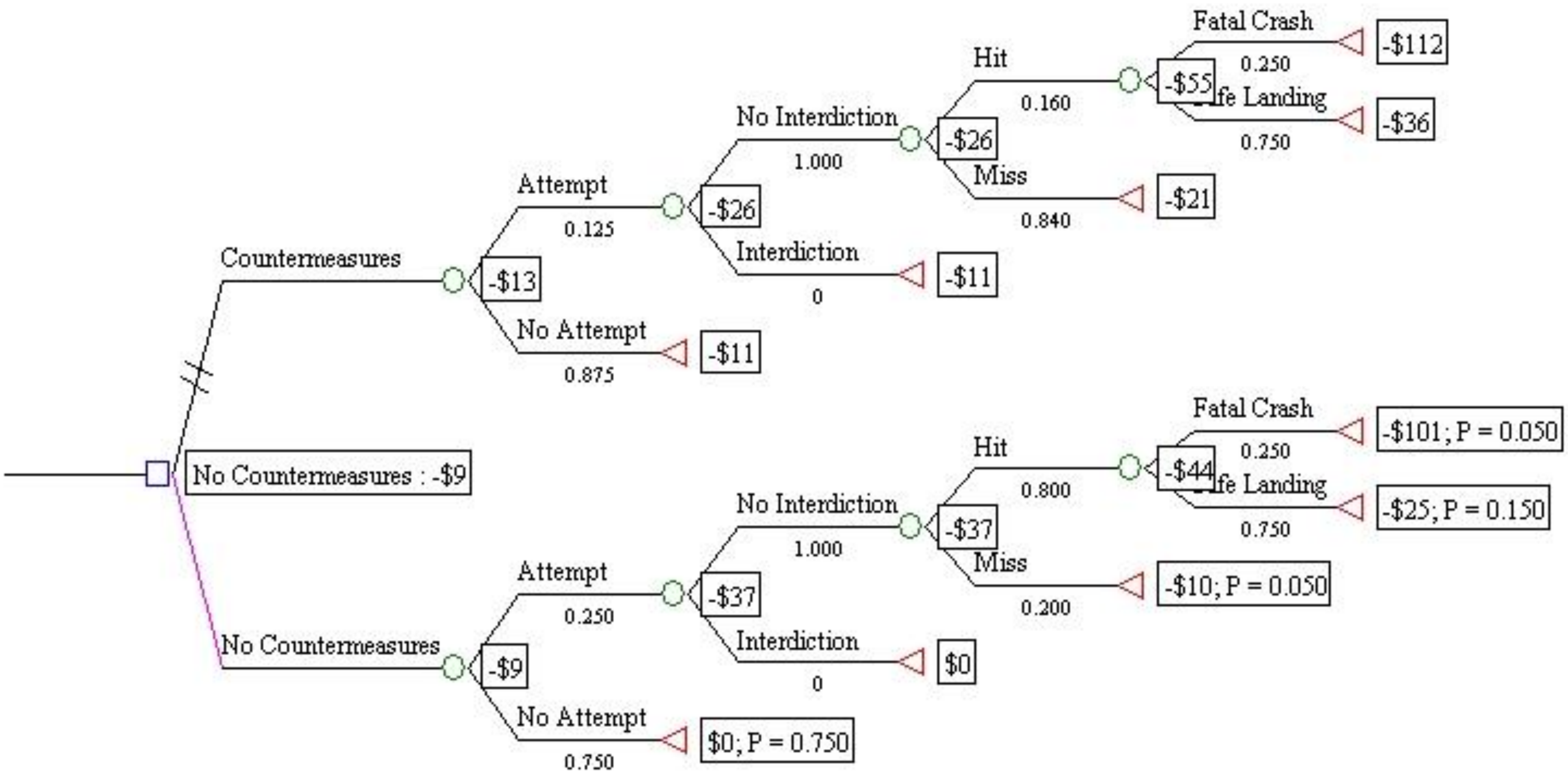
		Min	Base	Max
Probabilities				
p	Attempted attack in 10 years	0.00	0.25	1.00
q	Interdiction | attempt	0.00	0.00	0.25
h	Hit | attack, no countermeasures	0.50	0.80	1.00
r	Crash | hit	0.00	0.25	0.50
Effectiveness of countermeasures				
d	Deterrence effectiveness	0.00	0.50	1.00
f	Interdiction effectiveness	0.00	0.00	0.25
e	Diversion/destruction effectiveness	0.50	0.80	1.00
g	Crash reduction effectiveness	0.00	0.00	1.00

MANPADS Inputs: Consequences

Table 2 Base Case Consequences and Ranges

Consequences		Min	Base	Max
LL	Fatalities | crash	0	200	400
CP	Cost of the plane (millions)	0	200	500
EL	Economic loss | fatal crash (billions)	0	100	500
a	Percent of loss | hit and safe landing (%)	0	25	50
b	Percent of loss | miss (%)	0	10	25
FA	Number of false alarms/year	0	10	20
CC	Cost of countermeasures (billions)	5	10	50

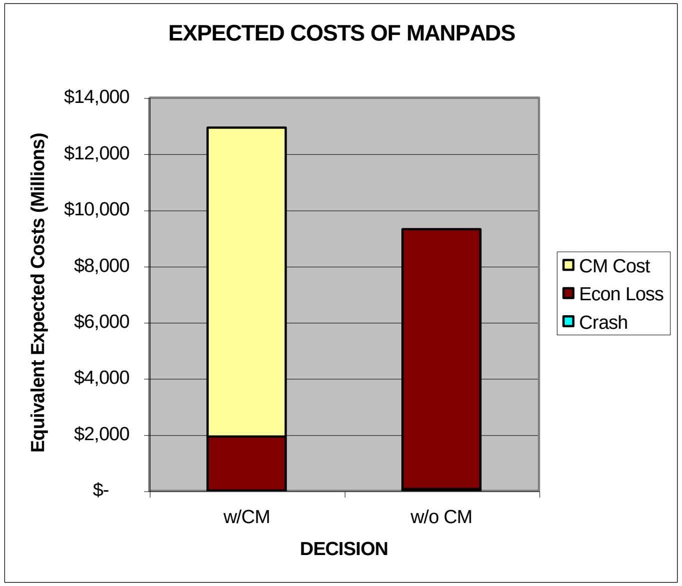
MANPADS – Solved Decision Tree



MANPADS – User Interface (& Demo)

Inputs and Ranges of the Manpads Model

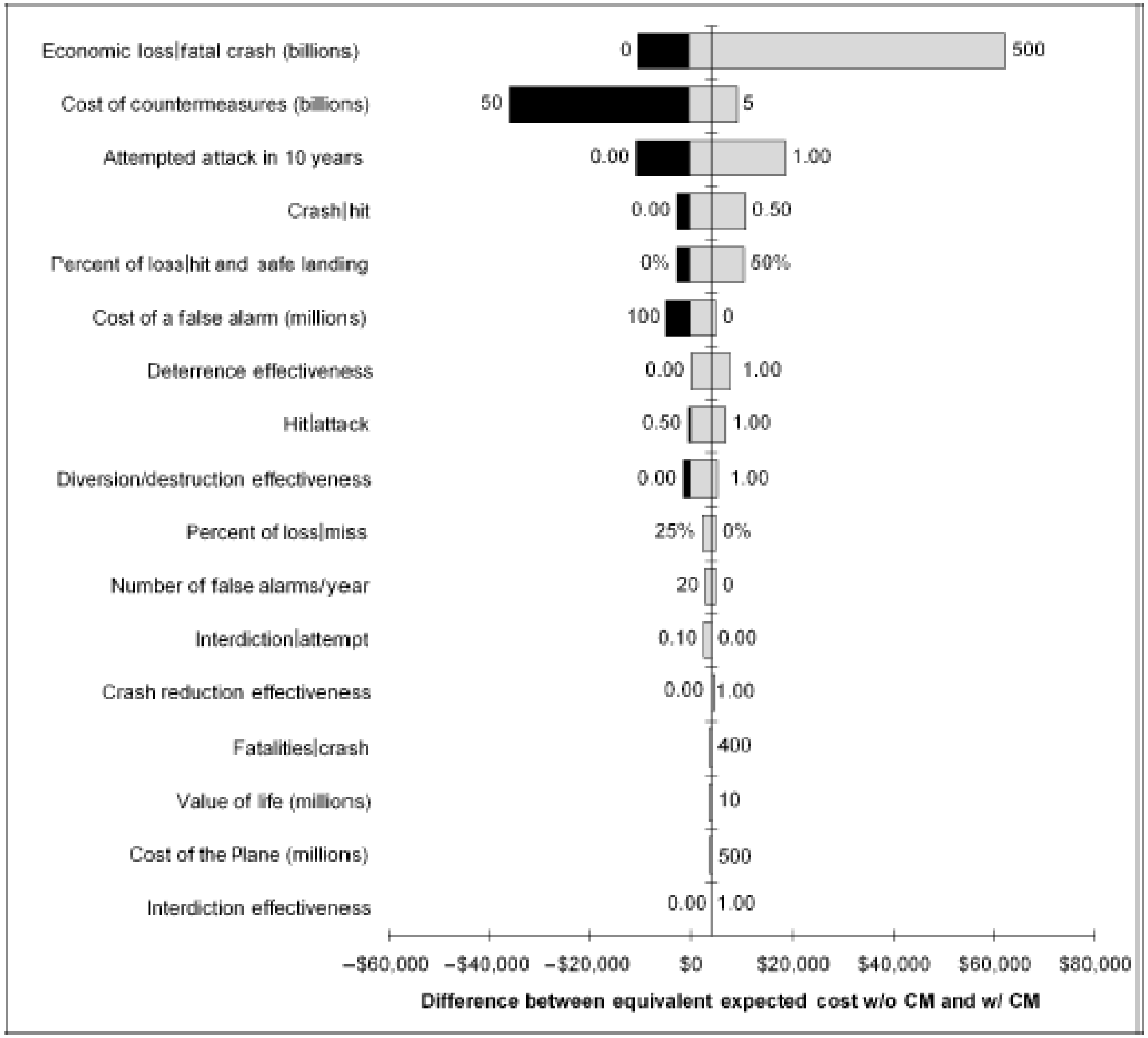
Probabilities	**Base**	**Case**	**Min**	**Max**
Attempted Attack in 10 years	0.50	0.25	0.00	1.00
Interdiction|Attempt	0.00	0.00	0.00	0.10
Hit|Attack	0.80	0.80	0.00	1.00
Crash|Hit	0.25	0.25	0.00	1.00
Effectiveness of Countermeasures				
Deterrence Effectiveness	0.50	0.50	0.00	1.00
Interdiction Effectiveness	0.00	0.00	0.00	1.00
Diversion/Destruction Effectiveness	0.80	0.80	0.00	1.00
Crash Reduction Effectiveness	0.00	0.00	0.00	1.00
Consequences				
Fatalities|crash	200	200	0	400
Cost of the Plane (millions)	200	200	0	500
Loss to Economy|Fatal Crash (billions)	100	100	0	500
Percent of Loss|Hit and Safe Landing	25%	25%	0%	50%
Percent of Loss|Miss	10%	10%	0%	25%
Number of False Alarms/Year	10	10	0	20
Cost of Countermeasures (billions)	10	10	5	50
Tradeoffs				
Value of Life (millions)	5	5	0	10
Cost of a False Alarm (millions)	10	10	0	100



Outputs of Manpads Model

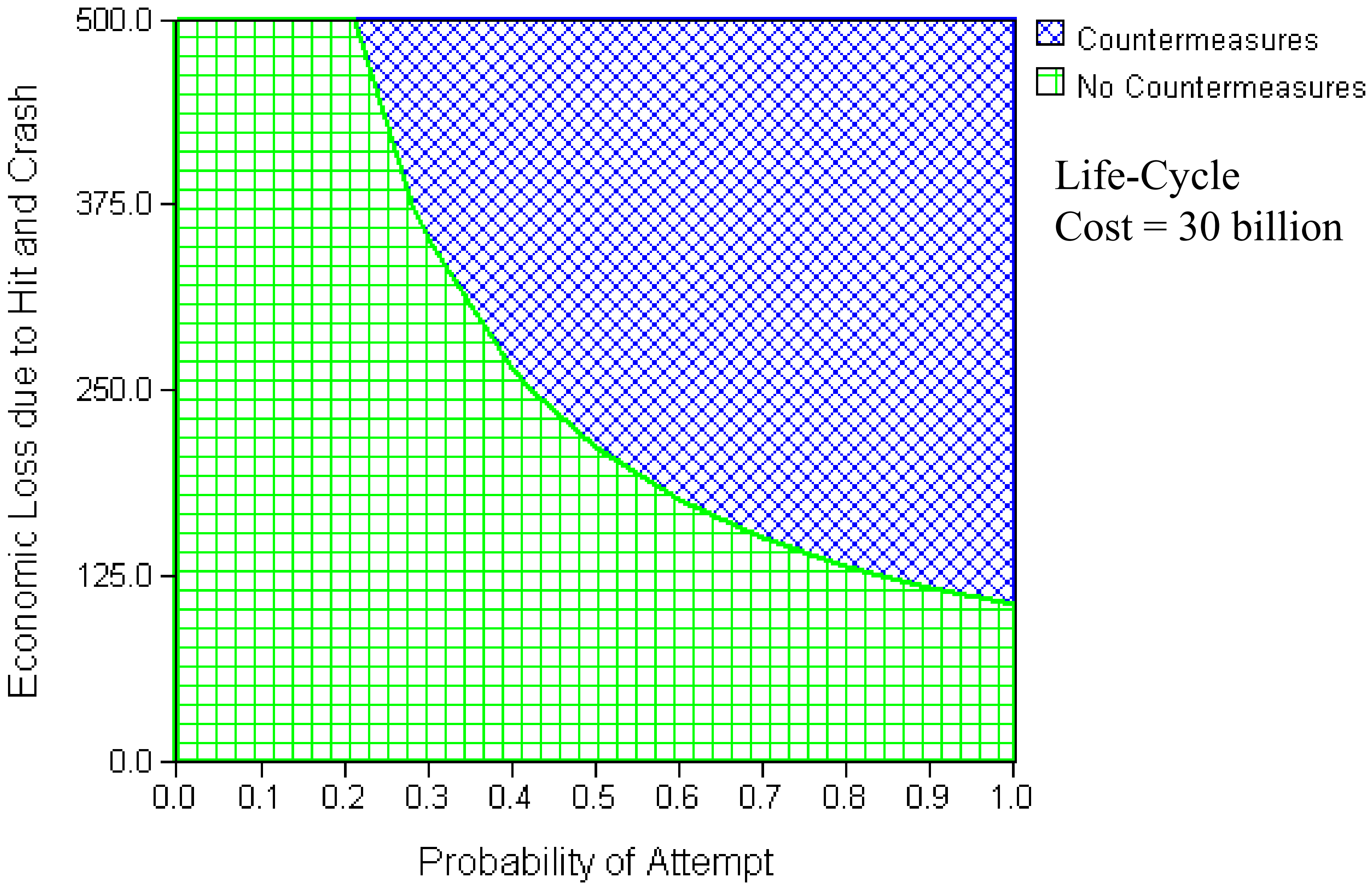
		Total	**Crash**	**Econ Loss**	**CM Cost**
Expected Costs w/ Countermeasures (millions)	**w/CM**	**$ 12,932**	$ 7	$ 1,925	$ 11,000
Expected Costs w/o Countermeasures (millions)	**w/o CM**	**$ 9,318**	$ 68	$ 9,250	$ -

Tornado Diagram



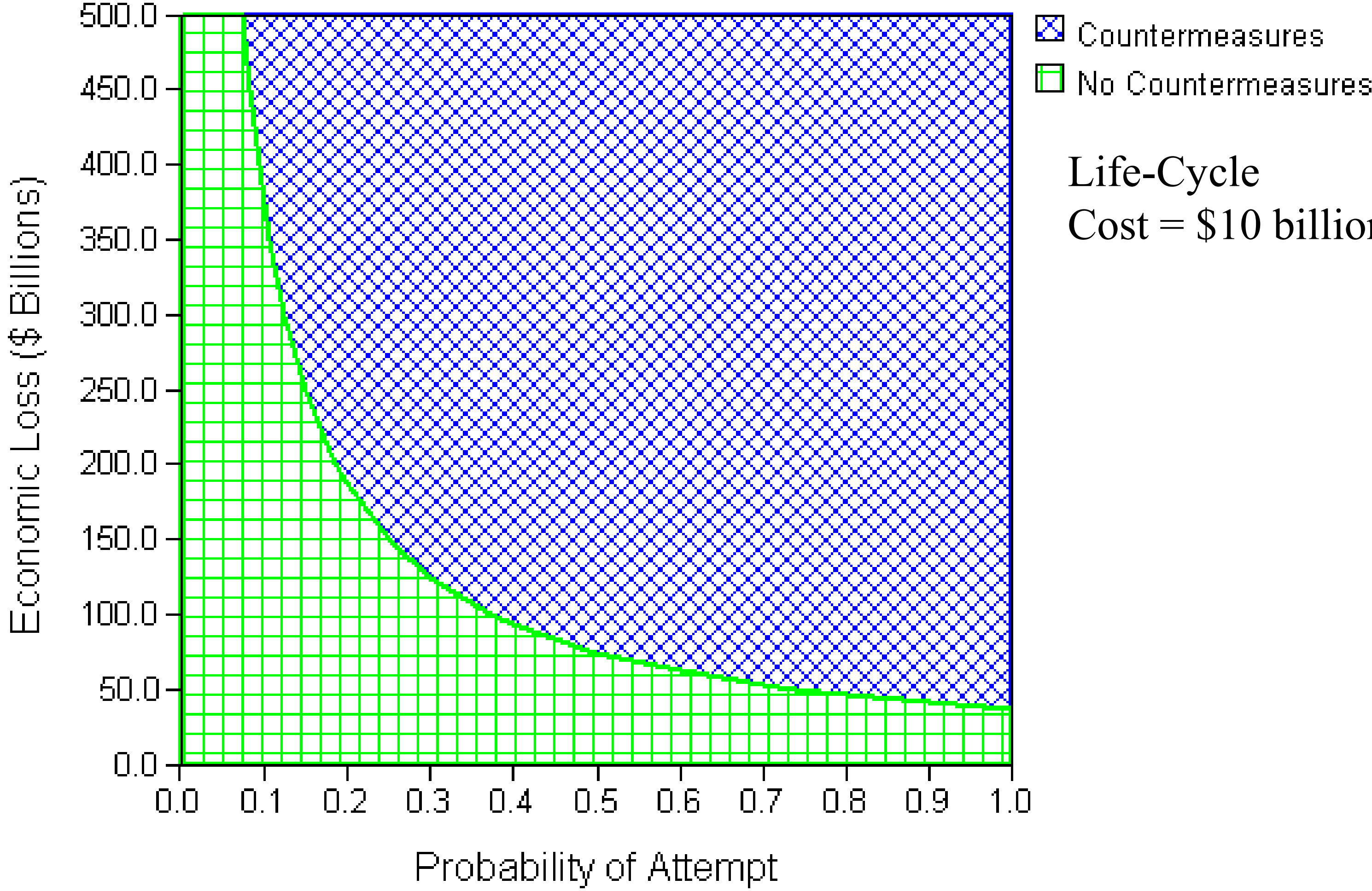
USC CREATE HOMELAND SECURITY CENTER

Sensitivity Analysis on
Probability of Attempt and Economic Loss due to Hit and Crash



Life-Cycle
Cost = 30 billion

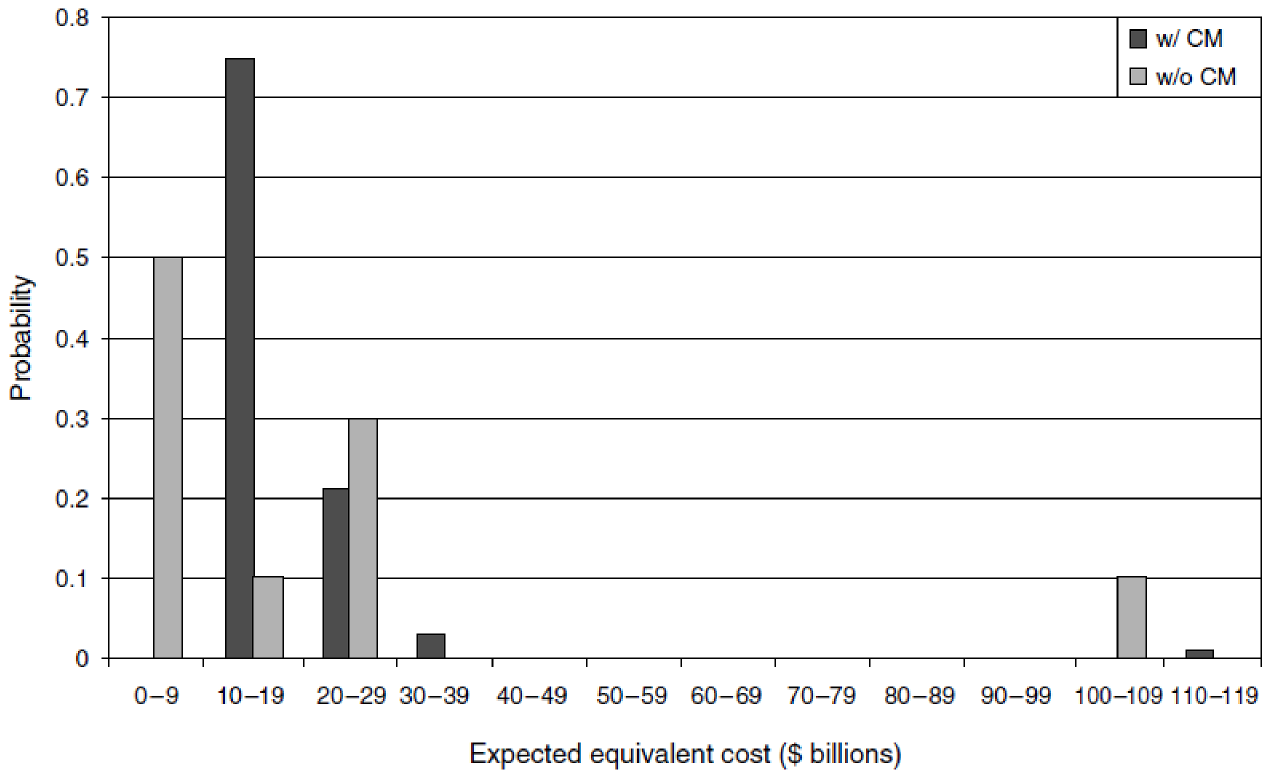
Sensitivity Analysis on
Probability of Attempt and Economic Loss due to Hit and Crash



Life-Cycle
Cost = $10 billion

Risk Profile

Probabilities of Consequences Associated With MANPADS Attacks (Black Solid Bar: with Countermeasures; Grey Shaded Bar: Without Countermeasures)



Observations about MANPADS

- You don’t need precise numbers to make a convincing argument, bounds and sensitivity analyses sometimes are enough
- Based on this and other studies the US Congress cancelled the $200 million/year MANPADS Countermeasures program
- Will the Malaysian attack change this?

Bioterrorism Risk Assessment (BTRA)

What is the Probability of Terrorists Using a Biological Agent in the USA in the Next Ten Years and what are the Consequences?

Bacillus Anthracias (Anthrax)

Non-communicable
100 kg fatal to 3 million people
25% mortality rate

Yersinia Pestis (Plague)

Communicable
One infected person creates ten more
15% mortality rate

Raciness Communis (Ricin)

Non-communicable
1 milligram can kill one adult
50 to 85% mortality rate

Expert Elicitation for BTRA

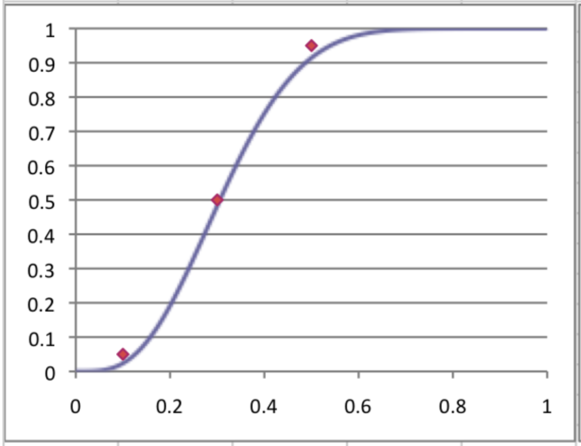
- Around 30 biological agents
- Intelligence analysts and social scientists
- Development of elicitation protocol
- Training
- Software support

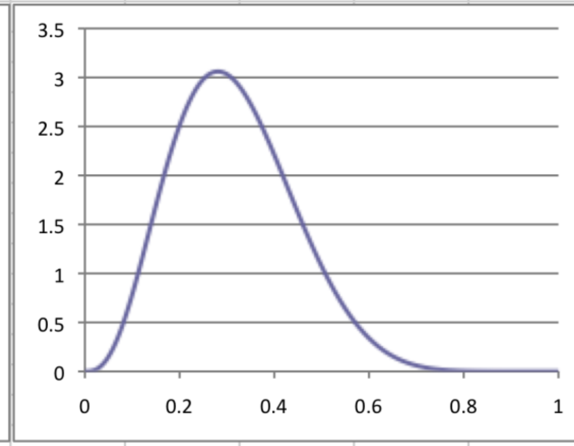
STEP 3: Define Scaling Parameter k

In this step, you can use the "slider" to adjust the scaling parameter k. Choose any event from the list box. You can then input fractiles in the greenly shaded areas and, by using the slider, visually fit the corresponding beta marginal. You also see the impact of the adjustments on all other marginal beta distributions.

Return to Main Menu

Subway	Event:	Subway	a	3.966316
	Avg. Freq.:	0.315789	b	8.593684

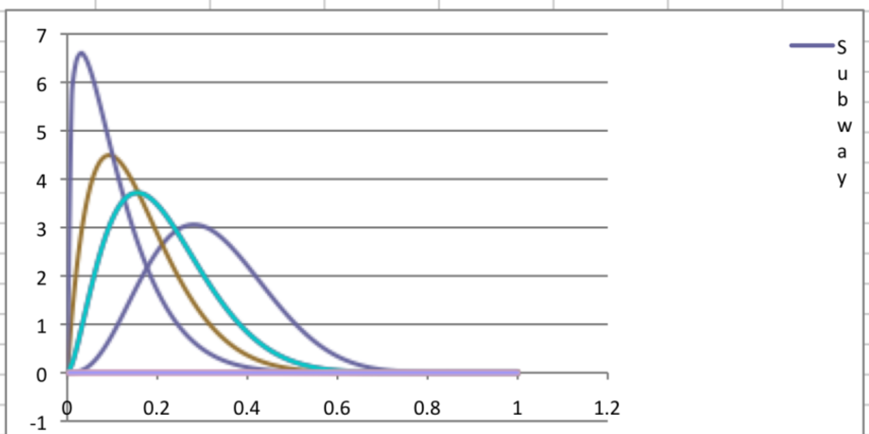




Change Scale

2	k =	12.56	50

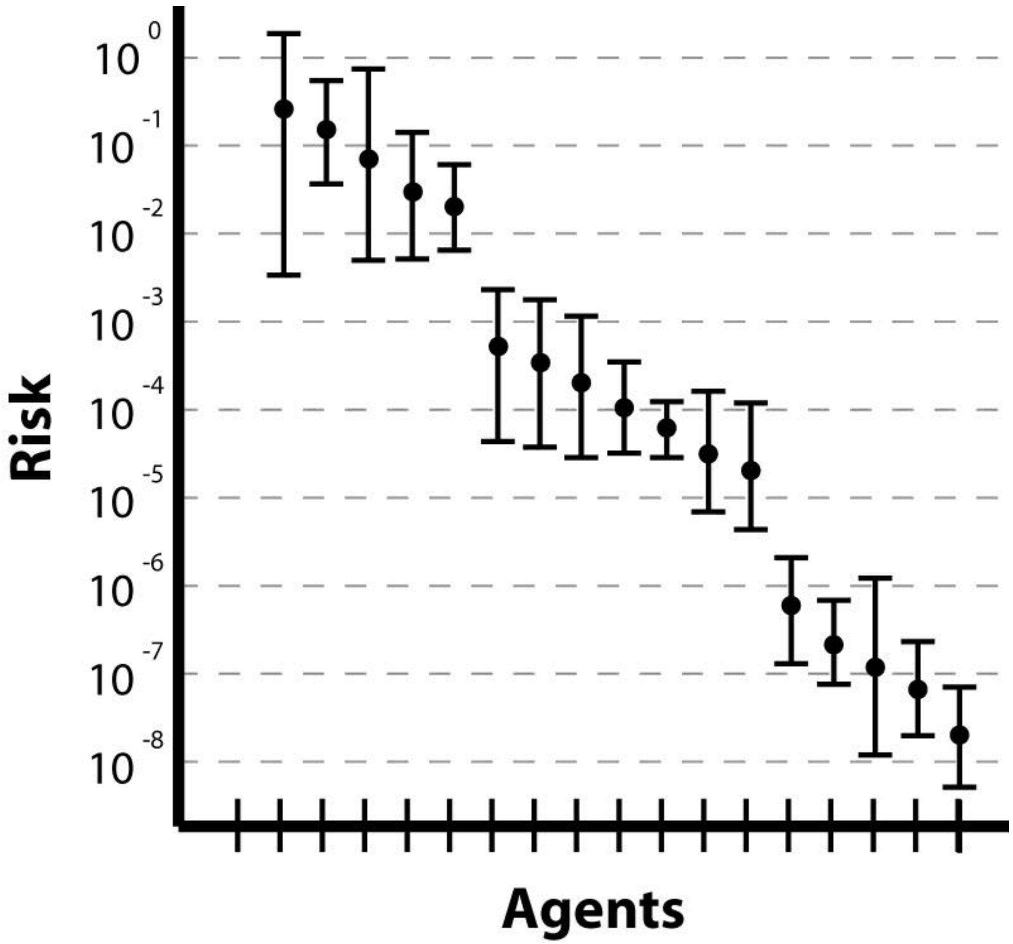
F(x)	x
0.05	0.1
0.5	0.3
0.95	0.5



Example Results (Hypothetical Expert)

Relative Probabilities (RP) of Selected Agents (Given a Bioterrorism Attack - Hypothetical Expert)	
Hi Lethal - Comm	**RP**
Yersinia pestis *	13%
Variola Major Virus	1%
Ebola	6%
Lassa	6%
Marburg	6%
Hi Lethal- Non Comm	
Bacillus anthracis *	25%
Clostridium botulinum *	13%
Ricinus communis (castor bean)	13%
Burkholderia mallei	1%
Nipah virus	1%
Bovine Spongiform Encephalopathy *	1%
Vibrio cholerae **	3%
Other Agents	**9%**

Example Output

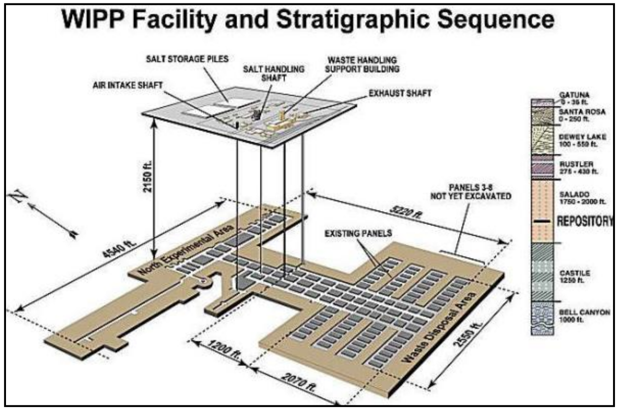


Observations about BTRA

- Experts were able to rank the relative likelihood of biological attack scenarios
- Different experts were remarkably consistent in their rankings
- Experts were also able to provide selected ratios of likelihoods
- Experts were relieved that they could express uncertainty about these ratios
- Dirichlet tool helped, but makes very strong assumptions

Human Intrusion into a Nuclear Waste Site

What is the likelihood that humans inadvertently dig up or drill into the WIPP repository in the next 10,000 years?



Approach to Expert Elicitation

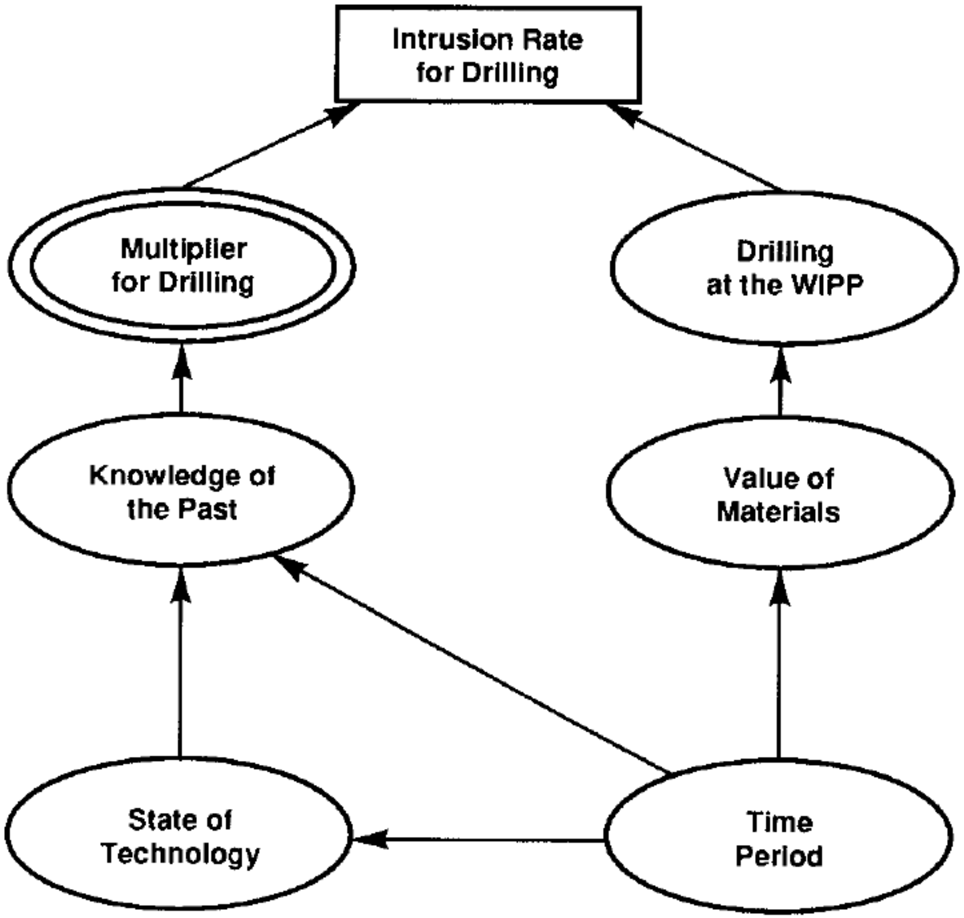
- 16 experts selected from 126 nominations
  - Science fiction writers
  - Futurologists
  - Sociologists
  - Risk analysts
- Organized as 4 teams of four
- Very different approaches to answering the elicitation question
  - Scenarios
  - Event trees
  - Influence diagrams

Modes of Intrusion

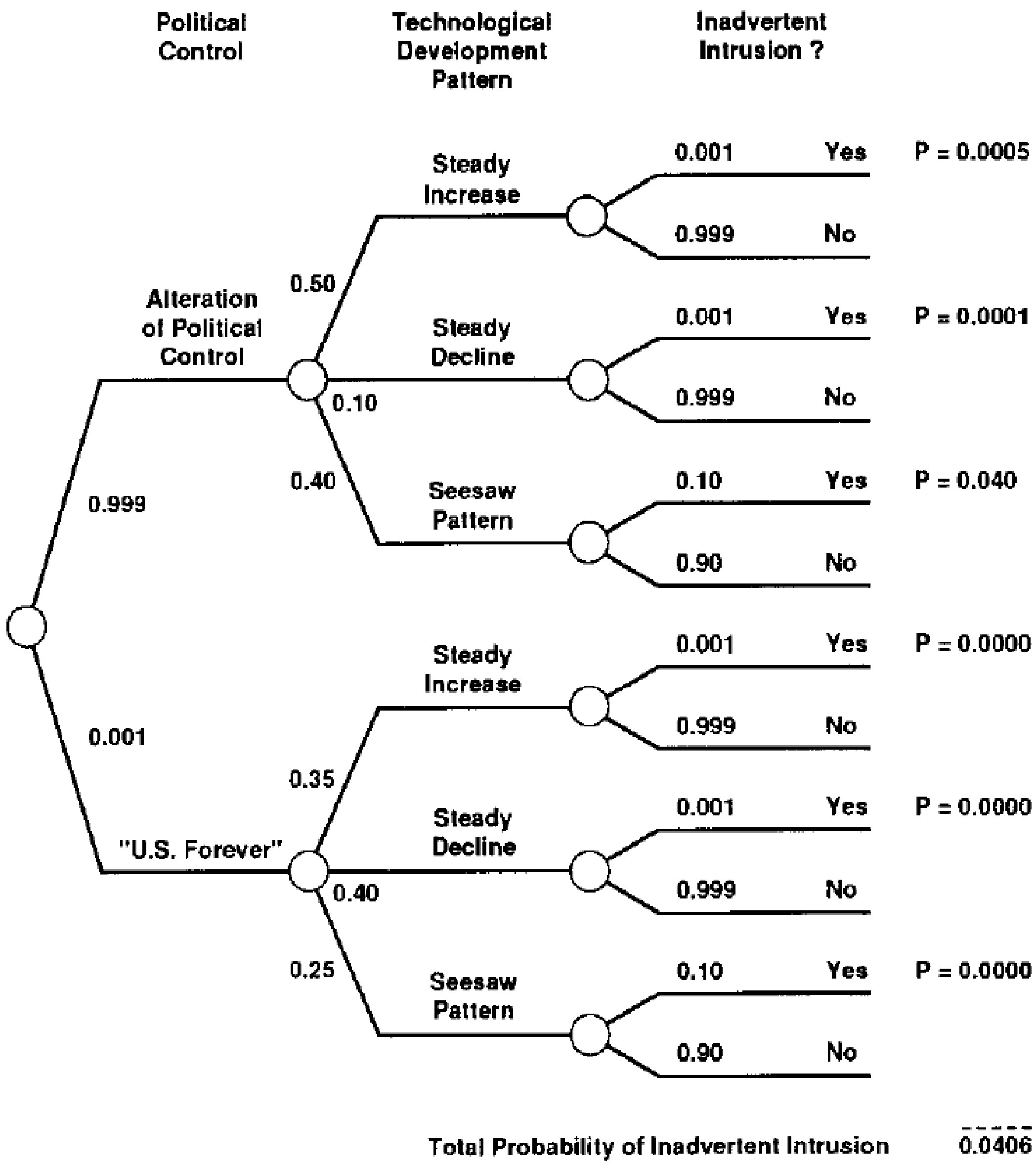
TABLE III-1. INTRUSION MODES

EXCAVATION	DRILLING
Archaeological	Hydrocarbons
Mineral	Water
Construction	Research
DISPOSAL/STORAGE	OFFSITE ACTIVITIES
Underground Injection	Water Impoundment
Petroleum Storage	Explosions
Additional Radioactive Waste Disposal	Water Well Field
TUNNELING	
Transportation	
Pipeline	
Mole Mining	

Influence Diagrams: Washington Team



Event Trees: CA/Arizona Team



Creative Point Scenarios: Boston Team

TABLE 1

Point Scenarios of Possible Future Societies—Boston Team

Scenario	Year	Description
A feminist world	2091	Women dominate society partially through selection of girl babies. Twentieth century science is discredited as male arrogance. Warnings about repository are dismissed as another example of muddled masculine thinking.
Mysticism and religion	2091	A religious cult emerges that rejects existing scientific consensus and realities. Settling in New Mexico, they searched for deeper meaning by digging up the WIPP site.
Buried treasure	2091	New Mexico secedes from the United States and is annexed by Mexico. Knowledge about the WIPP site is lost except for some rumors that something valuable is buried there. Treasure hunters are happy to find "warning signs" and begin to dig.
WIPP as the nation's nuclear waste site	2091	WIPP is expanded to receive all kinds of radioactive wastes and other waste, and it is enlarged to many times its planned capacity. Later, some of the wastes are recovered for processing or improved storage, leading to releases of radionuclides.
A Houston-to-Los Angeles tunnel	2991	A high-speed transportation tunnel is dug between Houston and Los Angeles with stops near Carlsbad and Phoenix. The tunnel is 2000 feet underground and passes close by the WIPP site. Construction and vibration disrupt the repository.
Global illiteracy	2991	A declining United States is replaced by a new State of Eastlandia, which establishes prison mines in New Mexico. Illiterate miners are incapable of reading the messages warning of the danger of the site.
Virus impairs computerized people	11991	Owing to a computer virus, robots disregard commands and begin to dig compulsively in the area of New Mexico, penetrating the WIPP site.
Human warriors return from space	11991	A battleship returning from a mission loses control upon re-entering the earth environment. Attempting to reduce speed, the ship fires lasers into the ground near the WIPP site. The effect of lasers and the crash impact penetrates the site.
Mickey Nuke and WIPP worlds	11191	The WIPP Museum and WIPP Worlds become major tourist attractions at the WIPP site. Mickey Nuke is a fictional character that survives many generations. As long as he lives, the warnings about WIPP survive.

Observations about WIPP Intrusion

- The four teams created very different approaches
- Yet they came up with similar probabilities of intrusion: Between 1% and 10% for 10,000 years
- The numbers may not mean much, though they suggest that there is a substantial risk of intrusion
- Consequences were not considered, but would likely be moderate (<1000 early fatalities, 10,000 latent cancers)
- The scenarios are most useful product, because they stimulated thinking about countermeasures

Overall Conclusions

- Expert elicitation can be useful even with “deep” uncertainty
- Parameterization and bounding is very useful and can lead to insights for decisions
- For large time scales, we should be modest:
  - Be creative in scenario construction, then systematic in elicitation frames
  - Don’t take probability assessments too seriously (ratios and orders of magnitude are OK)
  - Allow experts to express secondary uncertainty
  - Learn from red-blue teaming exercises in the military and terrorism risk and decision analysis
- For climate change
  - Frame climate change problems as decision problems
  - Find the decision relevant parameters (sea level rise, precipitation, frequency and severity of weather)
  - Determine bounds and conduct sensitivity analyses
  - Conduct expert elicitations on important parameters