A GAME THEORETIC APPROACH TO SAFEGUARD SELECTION AND OPTIMIZATION

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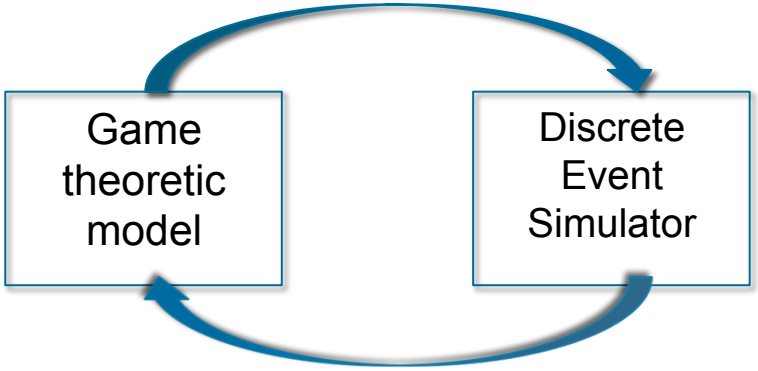
Motivation

- Expansion of nuclear power and divergence of fuel cycles pose new challenges for safeguards regime
- Probabilistic Risk Assessment (PRA) may not be the best method (NRC 2010)
- Does not account for ability of intelligent adversary to respond and adapt
  - Use of game theory will address this issue

Purpose

- Proof-of-concept model to demonstrate utility of game theory
- Coupled discrete event simulator and game theoretic model
- Conduct sensitivity analysis by varying relevant parameters and assessing strategy selection



General Methodology

- Threat scenario:
  - Attacker seeks to divert 1 kg of material from a safeguarded facility over 30-day period
- Two-person, zero-sum game
  - Inspector ("defender") seeks to maximize detection probability
  - Proliferator ("attacker") seeks to minimize detection probability
- Simple DES developed in Excel populates game theoretic model

Theory

- Cournot game- Non-transparent defense strategy
- Maxmin = Minmax for system in equilibrium

$$\sum_{i=1}^{\infty} a_{ij} x_i \leq v \text{ for } j = 1, \ldots$$

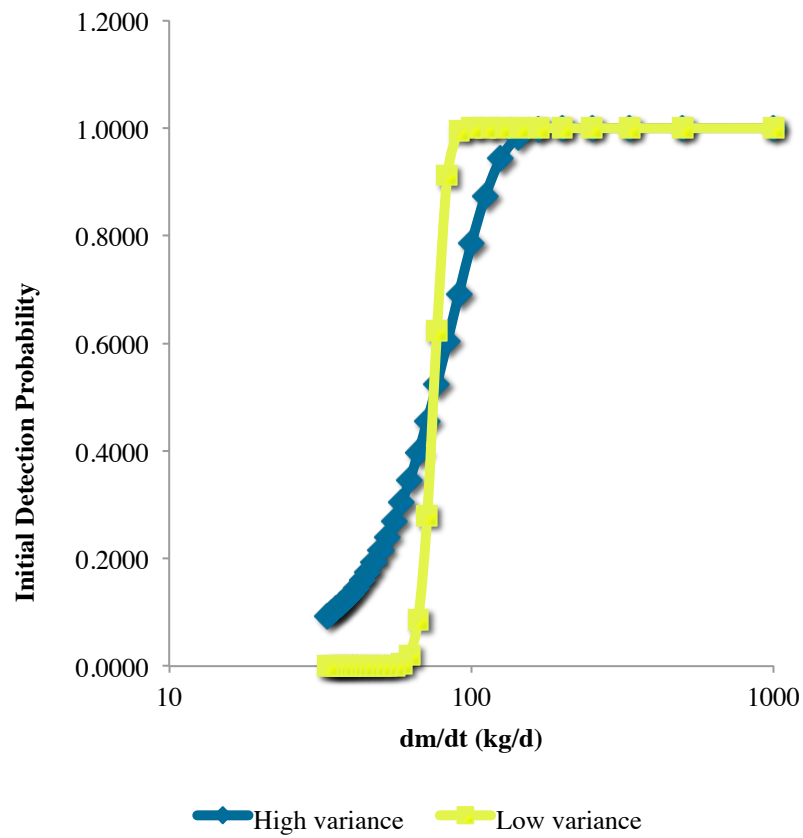
$$\sum_{j=1}^{\infty} a_{ij} y_j \geq v \text{ for } i = 1, \ldots$$

	y_1	y_2	
x_1	3	4	3
x_2	2	1	1
	3	4	

	Attacker		
	r_1	r_2	… r_n
Defender compl7 …mod1 low1	p_{11}	p_{12}	p_{1n}
	p_{21}	p_{22}	p_{2n}
	p_{31}	p_{32}	p_{3n}

Discrete Event Simulator

- Defender options:
  - Frequency- daily to weekly
  - Dependence- low, moderate, high, complete
- Defender is cost-constrained
- Attacker options:
  - Can divert in any even number of days between 2 and 30
  - Length of Diversion- related to initial detection probability

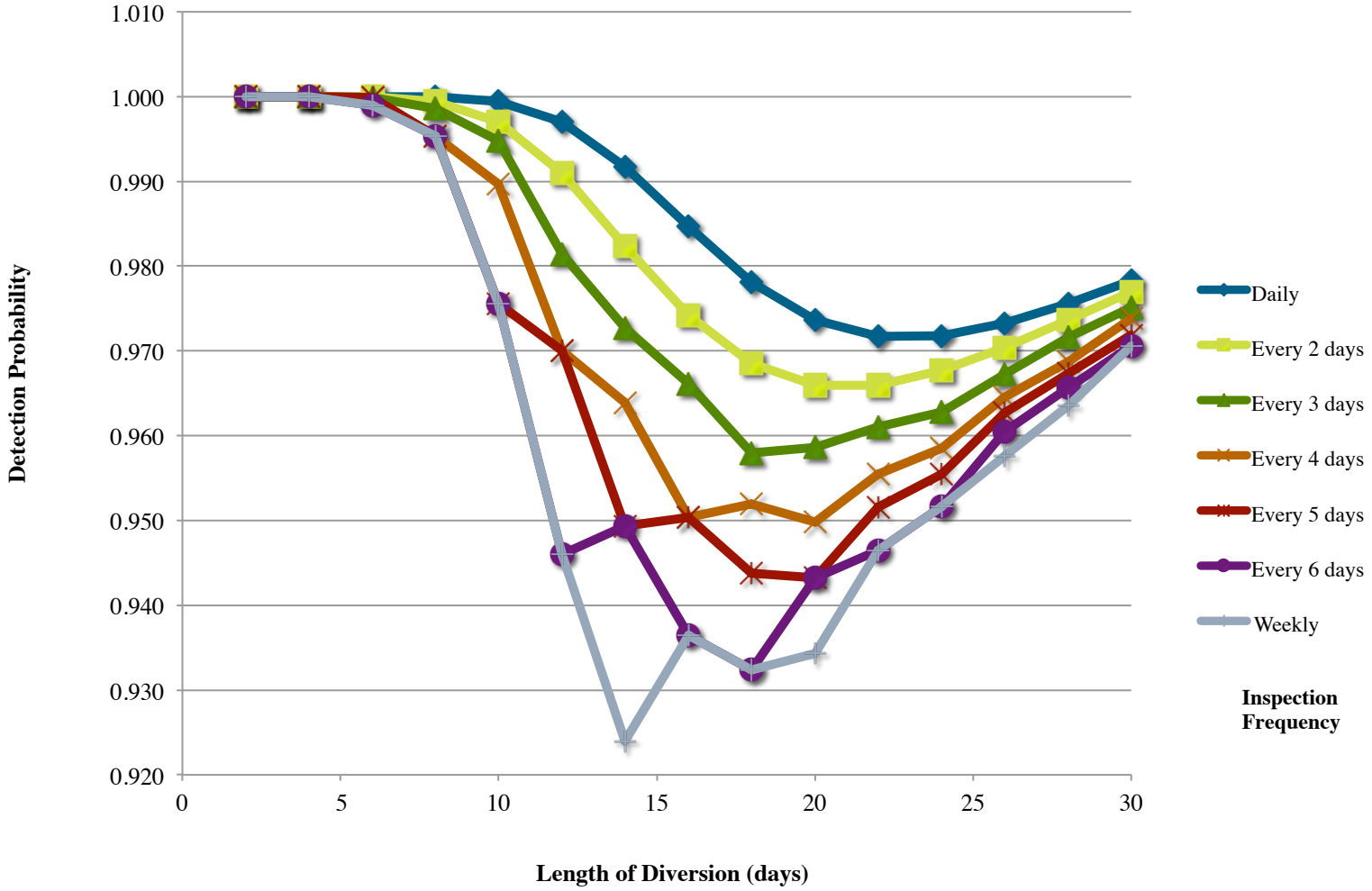


Discrete Event Simulator

- Extends insider theft methodology presented in Durán 2010 (Sandia National Lab/UT Austin)
  - Human reliability analysis used to incorporate dependency in MC&A activities

- Background detection probability used as surrogate for all safeguarding activities not explicitly modeled
  - Ranged from 0.0001 to 0.1 [day^{-1}]

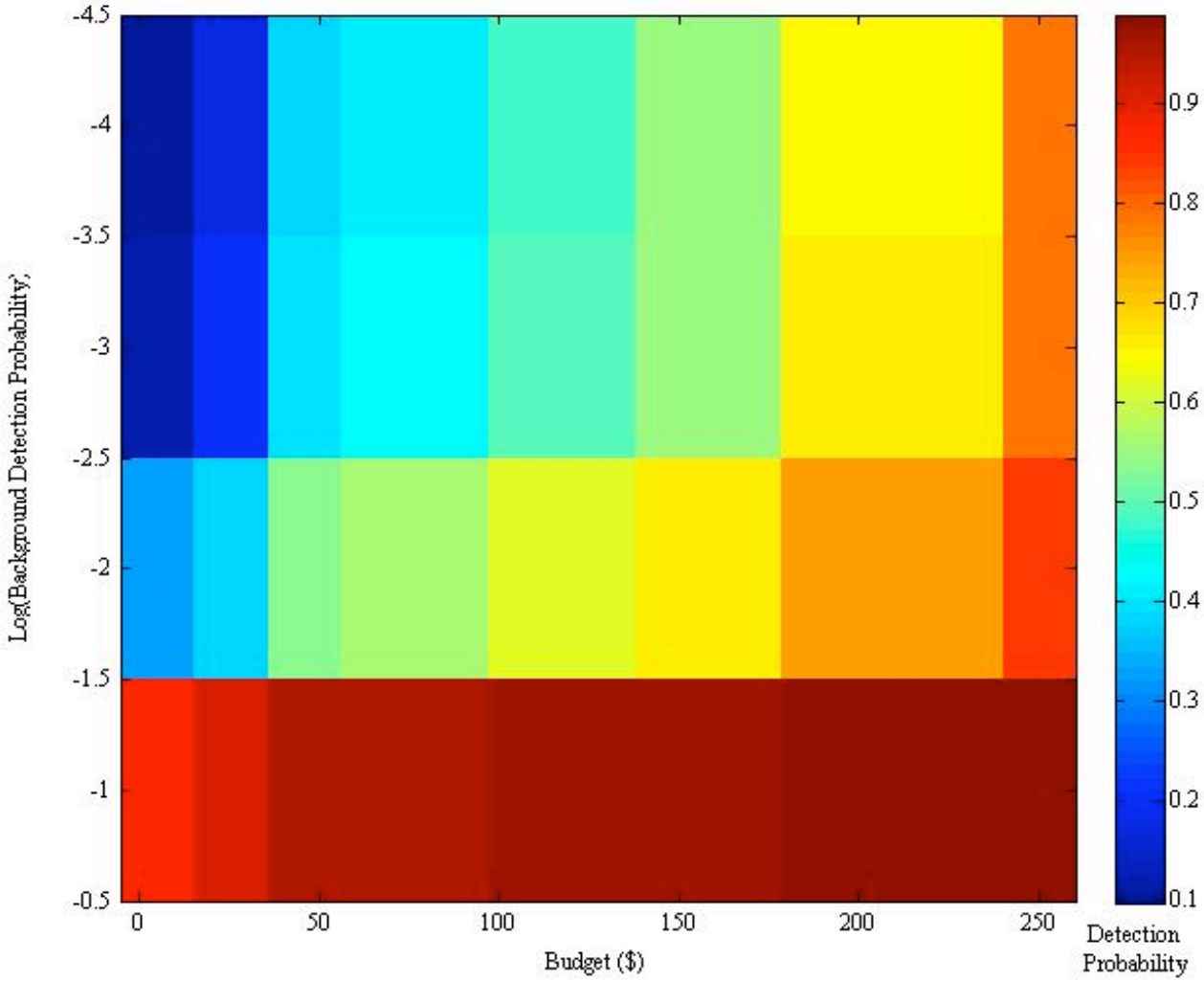
Results- Attacker Strategy



Results- Sensitivity Analysis

P_b	0.0001		0.001		0.01		0.1	
B ($)	**Defender strategy**	**LOD**	**Defender strategy**	**LOD**	**Defender strategy**	**LOD**	**Defender strategy**	**LOD**
5	comp6	30	comp6	30	comp6	26	comp6	14
10	high7	30	high7	30	high7	30	high6	16
30	mod4	30	mod4	30	mod4	30	mod4	20
40	mod3	30	mod3	30	mod3	30	mod3	18
50	mod3	30	mod3	30	mod3	30	mod3	18
60	low4	30	low4	30	low4 0.995; mod2 0.005	28	mod2	22
70	low4	30	low4	30	low4 0.995; mod2 0.005	28	mod2	22
80	low3	30	low3	30	low3	30	low3	18
100	low3	30	low3	30	low3	30	low3	18
120	low2	30	low2	30	low2	30	low2	22
150	low2	30	low2	30	low2	30	low2	22
200	low2	30	low2	30	low2	30	low2	22
250	low1	30	low1	30	low1	30	low1	28

Results- Overall Detection Probability



Conclusions and Future Work

- Demonstrated utility of game theory for modeling simple diversion scenario
- Provides insight into incremental benefit of adding element to existing safeguards regime
- Construct inspector timelines in more realistic way
- Adjust defense strategy cost assignments
- Expand scope of DES to incorporate full menu of transparent and non-transparent safeguarding options