A Visualization and Decision-Support Tool for Homeland Security Risk Prioritization

Modeling Area: Risk Assessment
Case Studies Supported: Risk-Based Resource Allocation
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Brief Description:
The integration of risk information into the homeland-security decision-making process continues to be a major challenge. Homeland-security risks must be communicated to DHS leadership, the White House, Congress, and the public in a way that is easy to understand, transparent in its construction, and highlights all of the important features that may be relevant for decision-making. Managers need guidance on how to use risk information to inform strategic directions and budgeting processes, evaluate performance, and make resource-allocation decisions, but there is often not adequate data to support quantitative decision-making methods. In the absence of sufficiently accurate and/or precise data, the ability to communicate the sensitivity of residual-risk results to various analysis assumptions and alternative data sources is essential. Understanding the dynamics of residual risk under assumptions about trends, system interdependencies, and future uncertainties will allow decision makers to forecast residual-risk results for potential future environments when risk-reduction strategies will have been implemented. Therefore, we propose to develop a decision-support system to enable managers to: (1) visualize risks using state-of-the-art visualization techniques; (2) test the influence of key assumptions and the sensitivity of the results to alternative data sources; and (3) extrapolate risk results into future scenarios based on assumptions about trends, system interdependencies, and resolution of uncertainties. All of this needs to be done without requiring precise judgments of quantities that may be difficult to estimate, and using a simple graphical user interface.

Objectives: The purpose of this project is to develop compelling risk visualizations appropriate for nontechnical executives, and a simple, practical decision-support tool to help managers understand the sensitivity of risk results to various modeling assumptions and future uncertainties. The goal is to develop a product that is flexible and easily customized to the needs of decision makers (by collaborating throughout the design and development process), rather than adopting a single preexisting approach. The result will be a portable, relatively platform-independent tool that can be used on a desktop or possibly even an iPhone, can be made available as open-source code for use in a variety of government domains with varying levels of data-security requirements (including in the classified domain, where only Microsoft Office may be available for use), and provides compelling visualizations that are appropriate for use in communicating to nontechnical leadership and the public.

Interfaces to other Center Projects: This work builds on past CREATE-sponsored work on innovations in risk and economic modeling of counter-terrorism—especially on trading off
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protections against natural disasters and protections against terrorism (Zhuang and Bier, 2007; Hausken et al., 2009), and on the cost-effectiveness of homeland-security investments (Jamshidi and Bier, 2009). This project also relates closely to work being done by Henry Willis on comparative risk assessment for homeland security, since it can be used as a “post-processor” for the types of estimates he is developing, showing the sensitivity of those estimates to alternative assumptions and risk-reduction strategies.

**Interfaces to non-Center Projects:** The principal investigator has worked working closely with the Infrastructure Assurance Center at Argonne National Laboratory. The proposed decision-support tool is anticipated to be of interest to their analysts, and to their clients—especially the Office of Cyber and Infrastructure Analysis (OCIA).

**Major Products and Customers:** The major product of our work will be a visualization and decision-support tool to enable managers to compare residual risks, evaluate their sensitivities to alternative analysis assumptions, and forecast residual risks in future environments, without the need for precise judgments of quantities that are extremely difficult to estimate (as are required for many game-theoretic and decision-theoretic methods). The primary application for our prototype tool will be to provide compelling visualizations to DHS leadership to support their evaluation of alternative courses of action for high-priority strategic decisions, as foundational work for the 2018 Quadrennial Homeland Security Review.

In this work, we will coordinate closely with the National Protection and Programs Directorate (NPPD, Susan Stevens) and the Office of Strategy, Planning, Analysis and Risk (SPAR) in the Department of Homeland Security’s Office of Policy. We will also work with DHS Science and Technology (S&T) to integrate the results of their Terrorism Risk Assessments. SPAR is an excellent and enthusiastic home for the project, since it has PhD-level staff trained in areas such as risk analysis and decision analysis, so can provide both knowledgeable technical guidance on promising approaches, but also a hands-on understanding of the strategic problems and tradeoffs to be addressed. S&T has the mission of providing terrorism risk assessments of chemical, biological, radiological, and nuclear events. In support of CREATE’s development of a visualization and decision-support tool, SPAR and S&T will provide iterative feedback on prototypes and methodologies, and will generate sample data sets to populate models, subject to availability of staff time. The decision-support tool that we plan to develop will be simple enough to be useful to a wide range of decision makers—e.g., in OCIA, and in the various agencies responsible for risk-informed homeland-security decision-making.

**Technical Approach:** We will begin by assessing what information top leaders and decision makers at DHS need to address important national problems involving risks, and which information formats would be most useful to them. Thus, this project will provide a capability that can be used to facilitate implementation of recommendations from the National Research Council (2010) that DHS adopt an enterprise-level approach to risk management.

Although the approach will be fine-tuned based on the above assessment, we initially propose to graphically display the impacts of differing decision-maker assumptions regarding quantitative parameters such as event frequency and severity, as well as assumptions about trends, system interdependencies, and future uncertainties. As part of the visualization effort, we will also explore techniques for communicating difficult-to-quantify decision criteria, such as public perceptions of risk. Alternatively, the graphical user interface from a commercial, off-the-shelf
tool could be used, if a more mathematically sophisticated programming environment is desired—e.g., to provide for future decision-support capabilities such as programmatic risk buy-down, quantitative and qualitative consequence tradeoffs, and solution capabilities such as portfolio optimization or game theory. The model will use existing data or estimates on the ranges of event frequencies and consequences where possible; see for example Figure 1, taken from Cheesebrough and Wise (2012). However, when data or estimates are not available, the software will allow decision makers to enter ranges of frequency and severity graphically.

Figure 1: Estimated probability with which a terrorist group would select each of four agents (elicited as a Dirichlet distribution using Excel + R)

The project will review state-of-the-art risk-visualization and risk-communication techniques and graphics tools. These will include tools used for visualization and communication of residual risks in domestic and international public-sector national risk assessments (see for example Figure 2), and in enterprise-risk management in the private sector.
Figure 2: Risk ranges for hurricanes, earthquakes, tornados, extreme heat, and lightning

Using the proposed graphical interface, decision makers will be able to explore the impacts of different assumptions, data sources, or future uncertainties. Software capabilities will reflect the fact that some risk-reduction measures affect event frequency, while others primarily affect consequences, and will also allow decision makers to specify alternative assumptions, data sources, trends, and dependencies. The result will be a tool that enables decision makers to make risk-informed decisions, fully exploring the impacts of uncertainties related to data quality and availability as well as future strategic environments, without requiring detailed numerical judgments of parameters that are difficult to quantify (e.g., the likelihood of a vehicle-bomb attack in the U.S.). The tool will also support the development and evaluation of scenarios that could be used to assess the performance of DHS components in achieving their mission objectives (see for example Figure 3 below), and the impact of potential or proposed changes in operations or capabilities. The complexity of the tool will be built up gradually (in a spiral fashion) as the tool is being developed, based on feedback from decision makers and/or decision-support staff, to ensure that the final result is a practical, user-friendly product that can be easily used by decision makers.
Figure 3: Sample presentation formats for decision-support tool

**Major Milestones and Dates:**
Due to the need for intensive stakeholder interaction in this work, the project will proceed in a spiral-development fashion, as follows:

1. Interview decision makers and staff to gather information on decision-making needs, available data, important criteria, and potential applications for prototype. – Months 1-2
2. Research availability of existing tools that could be used or modified to meet decision-maker needs. – Months 1-2
3. Begin work on construction of a user-friendly visualization and decision-support tool, with incremental prototypes delivered to DHS decision-support staff for review and feedback on a monthly cycle, as appropriate – Months 3-6
4. Populate prototype tool with actual and/or notional data, as available (e.g., from Willis or DHS stakeholders), with data realism, complexity, and comprehensiveness increasing as the prototype tool matures in sophistication – Months 4-6
5. Conduct pilot use of prototype tool in support of analyses being undertaken by NPPD and SPAR (e.g., visualizing comparative risk for the Homeland Security National Risk Characterization) – Months 7-10
6. Demonstrate prototype tool to other stakeholders at DHS, Argonne National Laboratory, and other DHS Centers of Excellence (such as Visual Analytics for Command, Control, and Interoperability Environments) to obtain feedback – Months 8-10
7. Make needed software enhancements identified by stakeholders (e.g., to address multiple types of consequences with different weights) – Months 8-10
8. Create production version of prototype tool (e.g., finalize user-interface improvements, prepare documentation or help screens), and make software available – Months 11-12
References:


Brief Bios:

Dr. Bier is a Professor in the Department of Industrial and Systems Engineering at the University of Wisconsin-Madison, where she has directed the Center for Human Performance and Risk Analysis (formerly the Center for Human Performance in Complex Systems) since 1995. She received a Ph.D. in Operations Research from the Massachusetts Institute of Technology in 1983, and a B.S. in Mathematical Sciences from Stanford University in 1976. Dr. Bier’s current research interests focus on problems of security and critical infrastructure protection. Dr. Bier has been a member of the Homeland Security Advisory Committee of the U.S. Environmental Protection Agency’s Science Advisory Board. Dr. Bier’s areas of expertise are in risk analysis, decision analysis, and operations research.

Dr. Jun Zhuang is an Associate Professor of Industrial and Systems Engineering at the University at Buffalo, State University of New York. He obtained his Ph.D. in Industrial Engineering in 2008 from the University of Wisconsin-Madison. Dr. Zhuang has a M.S. in Agricultural Economics in 2004 from the University of Kentucky and a bachelor’s degree in Industrial Engineering in 2002 from Southeast University, China.