Innovations in Risk and Economic Modeling of Counterterrorism

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1. Overview

The primary focus of the research at the University of Wisconsin-Madison has been to expand the existing tools and techniques of risk analysis to more effectively address security considerations, using the economic tool of game theory to take into account the fact that terrorists can observe our defenses and adapt their strategies accordingly. In particular, the basic models developed in earlier years of this effort have now been extended to account for the role of defender secrecy and deception in defenses, in the face of attackers with incomplete information about defender types (e.g., defense costs and effectiveness, asset values, etc.).

More specifically, because of concerns that terrorists may smuggle nuclear bombs or other weapons into the US, and persistent controversy about the feasibility and desirability of 100% container inspection, we chose to investigate how many containers would need to be screened in order to deter smuggling attempts. We provide analytical results for the optimal proportion of containers to inspect in order to minimize the defender's expected loss, using game theory to reflect the fact that the attackers are simultaneously trying to maximize their expected rewards. Moreover, our model recognizes that the container-screening policy of the US must simultaneously protect against different types of threats (such as nuclear bombs, dirty bombs, and assault rifles). Our model also suggests that threatening to retaliate against successful smuggling attempts may also be beneficial to defenders, as long as the threat is credible.

Finally, a project on building security explored the use of system dynamics to simulate the effects of bio-agent contamination in a building, and explore the cost-effectiveness of alternative defenses. The outcome of this research will be an integrated prototype model of how the building, its system, and its occupants respond to an incident of bio-agent contamination.

The research being done at the University of Wisconsin-Madison has had direct implications for risk-based resource allocation. In particular, methods developed during the course of this work are of direct interest to the Wisconsin Office of Justice Assistance.

Similarly, our research on building security is directly relevant to the case study on bioterrorism. Currently, methods are lacking for assessing the economic effectiveness of proposed building upgrades in a systematic and integrated manner. Our model for building-system integration will make it possible to

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make such economic decisions in a much more systematic manner. A prototype software tool for evaluating candidate upgrades to building security is currently under development, and will be transferred to CREATE when complete.

We are also contributing to an improved understanding of security in the food area through on-campus collaborations here at the University of Wisconsin-Madison. In particular, we are contributing our risk and homeland-security expertise to a collaborative on Managing Import Safety, being sponsored by the Center for World Affairs and the Global Economy. That collaborative also involves expertise from the Grainger Center for Supply Chain Management, the Law School, the School of Business, the Department of Animal Science, the Department of Consumer Science, and the Food Research Institute.

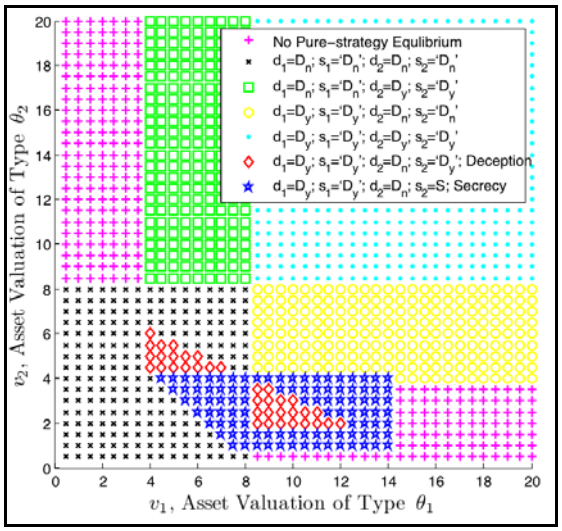
2. Research Accomplishments

2.1. Modeling Secrecy and Deception in Homeland Security Resource Allocation

In this research, we developed a game-theoretic model for what information (if any) a defender should disclose about her defensive resource allocations in the homeland-security context. Our model allows us to explore whether the defender should disclose correct information about her defensive resource allocations (truthful disclosure), incorrect information (deception), or no information (secrecy). For simplicity, and to help ensure that we are focusing on the most fundamental reasons for secrecy or deception, we chose to focus on a single-target game.

Our results show that in the case of complete information, or if only the attacker has private information, the defender would prefer secrecy to disclosure only under special circumstances (e.g., when the cost of disclosure is large relative to the cost of secrecy). However, in the more interesting case where the defender has private information (i.e., if the attacker does not know some defender attributes, such as asset values or costs), our analysis shows that there exist equilibrium solutions in which secrecy and/or deception can be strictly preferred by some types of defenders. The reasons for preferring secrecy or deception include a desire to mimic defender types that are of less interest to attackers (e.g., defenders that have invested in strong defenses), or a desire to distinguish oneself from defender types that are of greater interest to attackers. The figure below shows how the desirability of secrecy and deception depend on the asset values of the different types of defenders in a two-defender game.

We also studied secrecy and deception in a multiple-period game. In this game, we allow one of the three possible defender signals in each period (truthful disclosure, secrecy, or deception). We also allow two types of information updating—the attacker has the opportunity to update his knowledge about the defender type both after observing the defender's signals, and then again after observing the result of a "contest" or attack (if one occurs in each time period). Although our multiple-period model is not generally analytically tractable, due to its complexity, some special cases are readily solvable using dynamic programming. The results of our multiple-period model provide insights into the balance between long-term capital investments versus short-term expenses (e.g., police patrol) for defensive investments, and also illustrate the effects of different types of defender private information (such as private information about the costs and/or effectiveness of defenses, or private information about target valuations). Overall, our results show that defenders can in some cases achieve more cost-effective security through secrecy and deception in a multiple-period game.



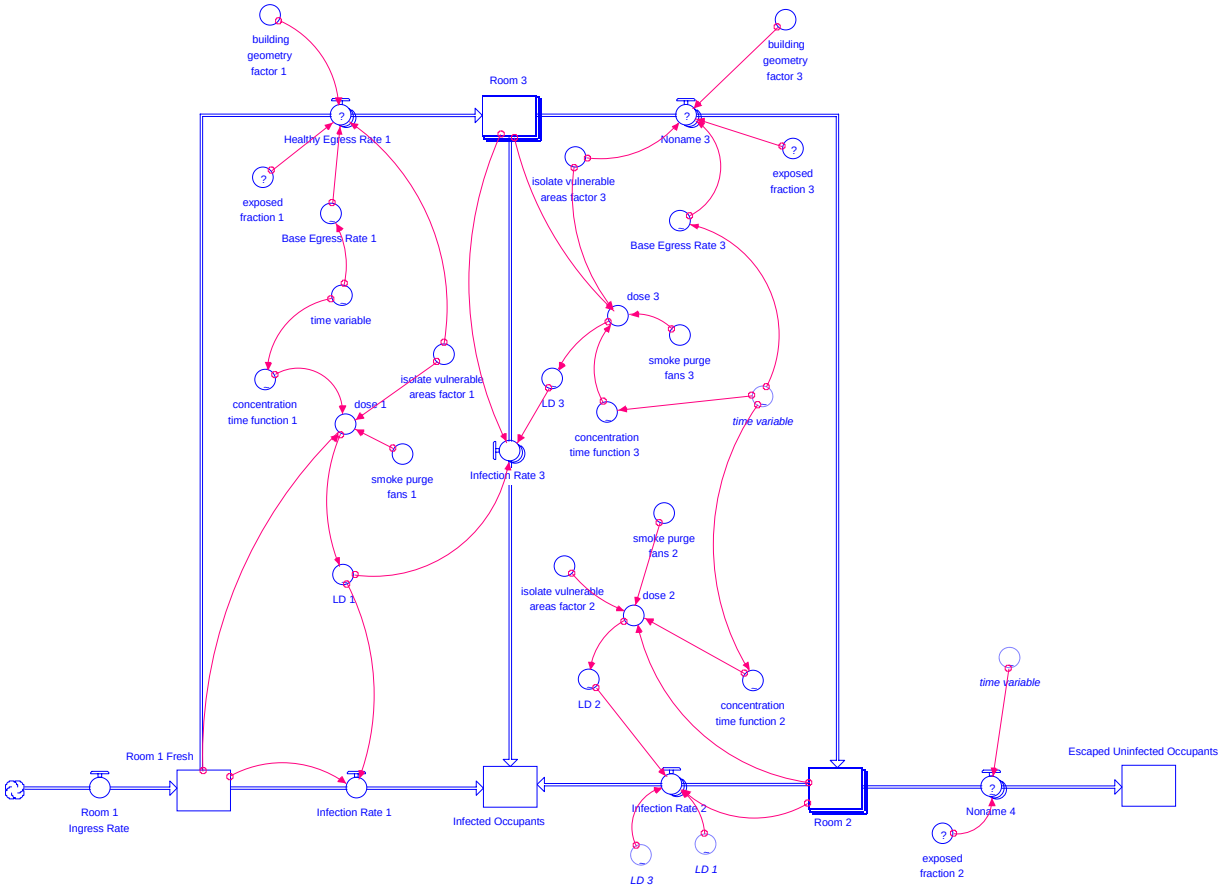
2.2. Border Security

This project is innovative relative to past work on inspection and deterrence, since we focus on the case where a single inspection effort and technology (i.e., container inspection) can detect multiple different types of weapons. To our knowledge, previous studies (e.g., during the cold war) focused primarily on the case when inspection effort must be divided among multiple attackers, because inspection of different nations must be conducted in different locations. Our study provides a rigorous basis for estimating how many containers the US should inspect in order to achieve the most cost-effective combination of deterrence and detection for nuclear weapons and other types of threats. Unfortunately, we have not been able to obtain numerical data with which to quantify our model, but we are pursuing collaboration with Henry Willis of Rand in order to do that.

2.3. Use of System Dynamics as a Decision-Making Tool in Secure Building Design

This project is using system dynamics to study and enhance the design of buildings with respect to security. The outcome of this research will be a building-system integration model that can be used as a prototype decision tool to simulate proposed modifications to a building, and rank the available alternatives on their economic effectiveness. This will assist building designers and owner/operators in making more cost-effective decisions when allocating limited budgets to security upgrades, both in retrofits and in evaluating options for new designs. Bioterrorism was used as a specific case study with which to test the applicability of the proposed tool. In particular, a simple model of bio-agent contamination was developed and validated for a single-zone building with a static occupant population.

A representative portion of the system-dynamics model that was developed is shown below. This figure represents the flow of occupants among various states in a sample building. The occupants flow among different states both over space (i.e., moving among various rooms and the outdoors), and over different health outcomes (i.e., moving from uninfected to exposed to infected). Movement among various rooms and the outdoors is based on results imported from an egress model developed using Pathfinder II (a computer program for egress simulation). The exposure of occupants to the bio-agent is based on results of the multi-zone airflow modeling program CONTAM 2.4. Data from these two programs are combined in the system-dynamics model, along with options for upgrading the building's defenses against a bioterrorist attack, to allow a user to determine the most effective leverage points to cost-effectively protect the building.



This model has been integrated manually with a system for building-information modeling (the Revit software by Autodesk) to incorporate spatial dimensions and occupancy characteristics. It is hoped that a process could, in future, be developed to automate the transfer of data between the two models. The outcome of this research will be an integrated model of how the building, its systems, and its occupants respond to an incident of bio-agent contamination. As part of this work, a detailed review of literature on risk perception, risk analysis, and risk management in civil engineering was performed. This review has been published in the *Journal of Architectural Engineering*.

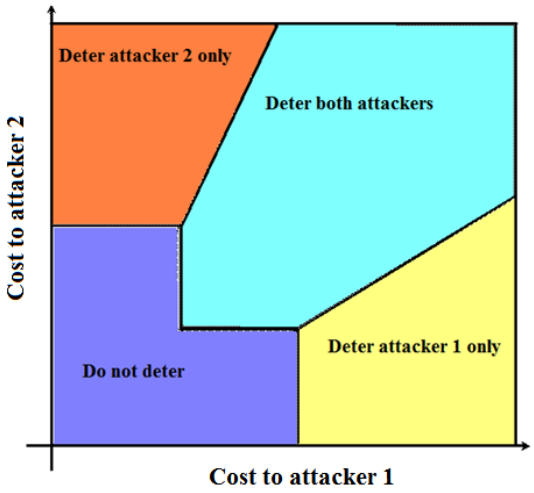
3. Applied Relevance

3.1. Secrecy and Deception in Homeland Security Resource Allocation

Previous game-theoretic research on homeland security has mostly yielded the unrealistic result that defenders should always disclose their defensive resource allocations. While disclosure can sometimes be desirable (to deter potential attacks), intuition suggests that this will not always be the case. Our results provide the building blocks for a more realistic and rigorous understanding of when and whether secrecy and/or deception may be preferable to disclosure in practice.

3.2. Border Security

Our research on border security provides a model that can be used to identify the optimal level of container inspection. The results suggest that it is easier to deter attack strategies that have high cost to the attacker (such as acquiring and smuggling in a nuclear bomb) than to deter low-cost attack strategies (such as smuggling in a dirty bomb, or a container of assault rifles); sample results for the case of two attackers (attempting to smuggle in two different types of weapons, with different costs) are shown below. Moreover, our results indicate that threatening to retaliate against detected smuggling attempts reduces the level of inspection needed to achieve attack deterrence (provided that the threat of retaliation is credible). The model can also be generalized to address questions such as the optimal level of manual passenger inspection at airport security gates, and the optimal level of inspection at land ports of entry (i.e., border stations).



3.3. Bioterrorism

The research done on use of system dynamics for decision making in building security has the potential to revolutionize the way security decisions are made in building design and retrofit—in particular, for bioterrorism. Currently, methods are lacking for assessing the economic effectiveness of proposed building upgrades in a systematic and integrated manner. The model for building-system integration will make it possible to make such economic decisions in a much more informed, systematic manner. We anticipate that this model could then be extended to other types of threats, such as blast security, intruder security, fires, and natural disasters. Eventually, this methodology also provides the potential to support enhanced performance-based design methods for building security.

4. Collaborative Projects

To generate a more realistic model for trading off border security and other overarching forms of protection (e.g., emergency preparedness, intelligence collection) against target hardening, we have initiated collaboration with the Wisconsin Office of Justice Assistance (Greg Engle and Josh Maas). This is the office that distributes funds for the Buffer Zone Protection Program and other similar security programs in the state of Wisconsin.

Personnel involved in the project on secrecy and deception have also initiated collaboration with the National Consortium for the Study of Terrorism and Responses to Terror at the University of Maryland. The goal of this potential collaboration is to develop models that can account for different types of terrorist groups, including the possibility of non-strategic actors.

Finally, we are contributing to an improved understanding of security in the food area through on-campus collaborations here at the University of Wisconsin-Madison. In particular, we are contributing our risk and homeland-security expertise to a collaborative on Managing Import Safety, being sponsored by the Center for World Affairs and the Global Economy. That collaborative also involves expertise from the Grainger Center for Supply Chain Management, the Law School, the School of Business, the Department of Animal Science, the Department of Consumer Science, and the Food Research Institute.

5. Research Products

Research Products (Please detail below)		**#**
5a	# of peer-reviewed journal reports published (during this reporting period)	3
5a	# of peer-reviewed journal reports accepted for publication	3
5a	# of non-peer reviewed publications and reports (during this reporting period)	3
5a	# of scholarly journal citations of published reports (from all years)	93
5b	# of scholarly presentations (conferences, workshops, seminars)	14
5b	# of outreach presentations (non-technical groups, general public)	1
5c	# of products delivered to DHS, other Federal agencies, or State/Local	
5c	# of patents filed	1
5c	# of patents issued	
5c	# of products in commercialization pipeline (products not yet to market)	
5c	# of products introduced to market	

5.1. Publications and Reports

Bier, Vicki - University of Wisconsin - Madison	**Ref**	**Not Ref**
1. Hausken, K., Bier, V. M., Zhuang, J., "Defending against Terrorism, Natural Disaster, and All Hazards," Bier, V. M., Azaiez M. N. (eds.), accepted for publication in *Combining Reliability and Game Theory* Springer, New York	x	
2. Zhuang, J., Bier, V. M., Alagoz, O., "Modeling Secrecy and Deception in a Multiple-period Attacker-Defender Signaling Game," submitted to *Operations Research*	x	
3. Okpara, U., Bier, V. M., "Securing Passenger Aircraft from Man-Portable Air Defense Systems (MANPADS)," *Risk Analysis*, in press	x	
4. Dighe, N., Zhuang, J., Bier, V. M., "Secrecy in defensive allocations as a strategy for achieving more cost-effective attacker deterrence," *International Journal of*	x	

	Performability Engineering, special issue on System Survivability and Defense against External Impacts, 5 (1): 31-43, 2009		
5.	Bordley, R., Bier, V. M., "Updating Beliefs about Variables Given New Information on How Those Variables Relate," in press, *European Journal of Operational Research*, 193 (1), 184-194, 2009	x	
6.	Bier, V. M., Azaiez M., "Game Theoretic Risk Analysis of Security Threats," http://www.springer.com/engineering/production+eng/book/978-0-387-87766-2, Springer, NY, 2009		x
7.	Zhuang, J., Bier, V. M., "Secrecy and Deception in Anti-Terrorism Resource Allocation and Policy Implication," submitted to *Economics and Politics*, 2008	x	
8.	Bier, V. M., Haphuriwat, N., Menoyo, J., Zimmerman, Z., Culpen, A., "Optimal Resource Allocation for Defense of Targets based on Differing Measures of Attractiveness," *Risk Analysis* 28 (3), 763-770, 2008	x	
9.	Zhuang, J., Bier, V. M., "Katrina vs 9/11: How Should We Optimally Protect Against Both?" *Natural Disaster Analysis After Hurricane Katrina: Risk Assessment, Economic Impacts and Social Implications*, Richardson, H. W., Gordon, P., Moore II, J. (eds.), Edward Elgar Publishing: Cheltenham, Chapter 4 , 71-83, 2008		x
10.	Bier, V. M., "Game-Theoretic Methods," *Encyclopedia of Quantitative Risk Assessment*, Everitt, B. (ed.) Wiley, New York, 2008		x
11.	Zhuang, J., Bier, V. M., "Balancing Terrorism and Natural Disasters - Defensive Strategy with Endogenous Attack Effort," *Operations Research* , 55 (5): 976-991, 2007	x	
12.	Bier, V. M., Oliveros, S., Samuelson, L., "Choosing What to Protect: Strategic Defensive Allocation against an Unknown Attacker," *Journal of Public Economic Theory*, Vol. 9, 563-587, 2007	x	
13.	Azaiez, M., Bier, V. M., "Optimal Resource Allocation for Security in Reliability Systems," *European Journal of Operational Research*, Vol. 181, 773-786, 2007	x	
14.	Bier, V. M., Gratz, E., Haphuriwat, N.., Magua, W., Wierzbicki, K., "Methodology for Identifying Near-Optimal Interdiction Strategies for a Power Transmission System," *Reliability Engineering and System Safety*, Vol. 92, 1155-1161, 2007	x	
15.	Zhuang, J., Bier, V. M., Gupta, A., "Subsidies in Interdependent Security with Heterogeneous Discount Rates," *The Engineering Economist*, Vol. 52, 1-19, 2007	x	
16.	Bier, V. M., "Choosing What to Protect," *Risk Analysis*, Vol. 27, 607–620, 2007	x	
17.	Hausken, K., Bier, V.M., "Defending against Multiple Different Attackers," submitted to the *European Journal of Operations Research*, 2007	x	
18.	Bier, V. M., Zach, L., King, S. B., O'Sullivan, T., Burgos, I., "Decision Support for Pandemic Planning for the State of Wisconsin," http://pandemic.wisconsin.gov/docview.asp?docid=14129&locid=106, September 2007		x
19.	Bier, V. M., "Game-Theoretic and Reliability Methods in Counter-Terrorism and Security," *Statistical Methods in Counter-Terrorism: Game Theory, Modeling, Syndromic Surveillance, and Biometric Authentication*, 23-40, Wilson, A.G., Wilson, G. D., Olwell, D. H. (eds.) Springer, New York, 2006	x	
20.	Bier, V. M., "Hurricane Katrina as a Bureaucratic Nightmare," *On Risk and Disaster: Lessons from Hurricane Katrina*, Daniels, R., Kettl, D., Kunreuther, H., (eds.) University of Pennsylvania Press, Philadelphia, 243-254, 2006		x
21.	Bier, V. M., *Risk Analysis (Homeland Security)*; *McGraw-Hill Yearbook of Science*		x

and Technology 2006, 283-284, McGraw-Hill, New York, 2006		
22. Bier, V. M., "Game-Theoretic and Reliability Methods in Counter-Terrorism and Security;" *Mathematical and Statistical Methods in Reliability*, Wilson, A., Limnios, N., Keller-McNulty, S., Armijo, Y., (eds.), series on quality, reliability and engineering statistics, 17-28, World Scientific, Singapore, 200		x
23. Bier, V. M. et al., "MANPADS Scenarios for Attack Risk Modeling," *CREATE Report*, 2005		x

5.2. Presentations

Conferences:

- Bier, V. M., "Optimal Resource Allocation for Defense of Multiple Targets," Argonne National Laboratory, August 2008
- Zhuang, J, Bier, V. M., "Secrecy and Deception in Anti-Terrorism Resource Allocation and Policy Implication," *Conference on Terrorism and Policy*, University of Texas at Dallas, Richardson, TX, May 15-17, 2008
- Bier, V. M., "Optimal Resource Allocation for Defending Multiple Targets," USC, Los Angeles, CA, May 2008
- Zhuang, J. "Game Theory and Homeland Security Resource Allocation," UW - Madison, April 30, 2008
- Haphuriwat, N., Bier. V. M., "How Many Containers to Inspect to Deter Terrorist Attacks," *Annual Department of Homeland Security University Network Summit*, Washington, DC, March 18-20, 2008
- Bier, V. M., "Optimal Resource Allocation for Defending Multiple Targets," Texas A&M University, March 2008
- Zhuang, J., "Game Theory and Homeland Security Resource Allocation," Texas A & M University, February 28, 2008
- Zhuang, J. "Game Theory and Homeland Security Resource Allocation," University at Buffalo, State University of New York, February 22, 2008
- Zhuang, J., "Game Theory and Homeland Security Resource Allocation," Northwestern University, February 5, 2008
- Zhuang, J., "Game Theory and Homeland Security Resource Allocation (with Relationships to Sustainability)," University of Pittsburgh, January 11, 2008
- Bier, V. M., Zach, L., King, S. , O'Sullivan, T., Burgos, I., "Assessing the Needs of the Working Poor during a Pandemic," *Society for Risk Analysis Annual Meeting 2007*, San Antonio, TX, December 9-12, 2007
- Bier, V. M., Haphuriwat, N. , Menoyo, J., "Optimal Resource Allocation for Defense of Multiple Targets," INFORMS Annual Meeting, Seattle, Washington, November 4-7, 2007
- Zhuang, J., Bier, V. M., "Modeling Secrecy and Deception in Homeland Security Resource Allocation," *INFORMS Annual Meeting*, Seattle, WA, November 2007
- Zhuang, J., "Game Theory and Homeland Security Resource Allocation," Rensselaer Polytechnic Institute, October 23, 2007
- Zhuang, J. Bier, V. M., "Modeling Secrecy and Deception in Homeland Security Resource Allocation," INFORMS Annual Meeting, Seattle, WA, November 4-7, 2007

Outreach:

- Bier, V. M., "What Is Different About Pandemic Planning?" seminar on "Disaster Recovery and Business Continuation Plan - No Longer Optional," Madison, Wisconsin, February 13, 2008

5.3. Models, Databases, and Software Tools and Products

A prototype building-system integration model has been developed. Model testing and revision is still proceeding.

6. Education and Outreach Products

Education and Outreach Initiatives (Please detail below)	#
# of students supported (funded by CREATE)	5
# of students involved (funded by CREATE + any other programs)	9
# of students graduated	2
# of contacts with DHS, other Federal agencies, or State/Local (committees)	2
# of existing courses modified with new material	
# of new courses developed	
# of new certificate programs developed	
# of new degree programs developed	

Research Assistants:

- Ben Thompson, Nara Haphuriwat, Jun Zhuang,
- Mavis (Chen) Wang, Taher Jamshidi
- (Jun Zhuang completed his Ph.D., and accepted a position at University at Buffalo)