# Robust Portfolio Methods for Risk-Based Counterterrorism Resource Allocation

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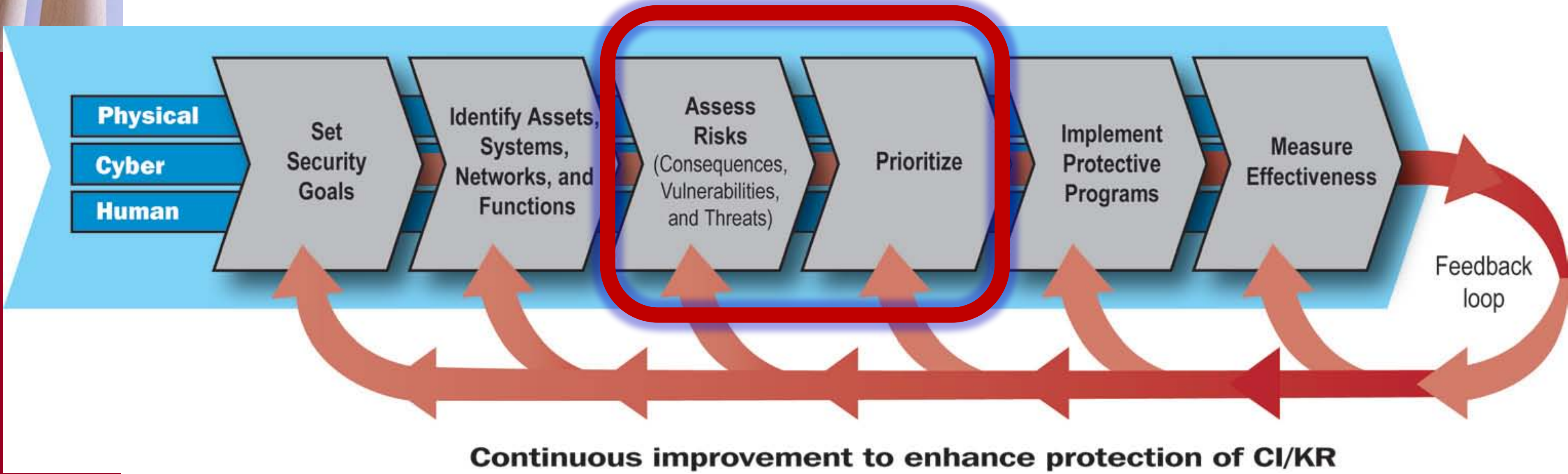
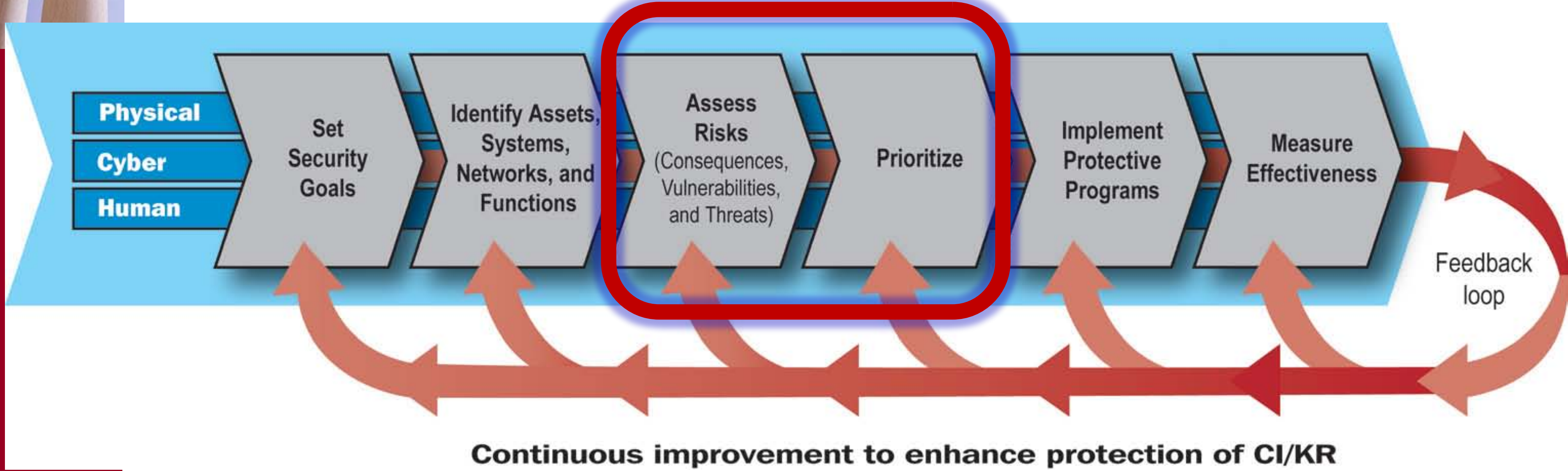
2009 DHS University Network Summit
March 17, 2009

# National Infrastructure Protection Plan Risk Management Framework




- Assess Risks
  - Determine risk by combining potential direct and indirect consequences of a terrorist attack or other hazards, known vulnerabilities to various potential attack vectors, and general or specific threat information

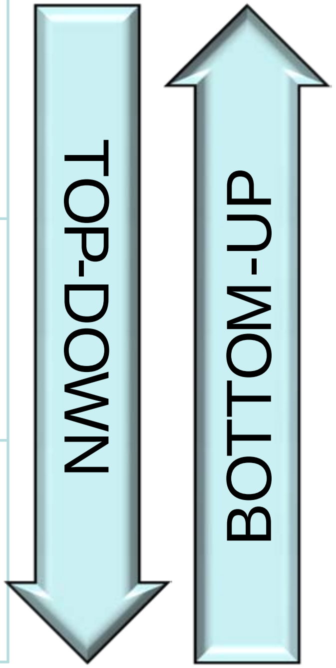
# National Infrastructure Protection Plan Risk Management Framework




- Prioritize
  - Aggregate and analyze risk assessment results to develop a comprehensive picture of asset, system, and network risk, establish priorities based on risk, and determine protection and business continuity initiatives that provide the greatest mitigations of risk

# Protecting Critical Infrastructure

| Level | Decisions |
| --- | --- |
| Federal Government | Allocate resources across sectors and regions (states or urban areas) |
| **State/Local Government** | **Allocate resources to specific facilities and asset** |
| Facility & Asset Owners/Managers | Identify and implement risk management measures and programs |



# Prioritizing Grant Money for Infrastructure Protection

- Buffer Zone Protection Program (BZPP)
  - DHS grant program provides funds to State and local authorities to prevent attacks and protect critical infrastructure
  - Total funding in FY 2006: $48.0 million (FY 2007: $48.5 million)
  - One of several DHS infrastructure protection grant programs
- Example: (all numbers approximate)
  - California Governor’s Office of Homeland Security (OHS) proposes 100+ critical sites (chemical facilities, financial institutions, power plants, dams, stadiums, etc.)
  - DHS amends and approves final list of about 100 sites
  - DHS allocates roughly $5 million in BZPP funds to state, based on number, type and character of sites
  - OHS determines how to allocate among qualified site
  - <u>How should they do it?</u>

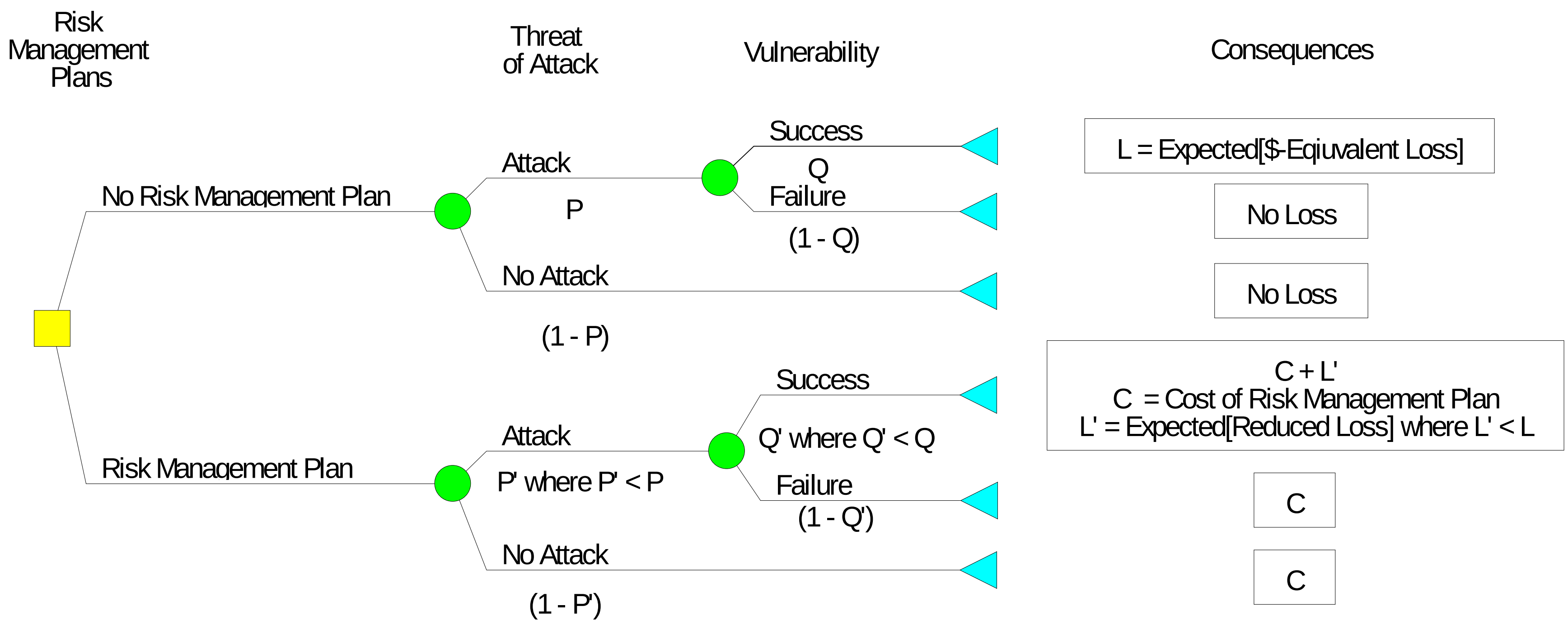
# Evaluating Consequences

- Evaluate consequences on distinct dimensions
  - Health, Economic, Mission, Psychological
- Assess importance weights for dimensions
  - Value-based judgments from policy-makers
- Approach #1: Compute Consequence Index (CI)
  - Combine weights and scaled consequence scores using multiattribute value (or utility) model

$$CI = \sum_i w_i \cdot s_i(C_i)$$

- Approach #2: Compute equivalent economic costs
  - Determine $ value for fatalities, security impact, symbolic value, and so on

# Simplified Framework for Evaluation of Risk Management Plans



# "Only" Five Inputs Required per Site

| | |
|---|---|
| 1. Threat: | Probability of Attack (P) |
| 2. Vulnerability: | Probability Attack Succeeds (Q) |
| 3. Consequences: | Expected Loss if Attack Succeeds (L) [\$-equivalent losses] |
| 4. Loss Reduction: | Loss Reduction with RMP ($0 < R < 1$) |
| 5. Cost: | Cost of Risk Reduction (C) |

**Expected loss:** No RMP: $EL = P \cdot Q \cdot L$

With RMP: $EL = P \cdot Q \cdot L \cdot (1-R) + C$

**Net loss reduction:** **<u>$(EL - EL) = P \cdot Q \cdot L \cdot R - C$</u>**

# Finding Optimal Portfolio of Risk Management Plans (RMPs)

- Decision variable:
  For each site, implement RMP (or not)
- Choose portfolio of RMPs that maximizes aggregate Expected Net Loss Reduction
  Subject to Constraints:
  - Budget or other resource constraints
  - Additional constraints for site or investment dependencies
- Solution approaches:
  - *Optimization:* Determine optimal portfolio with binary integer programming
  - *Heuristic:* Prioritize on ratio of risk reduction benefit to cost:

# Risk Reduction Benefit / Cost

$$\frac{Benefit}{Cost} = \frac{\left(P \cdot Q \cdot L\right) \cdot R}{C}$$

$$= \frac{(\text{threat} \cdot \text{vulnerability} \cdot \text{loss}) \cdot \text{reduction}}{\text{cost}}$$

# Implementation Challenges

- Required information is difficult to get, difficult to use, difficult to analyze
  - Daunting number of assessments required
    - 5 parameters × 100 sites = 500 distinct assessments
  - Threat probabilities are difficult to assess
  - Data on attack vulnerability and consequences are incomplete and incomparable
  - Indirect economic consequences are large but difficult to assess with precision
  - Assessments of risk management plan effectiveness are incomplete (or missing completely)
- Objective:
  - Develop rational approach to resource allocation that recognizes and embraces these limitations

# Liesiö, Mild, & Salo (2007) Robust Portfolio Modeling (RPM)

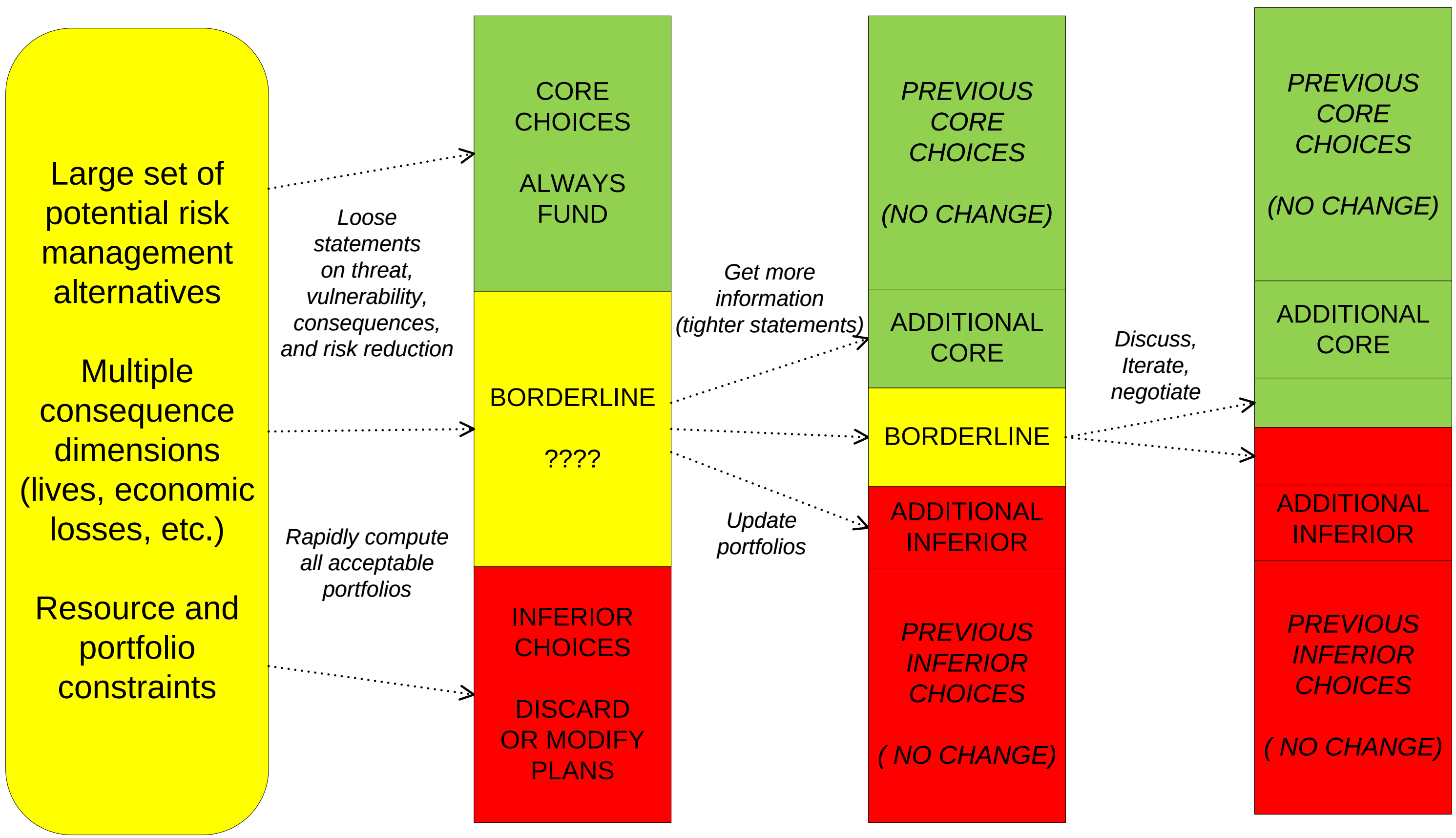
**Liesiö, J., Mild P., & Salo, A. (2007) Preference programming for robust portfolio modeling and project selection. *European Journal of Operational Research, 181*, 1488–1505.**

- Methodology for selecting subset of proposals subject to incomplete information
  - Multiattribute preferences (weighted additive value model)
  - Incomplete information on weights (e.g., $w_1 \geq w_2$)
  - Incomplete information on criteria scores (interval estimates)
- RPM algorithm
  - Dominance principles to eliminate inferior portfolios
  - Efficient algorithm for rapid identification of non-dominated portfolios
- Identify "robust" projects
  - Projects where funding decision would not change with additional information
  - Focus additional information collection on remaining projects

# Risk-Based
# Robust Portfolio Modeling (RB-RPM)

- RB-RPM adapts RPM to choosing among competing risk-reduction projects
  - Change objective function from:
    - Maximize sum of linear additive multiattribute values
  - To:
    - Maximize sum of expected risk reduction benefits
  - RPM method applies if certain assumptions are satisfied:
    - Criteria weights are known
    - Risk-neutral preferences over consequences
    - One and only one site will be attacked

# Risk-Based Robust Portfolio Process



# RB-RPM Assessment Protocol

- Ordinal information on threat / vulnerability
  - Rank-order sites based on RELATIVE probability of successful attack
- Interval estimates for expected consequences
  - Lower and upper bound on expected loss (conditional on successful attack occurring)
- Interval estimates for risk reduction
  - Expressed as percent reduction in expected loss
  - Lower and upper bounds on effectiveness of each risk management plan

# RB-RPM Example

- Disguised data, loosely based on sites in California
  - All data disguised / modified to conceal sensitive information
- Set of 29 infrastructure sites
  - Commercial buildings (3):
    High threat, limited risk reduction effectiveness
  - Dams (13):
    Large economic loss, good risk reduction potential
  - Chemical / Hazmat Plants (13):
    High fatality potential
- Risk management plan costs \$0.5 m per site
- Budget constraint of \$7.5 m available
- Probability of successful attack ≤ 0.10 for any single site

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# Assessments: Ranked Threats and Intervals

| Site | Ranked Threat | Expected Fatalities LB | Expected Fatalities UB | Exp. Monetary Loss LB | Exp. Monetary Loss UB | Risk Reduction LB | Risk Reduction UB | Expected Benefit LB | Expected Benefit UB |
|---|---|---|---|---|---|---|---|---|---|
| Commercial 1 | 1 | 1,750 | 2,250 | $ 10,000 | $ 40,000 | 5% | 10% | $ 938 | $ 5,125 |
| Commercial 2 | 2 | 1,250 | 1,750 | $ 4,000 | $ 16,000 | 5% | 10% | $ 513 | $ 2,475 |
| Chemical 1 | 3 | 30,000 | 50,000 | $ 400 | $ 800 | 15% | 25% | $ 22,560 | $ 62,700 |
| Dam 1 | 3 | 20,000 | 40,000 | $ 10,000 | $ 20,000 | 40% | 60% | $ 44,000 | $ 132,000 |

| Site | Ranked Threat | Expected Fatalities Lower Bnd. | Expected Fatalities Upper Bnd. | Exp. Monetary Loss Lower Bnd. | Exp. Monetary Loss Upper Bnd. | Risk Reduction Lower Bnd. | Risk Reduction Upper Bnd. | Expected Benefit Lower Bnd. | Expected Benefit Upper Bnd. |
|---|---|---|---|---|---|---|---|---|---|
| Chemical 4 | 5 | 7,500 | 15,000 | $ 250 | $ 500 | 15% | 25% | $ 5,663 | $ 18,875 |
| Chemical 5 | 5 | 7,500 | 15,000 | $ 150 | $ 300 | 15% | 25% | $ 5,648 | $ 18,825 |
| Chemical 6 | 5 | 7,500 | 12,000 | $ 400 | $ 800 | 15% | 25% | $ 5,685 | $ 15,200 |
| Dam 5 | 5 | 500 | 1,000 | $ 10,000 | $ 20,000 | 40% | 60% | $ 5,000 | $ 15,000 |
| Dam 6 | 6 | 500 | 1,000 | $ 10,000 | $ 20,000 | 40% | 60% | $ 5,000 | $ 15,000 |
| Dam 7 | 6 | 500 | 1,000 | $ 10,000 | $ 20,000 | 40% | 60% | $ 5,000 | $ 15,000 |
| Chemical 7 | 6 | 5,000 | 10,000 | $ 100 | $ 200 | 15% | 25% | $ 3,765 | $ 12,550 |
| Chemical 8 | 6 | 6,000 | 12,000 | $ 100 | $ 200 | 15% | 25% | $ 4,515 | $ 15,050 |
| Chemical 9 | 6 | 4,000 | 8,000 | $ 100 | $ 200 | 15% | 25% | $ 3,015 | $ 10,050 |
| Chemical 10 | 7 | 1,500 | 3,500 | $ 100 | $ 200 | 15% | 25% | $ 1,140 | $ 4,425 |
| Chemical 11 | 7 | 2,500 | 6,000 | $ 100 | $ 200 | 15% | 25% | $ 1,890 | $ 7,550 |
| Chemical 12 | 7 | 1,500 | 3,000 | $ 100 | $ 200 | 15% | 25% | $ 1,140 | $ 3,800 |
| Chemical 13 | 7 | 1,000 | 1,500 | $ 100 | $ 200 | 15% | 25% | $ 765 | $ 1,925 |
| Dam 8 | 7 | 500 | 1,000 | $ 20,000 | $ 40,000 | 40% | 60% | $ 9,000 | $ 27,000 |
| Dam 9 | 8 | 500 | 1,000 | $ 10,000 | $ 20,000 | 40% | 60% | $ 5,000 | $ 15,000 |
| Dam 10 | 8 | 500 | 1,000 | $ 10,000 | $ 20,000 | 40% | 60% | $ 5,000 | $ 15,000 |
| Dam 11 | 8 | 500 | 1,000 | $ 10,000 | $ 20,000 | 40% | 60% | $ 5,000 | $ 15,000 |
| Dam 12 | 8 | 100 | 200 | $ 5,000 | $ 10,000 | 40% | 60% | $ 2,200 | $ 6,600 |
| Dam 13 | 8 | 100 | 200 | $ 5,000 | $ 10,000 | 40% | 60% | $ 2,200 | $ 6,600 |

*Ranked Threat: Sites ranked based on relative probability of successful attack.*

*Monetary consequences are in million Dollar-equivalent value of each fatality is $5 million.*

# Apply RB-RPM Algorithm

- $2^{29} \approx 537$ million possible portfolios
- RPM algorithm rapidly identifies the subset of feasible non-dominated portfolios
  - Dynamic programming
  - Recursively discard portfolios based on infeasibility and/or dominance
- Algorithm implemented using LINGO (v. 10.0)
  - Windows XP with Intel Pentium M 1.7 GHz processor, 21.4 minutes to identify 209 non-dominated portfolios

# Identifying Robust Projects

- Core index for each project:
  - $N$ = number of non-dominated portfolios
  - $n_i$ = number of non-dominated portfolios where project $i$ is funded
  - $CI_i = n_i / N$
- Green projects: CI = 1
- Red projects: CI = 0
- Borderline projects: 0 < CI < 1

| Site | Ranked Threat | Expected Benefit LB | Expected Benefit UB | Core Index |
|---|---|---|---|---|
| Commercial 1 | 1 | $ 938 | $ 5,125 | **0.852** |
| Commercial 2 | 2 | $ 513 | $ 2,475 | **0.684** |
| Chemical 1 | 3 | $ 22,560 | $ 62,700 | **1.000** |
| Dam 1 | 3 | $ 44,000 | $ 132,000 | **1.000** |
| Commercial 3 | 3 | $ 388 | $ 2,225 | **0.699** |
| Dam 2 | 4 | $ 30,000 | $ 90,000 | **1.000** |
| Dam 3 | 4 | $ 20,000 | $ 60,000 | **1.000** |
| Dam 4 | 4 | $ 42,000 | $ 126,000 | **1.000** |
| Chemical 2 | 4 | $ 7,545 | $ 31,400 | **1.000** |
| Chemical 3 | 5 | $ 7,538 | $ 25,125 | **0.799** |
| Chemical 4 | 5 | $ 5,663 | $ 18,875 | **0.593** |
| Chemical 5 | 5 | $ 5,648 | $ 18,825 | **0.593** |
| Chemical 6 | 5 | $ 5,685 | $ 15,200 | **0.593** |
| Dam 5 | 5 | $ 5,000 | $ 15,000 | **1.000** |
| Dam 6 | 6 | $ 5,000 | $ 15,000 | **0.957** |
| Dam 7 | 6 | $ 5,000 | $ 15,000 | **0.957** |
| Chemical 7 | 6 | $ 3,765 | $ 12,550 | **0.421** |
| Chemical 8 | 6 | $ 4,515 | $ 15,050 | **0.134** |
| Chemical 9 | 6 | $ 3,015 | $ 10,050 | **0.120** |
| Chemical 10 | 7 | $ 1,140 | $ 4,425 | **0.000** |
| Chemical 11 | 7 | $ 1,890 | $ 7,550 | **0.000** |
| Chemical 12 | 7 | $ 1,140 | $ 3,800 | **0.000** |
| Chemical 13 | 7 | $ 765 | $ 1,925 | **0.000** |
| Dam 8 | 7 | $ 9,000 | $ 27,000 | **0.120** |
| Dam 9 | 8 | $ 5,000 | $ 15,000 | **0.120** |
| Dam 10 | 8 | $ 5,000 | $ 15,000 | **0.120** |
| Dam 11 | 8 | $ 5,000 | $ 15,000 | **0.120** |
| Dam 12 | 8 | $ 2,200 | $ 6,600 | **0.000** |
| Dam 13 | 8 | $ 2,200 | $ 6,600 | **0.000** |

# Obtaining Additional Information

- Additional information:
  - Narrower interval assessments on consequences or risk reduction effectiveness
  - Further constraints on estimated probability of attack
- If new information set is subset of original information, then set of non-dominated portfolios is subset of original set
  - Core projects remain core
  - Exterior projects remain exterior
  - Borderline projects may become either core or exterior

## Achieving Convergence

- Use RB-RPM at early stage, with wide intervals
  - Avoid unnecessary risk assessments for sites/assets that are already core or exterior
  - Focus attention where new information affects the funding decision
- Caveat:
  - In practice, new information sometimes (often?) leads to WIDER intervals or revisions outside of previous bounds

# Issues

- Multiple risk management plans to potentially address a threat (or multiple threats)
  - Nonlinear models (ouch!)
- Risk aversion
  - Nonlinear models and joint distributions (double ouch!)
- More complex attack scenarios
  - Example: multiple simultaneous targets
- Strategically adaptive opponents
  - Threat is almost certainly correlated with vulnerability and/or consequences