

**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 been extended to account for defender uncertainty about attacker goals and objectives, more complex system structures, tradeoffs between terrorism and natural disasters, the role of secrecy and deception in defenses, and tradeoffs involved in protection against multiple different attackers.

Results of this work have led to a new method of portfolio allocation for allocating defensive investments against multiple targets or assets (e.g., as in the Urban Area Security Initiative, or the Buffer Zone Protection Program). This method was applied to real-world data on the consequences of attacks against particular cities—expected fatalities and property losses (obtained from Rand), and airport and bridge infrastructure (obtained from Rae Zimmerman and her group at New York University). The results indicated the crucial importance of developing a better understanding of the cost-effectiveness of defensive investments in identifying the optimal resource allocation, and also the need for more realistic multi-attribute terrorist objective functions, such as those being developed by Richard John and Heather Rosoff at the University of Southern California.

The risk expertise available at the University of Wisconsin-Madison also supported the methods developed in this project have also been used in applied research on interdependent security in the supply chains for food products, undertaken for the National Center for Food Protection and Defense. In particular, a theoretical model of a game between defenders (developed by CREATE) was used to study which partners in the supply chain for dairy products could most cost-effectively invest in security.

In addition, we explored how methods for analysis of accident precursors could be applied to analysis of observed precursors to security threats. This project resulted in a white paper addressing the similarities and differences in using precursor data for safety versus security, focusing specifically on: (1) the frequency of observed precursors; (2) the likelihood of a disaster given a precursor; and (3) the consequences of a disaster if one does occur. The study concluded that fault-tree analysis could be a

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useful method for quantifying the severity of observed precursors, but noted that the lack of sufficient precursor data could be a limitation in estimating the frequency of attempted attacks.

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 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 have already been applied both to resource allocation among cities (e.g., as part of the Urban Area Security Initiative), and to resource allocation among particular sites in a given state (e.g., as part of the Buffer Zone Protection Program, using data provided by the Wisconsin Office of Justice Assistance). Through our collaboration with the Office of Justice Assistance (the office that distributes funds for the Buffer Zone Protection Program and other similar security programs in Wisconsin), we obtained sanitized data on the top 50 sites considered in the Buffer Zone Protection Program in 2005 (by sector), the risk score for each site/threat combination, and whether the site was funded by the Buffer Zone Protection Program in 2005. This enabled us to compare the recommendations of our model with the actual funding decisions in 2005. This analysis will help us evaluate the usefulness of the expenditures in that program.

Prototype software for risk-based portfolio allocation has already been transferred to CREATE. Upgrades to this software continue to be made to address decision problems with more realistic levels of complexity. A prototype building system integration model is currently under development for evaluating candidate upgrades to building security. Once complete, this model will be useful in helping building designers and owners/ operators make better decisions about cost-effective security upgrades.

We also contributed our risk expertise to the Center for Foreign Animal and Zoonotic Disease (FAZD), and the National Center for Food Protection and Defense (NCFPD). For FAZD, we conducted a prototype risk and uncertainty analysis for the spread of intentionally introduced foot-and-mouth disease, and developed a protocol for how uncertainty analysis could be done for other similar epidemiological models.

For NCFPD, we applied CREATE models of interdependent security between supply-chain partners. These models initially conceptualized “contamination” as a metaphor for how lack of security investment by one partner could have adverse effects on other partners. Through our involvement in FAZD, we realized that this type of contamination could be literal rather than figurative. Therefore, under funding from NCFPD, we applied our models to studying the spread of contamination (and the most cost-effective means for preventing it) in the dairy industry.

Similarly, the 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. Once the model for building system integration has been completed, it will be possible to make such economic decisions in a much more 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. A prototype software tool for evaluating candidate upgrades to building security is currently under development, and will be transferred to CREATE when complete.

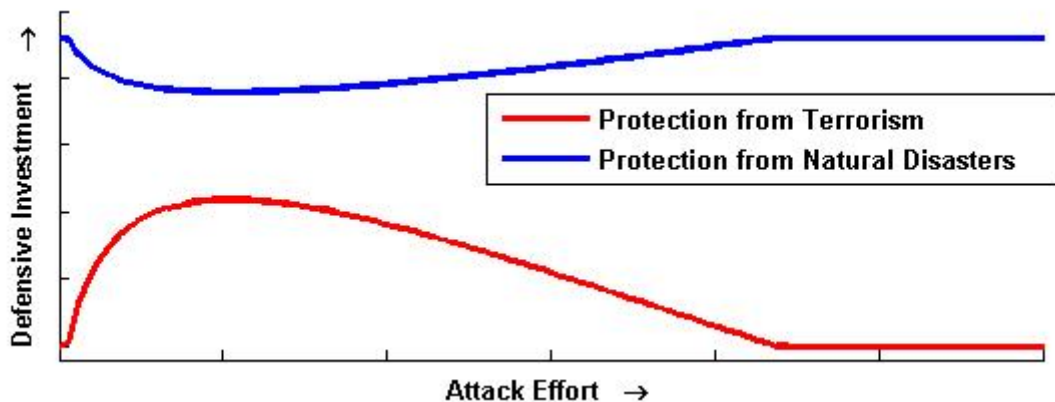
As part of the project on precursor analysis, we undertook an extensive study of the risks of radiological dispersion devices (“dirty bombs”), thereby enhancing the case study on border security dealing with a

possible dirty bomb in a harbor. In particular, a fault tree was developed to illustrate the steps that need to be completed for a successful attack on the ports of Los Angeles and Long Beach using a dirty bomb.

Under funding from the Wisconsin Department of Health and Family Services, we completed a project on decision support for pandemic planning, focusing on three key issues: school closure; business closure (including closure of entertainment venues); and the needs of the working poor. To our knowledge, the analysis of the economic impacts of a pandemic on the working poor was the first of its kind in the nation.

## 2. Research Accomplishments

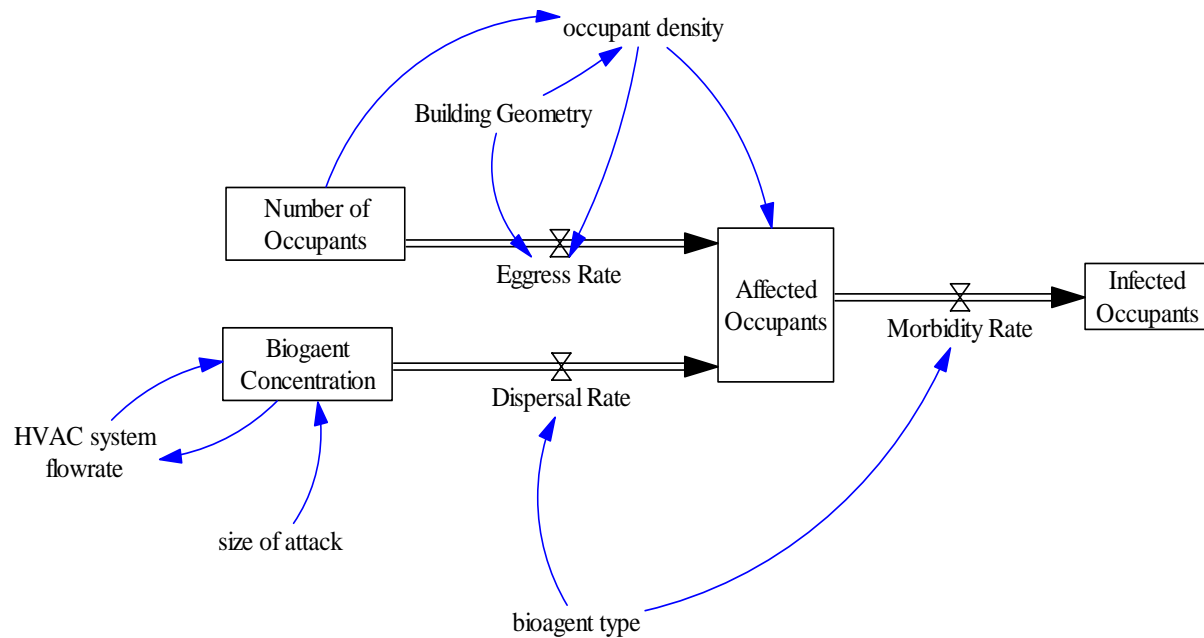
Innovations in risk and economic modeling of counter-terrorism: This project has focused on basic research to expand the existing tools and techniques of risk analysis to more effectively address security considerations, using the economic tool of game theory to take into account the fact that terrorists can observe our defenses and adapt their strategies accordingly. The basic game-theoretic models developed in earlier years have been extended to account for defender uncertainty about attacker goals and objectives, more complex system structures, tradeoffs between protection against terrorism and protection against natural disasters (as shown below), the role of secrecy in defensive allocations, and tradeoffs involved in protection against multiple different attackers. The models developed in this effort have been applied to risk-based portfolio allocation. Methods developed in this project have also been used in applied research on interdependent security in the supply chains for food products, undertaken for the National Center for Food Protection and Defense.



Precursor analysis: This project involved both basic research and tool development to explore how methods for analysis of accident precursors can be applied to analysis of observed precursors to security threats. This project resulted in a white paper addressing the similarities and differences in using precursor data for safety versus security, focusing specifically on: (1) the frequency of observed precursors; (2) the likelihood of a disaster given a precursor; and (3) the consequences of a disaster if one does occur. The case study on border security (in particular, the example of a dirty bomb at a harbor) was used as a working example to test the ideas developed during the course of the research. The conclusions of the case study identified some promising approaches based on precursor methods (in particular, the use of fault-tree analysis to quantify the severity of observed precursors), but also some limitations on the method (namely, the lack of sufficient precursor data to estimate the frequency of attempted attacks with reasonable accuracy).

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 (as shown below), including modules for occupant behavior and egress. This model is currently being integrated with a system for building information modeling (the Revit software by Autodesk) to incorporate spatial dimensions. The outcome of this research will be an integrated model of how the building, its system, 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 accepted for publication in the *Journal of Architectural Engineering*.

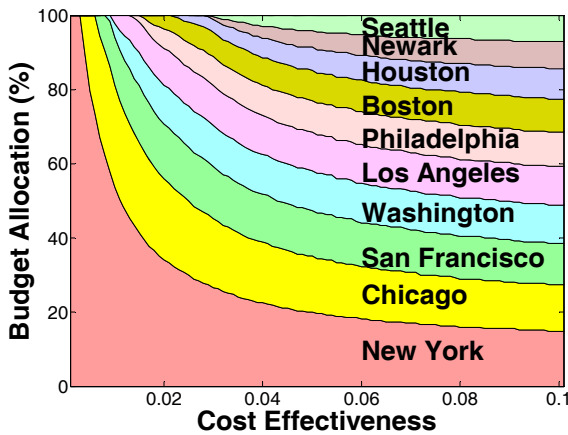


**Portfolio allocation:** The goal of this project was to transition the results of basic research to the level of workable software tools that could be used in practice. In particular, methods developed in years 1 and 2 were applied to real-world data on the consequences of attacks against particular cities. Data included estimates of expected fatalities and property losses from Rand, and data on bridges and airports compiled by Rae Zimmerman’s group at New York University, resulting in submission of a coauthored paper to *Risk Analysis*. The results indicated the crucial importance of understanding the cost-effectiveness of defensive investments in identifying the optimal resource allocation. Moreover, the results showed that different measures of damage (e.g., fatalities, property losses, infrastructure damage) can yield substantially different optimal budget allocations (and in particular different rankings of the various targets). This suggests that simplistic assumed terrorist objective functions (such as maximization of expected fatalities or property losses) may not be adequate, and more realistic terrorist objective functions, such as those being developed by Richard John and Heather Rosoff at the University of Southern California, are needed.

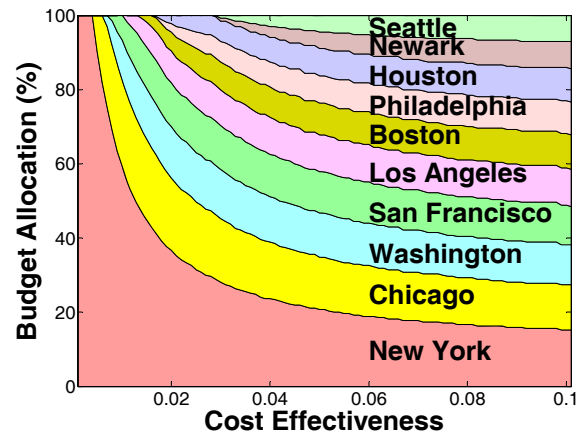
The results of this project are directly relevant to the case study of resource allocation. In particular, the software tools developed in this project have been applied not only to resource allocation among cities (e.g., as part of the Urban Area Security Initiative), but also to resource allocation among particular assets in a given state (using data provided by the Wisconsin Office of Justice Assistance).

### 3. Applied Relevance

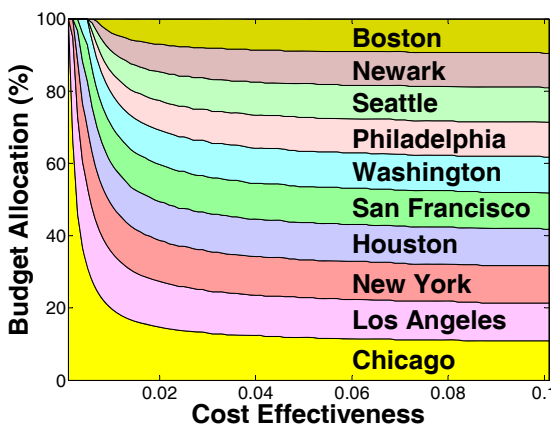
**Risk-based resource allocation:** Research on risk and economic assessment of terrorism events has had direct implications for risk-based resource allocation. In particular, the methods developed during the course of this work have already been applied both to resource allocation among cities (e.g., as part of the Urban Area Security Initiative), and to resource allocation among particular sites in a given state (using data provided by the Wisconsin Office of Justice Assistance), including sites in the agriculture, commercial, energy, government, hazardous materials, transportation, and water sectors. This project also involved collaboration with Rae Zimmerman’s group at New York University, with data on airport and bridge infrastructure provided by Zimmerman being used as one input to the resource allocation among cities (as shown below). The results indicate the crucial importance of understanding the cost-effectiveness of defensive investments in identifying the optimal resource allocation. Moreover, the results show that different measures of damage (e.g., fatalities, property losses, infrastructure damage) can yield substantially different optimal budget allocations (and in particular different rankings of the various cities or sites). This supports the importance of developing more realistic terrorist objective functions.



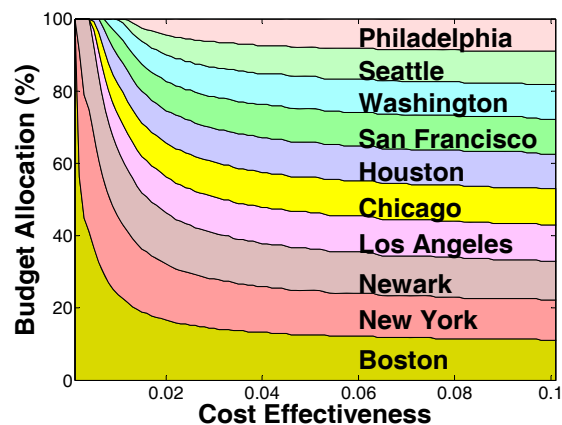
**Property losses as a measure of target attractiveness**



**Fatalities as a measure of target attractiveness**



**Total air departures as a measure of target attractiveness**



**Highest average daily bridge traffic as a measure of target attractiveness**

**Border security:** The research done on precursor analysis was directly relevant to the case study on border security—in particular, the risk of a dirty bomb in a harbor. Extensive data collection and literature review was conducted on the risks of radiological dispersion devices, to evaluate the types of radioactive emitters that could be used in such a device, the risk of incidents involving transport of radioactive material, the security threats involving dirty bombs and “suitcase” nuclear bombs, and the incidence of lost, stolen, and abandoned radiological sources. A fault tree was then developed to illustrate the steps that would need to be completed for a successful attack on the ports of Los Angeles and Long Beach using a dirty bomb. Finally, the economic consequences of an effective attack on a port using a dirty bomb were also surveyed.

**Bioterrorism:** The research being 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. Once the model for building system integration has been completed, it will be possible to make such economic decisions in a much more 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.

**Models and software products:** Prototype software for portfolio allocation has already been transferred to CREATE. Upgrades to this software continue to be made. Some of the recent upgrades include analysis of the unconstrained case (where the decision maker has to determine not only how to allocate a fixed budget, but also how much money should be spend on system defenses); and extensions to allow differing cost-effectiveness of defensive investments for differing targets or sites (for example, to account for the fact that some targets may be less well defended, so may offer more cost-effective improvement opportunities).

A prototype building system integration model is currently under development for evaluating candidate upgrades to building security. The module for bio-agent contamination (including simulation of fatalities) has been developed and tested, and the module for occupant behavior and egress is currently under development.

**Collaborative projects:** The project on portfolio allocation was greatly assisted by collaborating 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. This office graciously made available (sanitized) data on the top 50 sites considered in the Buffer Zone Protection Program in 2005 (by sector), the threat scenario(s) considered for each site, the resulting risk score for each site/threat combination, and whether the site was funded by the Buffer Zone Protection Program in 2005. We then used the risk scores developed by the Wisconsin Office of Justice Assistance as input to our model, to compare the recommendations of the model with the actual funding decisions in 2005. This enabled us to test our models on a second data set, and in particular challenged us to allow for different cost-effectiveness of defensive investments at different sites. We eventually hope to revisit our results with the revised risk scores computed after the 2005 funding has been expended and reassess, to evaluate the cost effectiveness of the program.

Under funding from the Wisconsin Department of Health and Family Services, we completed a project on decision support for pandemic planning, focusing on three key issues: school closure; business closure (including closure of entertainment venues); and the needs of the working poor. Adam Rose and Terry O’Sullivan of CREATE worked on the economic and historic parts of this project, respectively. CREATE also provided funding for a summer intern to assist with the project (Ivaniss Burgos, an

undergraduate at the University of Puerto Rico, Mayaguez). Burgos developed a detailed list of entertainment venues (based on the North American Industry Classification System), and worked on the identification of critical infrastructure that should remain operational in the event of a pandemic. Most importantly, she did extensive calculations to estimate the economic and job losses of a pandemic by county in the state of Wisconsin, and the average wages of the lost jobs. To our knowledge, this analysis (which enabled us to project the likely economic impacts of a pandemic on the working poor by county) was the first of its kind in the nation, and is a model for future work.

With funding from the Center for Foreign Animal and Zoonotic Disease, we conducted a prototype risk and uncertainty analysis for the spread of intentionally introduced foot-and-mouth disease. The resulting protocol for uncertainty analysis of epidemiological models (including expert elicitation, distribution fitting, expert aggregation, and two-dimensional Monte Carlo analysis) was illustrated in a sample application to foot-and-mouth disease.

Moreover, CREATE models of interdependent security between supply-chain partners initially conceptualized “contamination” as a metaphor for how lack of security investment by one partner could have adverse effects on other partners. Through our involvement in modeling foot-and-mouth disease, we saw that this type of contamination could be literal rather than metaphorical in some situations. Under funding from the National Center for Food Protection and Defense, we applied this idea to studying the spread of contamination (and the most cost-effective means for preventing it) in the dairy industry, in collaboration with William Njanje of North Dakota State University.