National Center for Risk and Economic Analysis of Terrorism Events
University of Southern California
Los Angeles, California

Game Theory or Not Game Theory?—Hybrid Defense Resource Allocations
October 2010 to September 2011

Jun Zhuang
University at Buffalo
jzhuang@buffalo.edu

"This research was supported by the United States Department of Homeland Security through the National Center for Risk and Economic Analysis of Terrorism Events (CREATE) under Cooperative Agreement 2007-ST-061-RE0001. However, any opinions, findings, and conclusions or recommendations in this document are those of the authors and do not necessarily reflect views of the United States Department of Homeland Security or the University of Southern California."

Cooperative Agreement No. 2010-ST-061-RE0001
Department of Homeland Security

December 31, 2011
ABOUT CREATE
The National Center for Risk and Economic Analysis of Terrorism Events (CREATE) was the first university-based Center of Excellence (COE) funded by University Programs of the Science and Technology (S&T) Directorate of the Department of Homeland Security (DHS). CREATE started operations in March of 2004. This annual report covers the seventh year of CREATE funding from October 2010 to September 2011, the first year under Cooperative Agreement 2010-ST-061-RE0001 from DHS. While the text of this report focuses on the seventh year, all data tables, publications, lists of participants, students, and presentations and events are cumulative from the inception of CREATE.

CREATE’s research mission is to develop advanced models and tools for risk assessment, economic assessment, and risk management to counter terrorism. CREATE accomplishes this mission through an integrated program of research, education, and outreach, spanning the disciplines of economics, psychology, political science, industrial and systems engineering and information science. CREATE develops models, analytical tools, methodologies and software, and tests these tools in case analyses, representing critical homeland security investment and policy decisions.

Due to the cross-cutting nature of research in risk, economics, and risk management, CREATE serves the need of many client agencies at the DHS, including the Transportation Security Agency, Customs and Border Protection, Immigration and Customs Enforcement, FEMA and the US Coast Guard. In addition, CREATE has developed relationships with clients in the Offices of National Protection and Programs, Intelligence and Analysis, General Council, Health Affairs, and Domestic Nuclear Detection. Using a mix of fundamental and applied research, CREATE faculty and students take both the long-term view of how to reduce terrorism risk through fundamental research and the medium-term view of how to improve the cost-effectiveness of counter-terrorism policies and investments through applied research.

Please visit www.create.usc.edu for more information.
1. Executive Summary

The primary focus of the research at the University at Buffalo has been to explore new decision and risk analysis models to better prepare for and respond to man-made and natural disasters. We use game theory to model the strategic interactions among players in homeland security, including terrorists, the federal/local/foreign governments, private companies, non-governmental organizations (NGOs), and private citizens. Figure 1 shows the general research framework. The governments and private citizens seek to protect lives, property, and critical infrastructure from both adaptive terrorists and non-adaptive natural disasters. In particular, the federal government can provide grants to local governments and foreign aid to foreign governments, and all levels of government can provide pre-disaster preparation/mitigation (including hazard/vulnerability analysis, hazard mitigation, emergency preparedness, and recovery preparedness) and post-disaster relief (including emergency response and disaster recovery) to private citizens. Private citizens can also, of course, make their own investments. The private corporations receive regulations from the government, pay taxes to the government, and balance efforts between safety and production. The NGOs receive donations and also play a key role in disaster preparedness and relief.

This has been a productive year for this CREATE-sponsored project (see Section 4 for details). We have 13 peer-reviewed journal papers published/accepted with 8 additional papers under review with journals. The research group (the PI and his students) made 35 conference presentations and the PI spoke at over 12 invited research seminars and guest lectures. The research has interested agencies from the DHS and other government organizations. For example, the PI was invited to present at the 2011 DHS University Network Summit. Two of the PI’s Ph.D. students were invited to present their research posters at the 2011 DHS University Network Summit (acceptance rate ~20%). One of the PI’s undergraduate students received the prestigious 2011 University at Buffalo’s Undergraduate Research and Scholarship Award of Distinction, based on her CREATE-sponsored research. One of the PI’s Ph.D. students was the Finalist of the 2010 Decision Analysis Society Student Paper Award. Another one of the PI’s Ph.D. students recently
received the 2011 Student Paper Award from the Society for Risk Analysis's Decision Analysis and Risk Specialty Group.

**Keywords:** Game theory, homeland security, Non-strategic players, hybrid model

2. **Research Accomplishments**

2.1. **Hybrid Defensive Resource Allocations in the Face of Partially Strategic Attackers, and Comparison with Fully Endogenous and Fully Exogenous Models**

Many models have been developed to study homeland security games between governments (defender) and terrorists (attacker, adversary, enemy), with the limiting assumption of the terrorists being rational or strategic. In this research, we develop a novel hybrid model in which a centralized government allocates defensive resources among multiple potential targets to minimize total expected loss, in the face of a terrorist being either strategic or non-strategic. The attack probabilities of a strategic terrorist are endogenously determined in the model, while the attack probabilities of a non-strategic terrorist are exogenously provided. We study the robustness of defensive resource allocations by comparing the government's total expected losses when: (a) the government knows the probability that the terrorist is strategic; (b) the government falsely believes that the terrorist is fully strategic, when the terrorist could be non-strategic; and (c) the government falsely believes that the terrorist is fully non-strategic, when the terrorist could be strategic. We find that game models are preferred even when the probability of a non-strategic terrorist is significantly greater than 50%. We conclude that defensive resource allocations based on game-theoretic models would not incur too much additional expected loss, as compared to non-game-theoretic models.

![Figure 2: Government's budget allocation as a function that the probability that the terrorist is non-strategic (left three columns); and comparing the government’s total expected losses using three types of defensive resource allocations (right three columns)](image)

2.2. **Balancing Congestion and Security in the Presence of Strategic Applicants with Private Information**

Concerns on security and congestion appear in security screening which is used to identify and deter potential threats (e.g., attackers, terrorists, smugglers, spies) among normal applicants wishing to enter an organization, location, or facility. Generally, in-depth screening reduces the risk of being attacked, but creates delays that may deter normal applicants and thus, decrease the welfare of the approver (authority, manager, screener). In this work, we develop a model to determine the optimal screening policy to
maximize the reward from admitting normal applicants net of the penalty from admitting bad applicants. We use an M/M/1 queueing system to capture the impact of security screening policies on system congestion and use game theory to model strategic behavior, in which potential applicants with private information can decide whether to apply based on the observed approver’s screening policy and the submission behavior of other potential applicants. We provide analytical solutions for the optimal non-discriminatory screening policy and numerical illustrations for both the discriminatory and non-discriminatory policies. In addition, we discuss more complex scenarios including imperfect screening, abandonment behavior of normal applicants, and non-zero waiting costs of attackers.

Figure 3: Equilibrium payoffs and approver’s screening probabilities and applicants’ submission probabilities under both discriminatory and non-discriminatory policies

2.3. Cost of Equity in Homeland Security Resource Allocation In the Face of A Strategic Attacker

Hundreds of billions of dollars have been spent in homeland security since September 11, 2001. Many models have been developed to study games between governments (defenders) and terrorists (attackers), however, few studies consider the tradeoff between equity and efficiency in homeland security resource allocation. In this research, we fill this gap by developing a novel model in which a government allocates defensive resources among multiple potential targets, while reserving a portion of defensive resources (represented by the equity coefficient) for equal distribution (according to geographical areas, population, density, etc.). The government is faced with a strategic terrorist whose attack probabilities are endogenously determined in the model. We study the effect of the equity coefficient on the optimal defensive resource allocations and the corresponding expected loss. We find that the cost of equity in terms of increases in loss increases convexly in the equity coefficient. Furthermore, such cost would be lower when: (a) government uses per-valuation equity, (b) the cost-effectiveness coefficient of defense increases, and (c) the total defense budget increases.
In this work, we propose a novel game-theoretic model for assigning defensive resources to protect a set of targets against intentional threats such as terrorist attacks. The novelty of our model is that we allow the defender to assign her defensive resources to any subset (arbitrary layers) of targets due to functional similarity or geographical proximity, while previous models in literature could only prescribe defensive investment on either individual targets or all targets together (e.g., border security). Figure 5 shows two examples of arbitrary layers of protection against three threats. In Example 1, the defender could protect against three types of attacks (chemical, biological, and explosive terrorism) either individually (\{1\}, \{2\}, and \{3\}) through specialty detectors, or collectively (\{1, 2, 3\}) by enhancing emergency responses. The defender could also protect against both chemical and biological terrorism jointly (\{1, 2\}) through public-health surveillance programs in order to facilitate early detection; but this method might not be effective for protection against explosive terrorism. Similarly, in Example 2, the defender can counter threats against three urban areas (New York, Washington, D.C., and Los Angeles) either individually (\{1\}, \{2\}, and \{3\}) through individual target hardening, or collectively (\{1, 2, 3\}) by improving U.S. border security. The defender can also protect New York and Washington, D.C. jointly (\{1, 2\}) due to their geographical proximity (200 miles away). This can be achieved by establishing a regional northeastern U.S. emergency response system, which would most likely not benefit the Los Angeles area (located 2450 miles from New York) too much. To the best of our knowledge, such game-theoretic models of arbitrary layers of protection in facing with strategic attacks, as provided in Figure 5, have not been studied in literature. We develop methods to solve for equilibrium, and illustrate our model using numerical examples. Compared to traditional models that only allow for individual target hardening, our results show that our model could significantly increase the defender's payoff, especially when the unit cost of defense is high.
2.5. Other Research Achievements

See [http://www.eng.buffalo.edu/~jzhuang/research.htm](http://www.eng.buffalo.edu/~jzhuang/research.htm) for the PI’s full list of research activities. Most of the PI’s papers are downloadable from this website. See Section 4 for a full list of the research achievement during the reported period. One of the PI’s undergraduate students received the prestigious 2011 University at Buffalo’s Undergraduate Research and Scholarship Award of Distinction, based on her CREATE-sponsored research. One of the PI’s Ph.D. students was the Finalist of the 2010 Decision Analysis Society Student Paper Award. Another one of the PI’s Ph.D. students recently received the 2011 Student Paper Award from the Society for Risk Analysis's Decision Analysis and Risk Specialty Group.

3. Applied Relevance

The research is applicable to agencies such as DHS and other government agencies, especially in homeland security resource allocation in the face of adaptive adversary. For example, the PI was invited to present at the 2011 DHS University Network Summit. Two of the PI’s Ph.D. students were invited to present their research posters at the 2011 DHS University Network Summit (acceptance rate ~20%). The theoretical models have matured in the past years to capture more realistic considerations to generate more robust and applicable models, including more players (local/federal/foreign governments, adversaries, private citizens/communities), more player options (e.g., attack/defense/contract/subsidy), more attributes in objective functions (e.g., balancing between security and congestion/waiting, balancing between equity and efficiency), and more realistic adversary behavior (e.g., partially strategic). All model parameters are tunable so that practitioners are able to customize and play with the software demos.

Following the PI’s DHS University Network Summit panel talk, the PI was contacted by a DHS writer for an article that would be published by *DHS Science & Technology (S&T) Snapshots*. The PI has been working with operations research specialists at Strategy and Risk Division, Office of Policy, U.S. Immigration and Customs Enforcement at DHS, on applications of game theory to risk analysis. Similarly, the PI has been working with risk analysts at Office of Risk Management and Analysis, National Protection and Programs Directorate at DHS, on homeland security resource allocations. The PI has also been working with other Federal agencies including federal emergency managers at the Department of Veterans Affairs—Western New York Healthcare Systems, researchers at Oak Ridge National Laboratory, and U.S. Army Engineer Research and Development Center.

4. Collaborative Projects

Within CREATE, this project maintains a close interface with the CREATE projects on Theme 1 “Management of Risks from Intelligent, Adaptive Adversaries” and Theme 6 “Evaluating the Effectiveness of Homeland Security Risk Management Approaches.” In particular, the PI has been working with Dr. Steve Hora on a project “A Model of Terrorism and Counter Terrorism Expenditures,” working with Drs. Milind Tambe and Bo An on modeling and applying secrecy and deception strategies to paroling games, and working with Drs. Lloyd Mitchell (Haskell Foundation at Haskell Indian Nations University) and Anne Garland (Applied Research in Environmental Science) on simulating and optimizing emergency preparedness partnerships among Indian communities and local/state governments. This project is also complementing Dr. Vicki Bier (University of Wisconsin-Madison)’s CREATE projects on risk and economic modeling of counter-terrorism.

Outside of CREATE, the PI is working with the DHS Center of Excellence to develop joint projects, including START (validating game models using START datasets), CAMRA (developing game theoretic microbial risk management), NCFPD (developing game theoretic food supply chain risk management),
and NCBSI (using queuing theory and game theory for optimal border control). Other funded projects include:


4.1. Publications and Reports

<table>
<thead>
<tr>
<th>CREATE PUBLICATIONS</th>
<th>Research Area</th>
<th>Referred</th>
<th>Not Referred</th>
<th>PDF Available for DHS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zhuang, Jun - University at Buffalo</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research Area</td>
<td>Referred</td>
<td>Not Referred</td>
<td>PDF Available for DHS</td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td>----------</td>
<td>--------------</td>
<td>----------------------</td>
<td></td>
</tr>
<tr>
<td>RA</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


4.2. Presentations - Conferences


4.3. Presentations – Outreach


2. “Strategic Interactions in Disaster Preparedness and Relief in the Face of Man-Made and Natural Disasters,” invited research seminar presented at Air Force Research Lab, Decision Support Systems Branch, July 14, 2011

3. “Decision Analysis and Game Theory,” invited guest lecture presented at University at Buffalo, Department of Industrial and Systems Engineering,” IE 101 Discover Industrial and Systems Engineering, April 18, 2011
4. “Economic Impacts of Geologic Hazards,” invited guest lecture presented at University at Buffalo, Department of Geology, GLY 428 Geologic Hazards and Risk, April 4, 2011

5. “Strategic Interactions in Disaster Preparedness and Relief in the Face of Man-Made and Natural Disasters,” invited research seminar presented at University of Toronto (Canada), Rotman School of Management, March 18, 2011

6. “Game Theory and Industrial and Systems Engineering,” invited research seminar presented at the meeting of Society of Hispanic Professional Engineers, University at Buffalo Student Chapter, February 24, 2011

7. “Strategic Interactions in Disaster Preparedness and Relief in the Face of Man-Made and Natural Disasters,” invited research seminar presented at University of Pittsburgh, Department of Industrial Engineering, February 1, 2011

8. “Strategic Interactions in Disaster Preparedness and Relief in the Face of Man-Made and Natural Disasters,” invited research seminar presented at University of Pittsburgh, co-sponsored by Center for Disaster Management and Graduate School of Public and International Affairs, January 31, 2011

9. “Strategic Interactions in Disaster Preparedness and Relief in the Face of Man-Made and Natural Disasters,” invited research seminar presented at University of Southern California, Center for Risk and Economic Analysis of Terrorism Events (CREATE), January 28, 2011

10. “Strategic Interactions in Disaster Preparedness and Relief in the Face of Man-Made and Natural Disasters,” invited research seminar presented at University of California-Irvine, co-sponsored by Merage School of Business and Institute for Mathematical Behavioral Sciences, January 27, 2011

11. “Strategic Interactions in Disaster Preparedness and Relief in the Face of Man-Made and Natural Disasters,” invited research seminar presented at University at Buffalo, SUNY, Department of Civil, Structural and Environmental Engineering, October 15, 2010

5. Education and Outreach Products

<table>
<thead>
<tr>
<th>Last Name</th>
<th>First Name</th>
<th>University</th>
<th>School</th>
<th>Department</th>
<th>Degree</th>
<th>Research Area</th>
<th>Funded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coles</td>
<td>John</td>
<td>U. Buffalo</td>
<td>COE</td>
<td>Industrial &amp; Systems Engineering</td>
<td>PhD</td>
<td>NGO-NGO games in disaster preparation</td>
<td></td>
</tr>
<tr>
<td>Guan</td>
<td>Peiqiu</td>
<td>U. Buffalo</td>
<td>COE</td>
<td>Industrial &amp; Systems Engineering</td>
<td>PhD</td>
<td>Public-private collaboration</td>
<td>summer 2011</td>
</tr>
<tr>
<td>He</td>
<td>Fei</td>
<td>U. Buffalo</td>
<td>COE</td>
<td>Industrial &amp; Systems Engineering</td>
<td>PhD</td>
<td>Disaster preparedness vs. relief</td>
<td>summer 2011</td>
</tr>
<tr>
<td>Xiaojun</td>
<td>Shan</td>
<td>U. Buffalo</td>
<td>COE</td>
<td>Industrial &amp; Systems Engineering</td>
<td>PhD</td>
<td>Equity, non-strategic attacker</td>
<td></td>
</tr>
<tr>
<td>Song</td>
<td>Cen</td>
<td>U. Buffalo</td>
<td>COE</td>
<td>Industrial &amp; Systems Engineering</td>
<td>PhD</td>
<td>Food supply chain risk management</td>
<td>summer 2011</td>
</tr>
</tbody>
</table>
## CREATE Students

<table>
<thead>
<tr>
<th>Last Name</th>
<th>First Name</th>
<th>University</th>
<th>School</th>
<th>Department &amp; Engineering</th>
<th>Degree</th>
<th>Research Area</th>
<th>Funded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xu</td>
<td>Jie</td>
<td>U. Buffalo</td>
<td>COE</td>
<td>Industrial &amp; Systems</td>
<td>PhD</td>
<td>Deception and attacker learning</td>
<td></td>
</tr>
<tr>
<td>Hsu</td>
<td>Wei-Yuan</td>
<td>U. Buffalo</td>
<td>COE</td>
<td>Industrial &amp; Systems</td>
<td>MS</td>
<td>Military gaming strategies</td>
<td></td>
</tr>
<tr>
<td>Golalikhani</td>
<td>Mohsen</td>
<td>U. Buffalo</td>
<td>COE</td>
<td>Industrial &amp; Systems</td>
<td>MS</td>
<td>Arbitrary level of defense</td>
<td></td>
</tr>
<tr>
<td>Wu</td>
<td>Han</td>
<td>U. Buffalo</td>
<td>COE</td>
<td>Industrial &amp; Systems</td>
<td>MS</td>
<td>Post-disaster NGO-donor game</td>
<td></td>
</tr>
<tr>
<td>Zhang</td>
<td>Long</td>
<td>U. Buffalo</td>
<td>COE</td>
<td>Industrial &amp; Systems</td>
<td>MS</td>
<td>Health care games</td>
<td></td>
</tr>
<tr>
<td>Ndayishimiye</td>
<td>Jerome</td>
<td>U. Buffalo</td>
<td>COE</td>
<td>Industrial &amp; Systems</td>
<td>MS</td>
<td>Post-event emergency room scheduling</td>
<td></td>
</tr>
<tr>
<td>Cheung</td>
<td>May</td>
<td>U. Buffalo</td>
<td>COE</td>
<td>Industrial &amp; Systems</td>
<td>BS</td>
<td>Government/company regulation game</td>
<td></td>
</tr>
<tr>
<td>Newell</td>
<td>Elizabeth</td>
<td>U. Buffalo</td>
<td>COE</td>
<td>Industrial &amp; Systems</td>
<td>BS</td>
<td>Public/private partnership</td>
<td></td>
</tr>
<tr>
<td>Duquesnay</td>
<td>Jodie-Ann</td>
<td>U. Buffalo</td>
<td>COE</td>
<td>Industrial &amp; Systems</td>
<td>BS</td>
<td>Public/private partnership</td>
<td></td>
</tr>
</tbody>
</table>

## CREATE Related Courses

<table>
<thead>
<tr>
<th>Instructor</th>
<th>University</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zhuang</td>
<td>U. Buffalo</td>
<td>Game Theory</td>
</tr>
<tr>
<td>Zhuang</td>
<td>U. Buffalo</td>
<td>Decision Analysis</td>
</tr>
<tr>
<td>Zhuang</td>
<td>U. Buffalo</td>
<td>Applied Stochastic Processes</td>
</tr>
</tbody>
</table>

## Education and Outreach Initiatives (Please detail below)

<table>
<thead>
<tr>
<th>Initiative</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td># of students supported (funded by CREATE)</td>
<td>3</td>
</tr>
<tr>
<td># of students involved (funded by CREATE + any other programs)</td>
<td>14</td>
</tr>
<tr>
<td># of students graduated</td>
<td>5</td>
</tr>
<tr>
<td># of contacts with DHS, other Federal agencies, or State/Local (committees)</td>
<td>3</td>
</tr>
<tr>
<td># of existing courses modified with new material</td>
<td></td>
</tr>
<tr>
<td># of new courses developed</td>
<td></td>
</tr>
<tr>
<td># of new certificate programs developed</td>
<td></td>
</tr>
<tr>
<td># of new degree programs developed</td>
<td></td>
</tr>
</tbody>
</table>