

Is Game Theory Ready for Prime Time?

May 2015

**Vicki M. Bier
University of Wisconsin-Madison**

Is Game Theory Ready for Prime Time?

- **Yes:** Models are getting more realistic (multiple attributes, defender uncertainty, deterrence, more complex systems)
- **No:** Quantification and validation are still a challenge
- **Hopefully soon:**
 - Some models make extensive use of empirical data
 - Project on adaptive-adversary models (2010-2011) proved that game theory could generate useful quantitative results through convergent validation
 - Interview methods can be used to quantify deterrence
 - Methods for empirical calibration of expert opinion using seed questions have been applied to terrorism

Game Theory



- Determine the optimal defense against an optimal attack
- Game theory is a useful model for security and critical infrastructure protection:
 - Appropriate when protecting against intelligent and adaptable adversaries
 - Recognizes that defensive strategies must account for attacker behavior

Early after September 11

- **Early applications of game theory to homeland security by academics were unrealistically simple**
- **Assumptions included:**
 - Adversaries care about one thing (e.g., maximize fatalities), rather than having multiple goals
 - Defender knows adversary goal with no uncertainty
 - No adversary deterrence
 - Models considered only individual assets (e.g., buildings), rather than **systems** (e.g., multiple screening methods)
- **Little or no thought about how to quantify models**

Models Now More Realistic

- **Multi-attribute** adversary goals (John/Beitel)
- **Treatment of defender uncertainty** (Bier):
 - But difficult to get adequate hedging
- **Considering simple series/parallel systems:**
 - But large networks are still challenging to analyze
- **Models of adversary deterrence** (Bier/John):
 - E.g., using target-oriented utility theory
- **More thought devoted to model quantification**

Work on Model Validation

- **Terrorism models can be quantified with empirical data**
- **Enders and Sandler (2002):**
 - “the installation of screening devices in US airports in January 1973 made skyjackings more difficult”
 - “thus encouraging terrorists to substitute into other kinds of hostage missions or to stage a skyjacking from an airport outside of the United States”
- **Barros and Proença (2005):**
 - “attacks that result in assassination have a higher probability of being Islamic”
- **Mohtadi and Murshid (2009):**
 - “a credible worst-case scenario would involve losses of about 5000 to 10,000 lives”
 - “return time for events of such magnitude is shortening”

Model Quantification

- **Project on adaptive-adversary models (2010-2011) proved game theory can generate useful realistic results:**
 - With reasonable levels of effort
- **Two approaches to quantify adversary attribute weights:**
 - Detailed elicitation of “proxy” experts
 - Probabilistic inversion of target rankings
- **Multiple methods give convergent validity:**
 - Do different approaches yield similar results?
 - Are differences of practical significance?

Model Quantification

- **Applications of game theory to aviation:**

- Research has questioned the merits of protection against man-portable air defense systems (Bier, von Winterfeldt)
- Tambe has shown that game theory can be used to improve on random or subjective allocation of air marshals or airport security (better protection for the same resources)

Quantifying Deterrence

- **Interview methods can be used to quantify deterrence:**
 - Anthony, "A calibrated model of the psychology of deterrence," *Bulletin on Narcotics*, 2004
 - Loughran et al., "Re-examining the functional form of the certainty effect in deterrence theory," *Justice Quarterly*, 2011 (serious youth offenders)

Approaches to Validation

- **Use of empirical data (when available)**
- Use of “seed questions” when directly relevant data not available

Work on Model Validation

- Methods for calibration of expert opinion using seed questions:
 - **Cooke, "Experts in Uncertainty" (1991)**
- Bier showed that seed questions can be developed for terrorism:
 - But the resulting confidence intervals in a sample application were too broad to be of practical usefulness

Work on Model Validation

- First conference on **Validating Models of Adversary Behavior**, Buffalo/Niagara Falls, NY, June 2013
- Model validation in adversary modeling is challenging and sometimes not feasible, due to lack of data for rare events:
 - But many alternative were presented and discussed
- Conference included exercises using real/hypothetical data:
 - To encourage model builders/developers to engage data
- **Second conference planned for August 2015**

Backup Slides (Bibliography)

Bibliography

- **Multi-attribute models of adversary goals:**
 - Beitel et al., 2004. Balanced scorecard method for predicting the probability of a terrorist attack. *Risk Analysis* 24(4)
 - John and Rosoff, 2010. Modeling terrorist beliefs and motivations, CREATE Homeland Security Center, USC

Bibliography

■ Treatment of defender uncertainty:

- Bier et al., Choosing what to protect: Strategic defensive allocation against an unknown attacker, *J. Public Economic Theory*, 9:563-587, 2007.
- Bier et al., Optimal resource allocation for defense of targets based on differing measures of attractiveness, *Risk Analysis*, 28:763-770, 2008.
- Bier et al., Achieving realistic levels of defensive hedging based on non-monotonic and multi-attribute terrorist utility functions, *Handbook of Operations Research for Homeland Security*, 2012.

Bibliography

■ Treatment of deterrence:

- Bier and Kosanoglu. 2014. Target-oriented utility theory for modeling the deterrent effects of counterterrorism. *Reliability Engineering & System Safety* (November), 1-35.
- John and Rosoff, 2010. Modeling terrorist beliefs and motivations, CREATE Homeland Security Center, USC.
- Anthony, A calibrated model of the psychology of deterrence, *Bulletin on Narcotics*, 2004
- Loughran et al., Re-examining the functional form of the certainty effect in deterrence theory, *Justice Quarterly*, 2011

Bibliography

■ Use of empirical data:

- Enders, Sandler (2000) Is transnational terrorism becoming more threatening: A time-series investigation. *J. Conflict Resolution* 44(3):307–332.
- Barros, Proença (2005) Mixed logit estimation of radical Islamic terrorism in Europe and North America: A comparative study. *J. Conflict Resolution* 49(2):298–314.
- Mohtadi, Murshid (2009) The risk of catastrophic terrorism: An extreme value approach. *J. Appl. Econometrics* 24:537–559.

Bibliography

- **Quantification of expert opinion:**
 - Cooke, *Experts in Uncertainty: Opinion and Subjective Probability in Science*, 1991
 - Wang and Bier, 2013, Expert elicitation of adversary preferences using ordinal judgments. *Operations Research* 61(2):372-385

Bibliography

- **Applications of game theory to aviation:**
 - Okpara and Bier, Securing passenger aircraft from man-portable air defense systems (MANPADS), *Risk Analysis*, 28:1583-1599, 2008.
 - Von Winterfeldt and O'Sullivan, Should we protect commercial airplanes against surface-to-air missile attacks by terrorists? *Decision Analysis* 3, 2006
 - Tambe, *Security and Game Theory: Algorithms, Deployed Systems, Lessons Learned*, 2011