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

Center of Excellence Landscape Study- Phase 1

Submitted to

Office of University Programs
Science and Technology Directorate
U.S. Department of Homeland Security

Attention: Georgia Harrigan, Jessica Wilson

February 17, 2018
Revised March 18, 2018
Revised June 9, 2018
Revised September 26, 2018

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 Basic Ordering Agreement HSHQDC-10-BOA19/HSHQDC-16-J-00467. However, any opinions, findings, 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.

Basic Ordering Agreement HSHQDC-10-A-BOA19/HSHQDC-16-J-00467
Department of Homeland Security

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 the Office of University Programs (OUP) of the Science and Technology (S&T) Directorate of the Department of Homeland Security (DHS). CREATE started operations in March of 2004 and has since been joined by additional DHS centers. Like other COEs, CREATE contributes university-based research to make the nation safer by taking a longer-term view of scientific innovations and breakthroughs and by developing the future intellectual leaders in homeland security.

CREATE's mission is to improve homeland security decisions to make our nation safer. We are accomplishing our mission through an integrated program of research, education and outreach that is designed to inform and support decisions faced by elected officials and governmental employees at the national, state, and local levels. We are also working with private industry, both to leverage the investments being made by the DHS in these organizations and to facilitate the transition of research toward meeting the security needs of our nation.

CREATE employs an interdisciplinary approach merging engineers, economists, decision scientists, and system modelers in a program that integrates research, education and outreach.

This approach encourages creative discovery by employing the intellectual power of the American university system to solve some of the country's most pressing problems. The Center is the lead institution where researchers from around the country come to assist in the national effort to improve homeland security through analysis and modeling of threats. The Center treats the subject of homeland security with the urgency that it deserves, with one of its key goals being to produce rapid results by leveraging existing resources so that benefits accrue to our nation as quickly as possible.

By the nature of the research in risk, economics, risk management and operations research, CREATE serves the need of many agencies at the DHS, including the Transportation Security Administration, Customs and Border Protection, Immigration and Customs Enforcement, Federal Emergency Management Agency and the US Coast Guard. In addition, CREATE has developed relationships with clients in the Offices of National Protection and Programs, Intelligence and Analysis, the Domestic Nuclear Detection Office and many State and Local government agencies. CREATE faculty and students take both the long-term view of how to reduce terrorism risk through fundamental research, and the near-term view of improving the cost-effectiveness of counter-terrorism policies and investments through applied research.

Centers of Excellence Funded by the Office of University Programs

Current Centers

ADAC	Arctic Domain Awareness Center of Excellence
BTI	Borders, Trade, and Immigration Institute
CAOE	Center for Accelerating Operational Efficiency
CINA	Criminal Investigation and Network Analysis Center
ALERT	Center of Excellence for Awareness and Localization of Explosives-Related Threats
CRC	Coastal Resilience Center of Excellence
CIRI	Critical Infrastructure Resilience Institute
MSC	Maritime Security Center of Excellence
START	National Consortium for the Study of Terrorism and Responses to Terrorism

Emeritus Centers

CREATE	National Center for Risk and Economic Analysis of Terrorism Events
CVADA	Center for Visualization and Data Analytics
FPDI	Food Protection and Defense Institute
ZAAD	Center of Excellence for Zoonotic and Animal Disease Defense
CHC	Coastal Hazards Center of Excellence
NTC	National Transportation Center

Ten Tools, Technologies, and Knowledge Products (TTKPs) Developed by the Centers of Excellence
(COE Developer)

ADCIRC	Advanced Circulation Storm Surge Model (CHC)
ARMOR	Assistant for Randomized Monitoring Over Routes (CREATE)
BOARD	Bus Operator Awareness R&D Training Module (NTC)
CGSARVA	Coast Guard Search and Rescue Visual Analytics (CVADA-VACCINE)
E-CAT	Economic Consequences Analysis Tool (CREATE)
Engineered Swabs	Improved Swab Design for Collecting Explosives Residue (ALERT)
GeoXray	Spatial Representation of Social Media Key Words (CCICADA)
HOAX Calls	Voice Pattern Analysis Tool to Identify Hoax Callers (CCCICADA)
PROTECT	Port Resilience Operational/Tactical Enforcement to Combat Terrorism (CREATE)
TraffiCop	Social Media Search Tool to Identify Sex Traffickers (CCICADA)

Table of Contents

List of Tables

List of Figures

Center of Excellence Landscape Study- Phase 1

Executive Summary

For the past fifteen years the Office of University Programs (OUP) of the Science and Technology Directorate of the Department of Homeland Security (DHS), has funded university-based research through its Centers of Excellence (COE). In the process, the COEs have developed several hundred tools, technologies, and knowledge products (TTKPs) for use by DHS components. In 2016, the OUP funded a two-year effort to assess the costs and benefits of selected TTKPs. This project has two phases: In Phase 1, ten TTKPs relevant to the United States Coast Guard (USCG) were analyzed. In Phase 2, another set of TTKPs relevant to the Transportation Security Agency and to Customs and Border Protection are being analyzed. This report summarizes the results of Phase 1.

To begin the process, USCG staff familiarized themselves with about 200 TTKPs, covering a wide range of topics. Based on the USCG staff's judgments of the likelihood of a successful transition and the beneficial impacts to the Coast Guard, if successfully transitioned, ten TTKPs were selected for further study. These included some tools that had been applied in the past, including PROTECT, a tool to randomize Coast Guard patrols in U.S. harbors. Other selected TTKPs were seen as having high potential, including HOAX Calls, a voice print analysis tool to identify fraudulent maritime emergency calls to the Coast Guard. Because the USCG staff selected TTKPs with high actual or perceived potential, the ten TTKPs most likely represent a "high benefit" subset of the 200 TTKPs that in hindsight might have been among the first projects chosen to optimize the research budget; they are neither a representative nor random sample.

Each TTKP was analyzed using a similar process. First, a baseline performance was established without the use of the TTKP. Baseline metrics varied across applications and included, for example, detection and false positive rates, the annual number of seizures of contraband, and number of hoax calls to the USCG. Subsequently, the cost of developing the TTKP was ascertained through the records of the COE that supported its development, and interviews or e-mail exchanges with the principal investigator and users. Cost estimates included pre-funding prior to OUP's engagement, OUP and COE funding, cost share by the universities, cost of OUP oversight, and transition and implementation costs including, where appropriate, costs to the public or other stakeholders. Past and future costs (and later benefits) are reported in present value 2017 dollars. Costs varied widely, from about $183 thousand for the HOAX Call tool to about $7.1 million for ADCIRC, a storm surge and wind speed prediction model. The next step was an assessment of the benefits, of the TTKPs. This usually involved building models of the variables that affect the benefits and analyzing the model results, using different assumptions and parameters. In the process, we identified several different types of benefits including cost savings, improved detection rates, reduced false alarm rates, increased deterrence, and improved information for decision making.

The net present value (NPV) of each TTKP (in 2017 dollars) was computed by subtracting the present value costs from the present value benefits. To standardize the comparison between the benefits of different TTKPs, we used a ten-year time frame (past or future benefits) to estimate the NPVs. In one case we only had evidence of a single although major application and used the benefits estimate from this application as a lower bound of benefits. We then calculated the resulting NPV by subtracting the development and transition cost from the NPV of the net benefits.

Like costs, the NPV varied widely, from about $806,000 for E-CAT, a simplified economic consequence analysis tool, to $286 million for ADCIRC. In total, the median NPV estimates combined to about $432 million for the ten selected TTKPs. Because NPV estimates often depend on highly uncertain parameters, we also conducted a break-even analysis, followed by a sensitivity analysis and an uncertainty analysis. Table 1 shows a summary of the results including both low-end and high-end NPV estimates from the uncertainty analysis.

Overall, the cost estimates reported in Table 1 are quite solid, although in some cases the pre-OUP funding and the implementation funding by users was harder to track than the funding by OUP through its Centers of Excellence. The most solid NPV estimates (indicated by a relatively small uncertainty range) were associated with benefits of TTKPs that had a history of use, such as ARMOR and PROTECT, which are both scheduling tools that randomize patrols and checkpoints for maximum protection, given constraints on scheduling and maintaining a high degree of uncertainty subject to these constraints. Some of the employed TTKPs had no systematic evidence of their benefits. For example, ADCIRC was used by the Coast Guard since 2011 to make decisions on protecting and deploying assets, but it was not easy to quantify the benefits of these applications. Yet other TTKPs had not been used at all and the benefit estimates had to be based on models with several uncertain parameters, e.g., deterrence effects.

We recognize that due to these limitations, the actual NPV estimates are sometimes uncertain. Nevertheless, a major advantage of conducting the uncertainty analyses was the identification of information that should be collected to reduce the uncertainty about benefits. In addition, more solid benefit-cost analyses could be conducted if TTKP developers were to include an evaluation component with well-defined benefits metrics and collected relevant data on these metrics in collaboration with TTKP users.

In spite of these limitations, we also found that the NPV calculations are surprisingly resistant to changes in model assumptions and estimates of model parameters. All analyses have gone through multiple iterations, yet we found few cases in which the net benefits changed substantially.

Table 1: Costs, Medians and Ranges of Net Present Values for Ten TTKPs

Updated June 7, 2018		Ranges of Net Present Values (in 2017 $1000)			
Tool, Technolgy, or Knowledge Product (TTKP)	Cost (in 2017 $1000)	Low NPV (5th Percentile)	Median NPV (50th Percentile)	High NPV (95th Percentile)	Years of Use for Net Benefit Calculations
		TTKPs with Past Applications			
PROTECT	$710	$20,500	$35,505	$58,798	6 Past & 4 Future Years
ARMOR	$1,056	$25,428	$28,969	$32,229	10 Years, Past Use
CgSARVA	$803	$570	$5,247	$13,170	One Time (Sandy)
		TTKPs with Potential Future Applications			
ADCIRC	$7,095	$101,934	$286,209	$562,793	10 Years, Future Use
Engineered Swabs	$1,867	($77,597)	$22,528	$159,825	10 Years, Future Use
GeoXray	$273	$8,425	$18,404	$35,212	10 Years, Future Use
TraffiCop	$1,413	$3,214	$10,444	$24,562	10 Years, Future Use
Hoax Calls	$183	$1,731	$4,646	$9,442	10 Years, Future Use
BOARD	$1,018	$239	$2,435	$7,902	10 Years, Future Use
E-CAT	$945	($416)	$806	$2,603	10 Years, Future Use
TOTAL	**$15,363**	**$84,027**	**$415,193**	**$906,536**	

COE Landscape Study Year 1 Final Report

Overview

1. Purpose of the Analyses

The Office of University Programs (OUP) of the Science and Technology Directorate of the Department of Homeland Security (DHS) was created in 2003. During the past 15 years OUP has received approximately $40 million per year in funding, much of which went to the university-based Centers of Excellence (COEs). The primary purpose of the COEs is to support fundamental research. In the process, the COEs have developed several hundred tools, technologies, and knowledge products (TTKPs), which have been used by DHS components or are in transition to be used.

While the COEs' focus is on fundamental research, a question is frequently asked about the return on the investment by OUP. The purpose of this report is to address this question by analyzing the costs and benefits of selected TTKPs that the COEs have produced in the past 14 years.

The project started by selecting customers of OUP research at DHS and identifying TTKPs that they have used or anticipate using in the future. In the first phase of this project, ten TTKPs were selected by the U.S. Coast Guard (USCG). This report describes the process of selecting the ten TTKPs, the general analysis approach, the common rules for analysis used in all ten studies, and the lessons learned. Subsequently, the ten individual studies are described, and a common format is used for the analysis of their costs, benefits, and return on investment.

2. Selecting the TTKPs

In the first phase of this project, the USCG staff at its Research and Development Center in New London, CT, selected the TTKPs they deemed most beneficial to USCG operations. Two UCSG staff members reviewed approximately 200 TTKPs identified by OUP and made initial judgments of their value for the Coast Guard. In a meeting held on September 30, 2016, a larger group of Coast Guard staff evaluated the 200 TTKPs more formally by rating each TTKP on two criteria:

1. The likelihood of a successful transition (on a 1 to 10 scale, later converted to a 0-1 probability scale)
2. The impact on the USCG, if successfully transitioned (on a 1-10 impact scale)

Using these two inputs, ten TTKPs were identified, which scored highest on the product of the two input numbers (see Table 2). The table also provides brief descriptions of each TTKP, identifies the COE that developed the TTKP and the corresponding OUP program manager.

This process identified TTKPs that USCG staff considered to be actually or potentially successful rather than a random sample of cases. This approach is consistent with a retrospective analysis of how a fixed budget might optimally have been allocated, first to the higher expected return projects, and then proceeding to lower return projects.

3. Modelling Process and Shared Assumptions

The goal of each analysis was to determine the net present value (NPV) and the return on investment in the form of a monetized expected present value benefit-cost analysis consistent with professional standards. Budgetary impacts on DHS components and the U.S. Government were central to all the analyses, but benefits and costs to U.S. citizens were included where they could be determined. Limitations on data, especially regarding uncertainty, often led to simpler approaches. The sequence of analysis steps carried out for each TTKP case consisted of

1. Determining the baseline performance without the use of the TTKP
2. Estimating the past cost of investment in the TTKP
3. Estimating the benefits of the past or future use of the TTKP, including the cost of maintaining the TTKP and possible upgrades, and determining the net present value (NPV)
4. Conducting a benefit-cost analysis by calculating the overall NPV minus the investment cost (all in 2017 dollars), the benefit to cost ratio and the return on investment

Because several of the input parameters for our NPV calculations were uncertain, we analyzed the impact of changing these input parameters through reasonable ranges by

1. Assessing the break-even point at which the improvement in performance just equaled the cost of the investment
2. Creating a tornado diagram that shows how the NPV changes, when changing input parameters through a range of possible values
3. A full uncertainty analysis using Monte Carlo simulation which uses distributions for the input parameters

Assessing benefits was often the most difficult step. Some benefits accrued through cost savings, others through risk reduction, others through reduction of false alarms or improved detection rates, and yet others through a mix of benefits.

Table 2: Ten TTKPs Selected by the USCG Staff

Center of Excellence (COE)	TTKP Name	Brief Description	USCG Scores (Impact, Transition Liklihood)	Transition Liklihood	Liklihood x Impact
ALERT	Engineered Detection Swabs	These swabs are being developed in the R2 Thrust in an effort to improve detection of trace explosives on luggage and persons through contact sampling/IMS. The goal is to patent and license swab development to a commercial partner once proof of concept has been achieved. Preliminary results have already demonstrated the superior performance of these traps at harvesting residue.	7, 6	0.56	3.89
CCICADA	GEOXray	Tool to display a geographic area and overlay relevant emergency response and other services (schools, hospitals, parking areas, etc.), content from news, events, databases, tweets, and blogs and clusters and summarizes text associated with map locations.	8, 7	0.67	5.33
CCICADA	HOAX Calls	Software to create a "voice print" of a caller, used to identify "hoax" callers, who request maritime emergency assistance from the U.S. Coast Guard, even though no emergency exists	6, 4	0.33	2.00
CCICADA	TraffiCop	Analysis of Twitter and social media to detect human trafficking.	7, 4	0.33	2.33
CHC	ADCIRC storm surge/inundation modeling	This modeling suite is the next generation of coastal hazard models for predicting coastal flooding. The models couple rain and wind forecasts with hydrologic, storm surge, and wave models to provide holistic coastal flooding predictions.	9, 7	0.67	6.00
CREATE	Assistant for Randomized Monitoring over Routes (ARMOR)	Software that randomizes schedules, plans or actions for security agencies. Successfully deployed at the Los Angeles International Airport (LAX) since August 2007 for randomized scheduling of LAX police. Currently undergoing deployment nation-wide.	10, 10	1.00	10.00
CREATE	Economic Consequences Analysis Tool (E-CAT)	Tool intended for policymakers and analysts who need quick estimates of the economic impact of threats listed in the Homeland Security National Risk Characterization (HSNRC) Register. It provides estimates of the impact of terrorist attacks, natural disasters, and technological accidents on US gross domestic product and employment. It is programmed in Excel and Visual Basic in order to facilitate its use.	8, 7	0.67	5.33
CREATE	Port Resilience Operational / Tactical Enforcement to Combat Terrorism	Software that randomizes patrol schedules in a port environment. Successfully piloted in USCG Boston Harbor and USCG Sector NY. Based on CREATE's ARMOR.	10, 10	1.00	10.00
NTSCOE	Bus Operator Awareness R&D (BOARD)	Training program to provide bus operators with enhanced awareness in behavioral assessment to better recognize and respond to security threats. The goal of the program is to enhance bus operators' abilities to quickly and effectively evaluate suspicious and dangerous behaviors, and take actions to protect themselves and their passengers.	7, 7	0.67	4.67
VACCINE	Coast Guard Search and Rescue Visual Analytics (cgSARVA)	Enables the interactive analysis of trends, patterns, anomalies, and distribution of Search and Rescue cases and associated sorties. Additionally, this assessment tool enables the determination of potential increase or decrease in risk with a reallocation of a resource; as well as known increases or decreases in the response time.	10, 10	1.00	10.00

4. Baseline Performance

In this initial step, we defined a baseline metric and assessed the performance of the strategies, decisions, and operations without the use of the TTKP. The baseline metric varied from TTKP to TTKP and in some cases there were multiple metrics. For example, in the analysis of the HOAX

Call TTKP, the baseline was the number of hoax calls the USCG received in a given year (167 calls in 2016) and the costs associated with them. An additional metric for this TTKP was the rate of identifying and convicting a hoax caller and the amount collected in restitution payments.

Another example is the baseline performance of scheduling checkpoints and patrols at the Los Angeles International Airport, prior to the use of the Assistant for Randomizing Monitoring Over Routes (ARMOR). ARMOR is a software tool that provides a smart randomization of checkpoints and patrols. It was applied during the past ten years at the Los Angeles International Airport to randomize checkpoints and canine patrols.

Because the main benefit of ARMOR is the reduction of staff costs, while keeping the protective value the same, the baseline was the cost of four teams of police officers per shift to staff the checkpoints, which were used prior to the implementation of ARMOR. Another baseline metric in this analysis was the number of seizures of drugs and guns prior to the implementation of ARMOR. Table 3 shows some of the baseline estimates for ARMOR. In this table we included the estimates for four teams (base line) and two teams (ARMOR) as well as estimates using regular pay rate and overtime rate.

Table 3: Nominal Staffing Costs for Checkpoints at the Los Angeles International Airport

		Regular	Overtime
Lieutenant	per hour	$64	$96
Sargeant I	per hour	$55	$82
Sargeant 2	per hour	$52	$77
Police Officer 1	per hour	$45	$68
Police Officer 2	per hour	$48	$72
Total cost/hour		$264	$396
Cost/day with 2 shifts of 7 hours/each		$3,692	$5,538
Annual Costs for 2 Teams per Shift (ARMOR)		$2,695,014	$4,042,521
Annual Costs for 4 Teams per Shift (Before ARMOR		$5,390,028	$8,085,042

5. Cost Analysis

To determine the investment costs, we contacted the COE director and the principal investigator responsible for the development of the TTKP. This was a fairly straightforward task, though in some cases, cost estimates of initial development prior to OUP funding were harder to obtain.

Costs included the pre-OUP funds, direct costs of funding by OUP, the overhead costs for OUP oversight, the overhead costs by the COE, transition and implementation costs, and finally costs for operating the TTKP on an annual basis (e.g., for training personnel).

In some cases, operational costs were provided by the users or estimated by the CREATE team based on personnel costs, training time, etc. A cost template was developed and then adapted slightly for each case. That general template is presented in Table 4. An example of the cost estimates is shown in Table 5 for the ARMOR

Table 4: Cost Data Collection Template

Cost Category	Start	End	Amount	Source
Pre-project costs (COE)				
Pre-project costs (other funding)				
Project costs (COE)				
Project costs (university cost share)				
Oversight cost at the COE				
Oversight cost at OUP				
Transition development cost				
Implementation start up cost				
Implemementation cost (User)				
Implementatioon cost (COE)				
Implementation cost (Other users)				
TOTAL COST				

Notes
Pre-project cost (COE): Costs that are clearly linked to the project funded by the COE prior to the actual project kick-off
Pre-project costs (other): Costs that are clearly linked to the project funded by other agencies prior to the actual project kick-off
Project costs (COE): Project costs paid directly by the COE to develop the TTKP, including burdened salaries, travel, M&S, etc.
Project costs (university cost share): Fraction of project costs paid for by COE's university as cost share
Oversight cost at COE: Fraction of COE management cost to support the TTKP
Oversight cost by OUP: Fraction of the OUP management cost devoted to the TTKP
Transition development cost: Cost by the COE and the user to transition the TTKP to a user
Implementation start-up costs: Cost to the COE and user to start up the implemementation
Implementation costs (User): User cost of maintaining the implementation of the TTKP though its life cycle
Implementation costs (COE): COE cost of maintaining the implementation of the TTKP throgh its life cycle
Implementation costs (other users): Costs of implementation of the TTKP for other users and parties

Table 5: Example of Cost Estimates for the ARMOR Software Development

Cost Category	Start	End	Amount	Source	2017 Dollars
Pre-project costs (COE)					
Pre-project costs (other funding)	7/1/03	6/30/05	$100,000	NSF	$126,000
Project costs (COE)	8/15/05	8/14/07	$200,000	CREATE/OUP	$242,000
Project costs (university cost share)	8/15/05	8/14/07	$30,000	USC	$36,300
Oversight cost at the COE	8/15/05	8/14/07	$40,000	CREATE/OUP	$48,400
Oversight cost at OUP	8/15/05	8/14/07	$40,000	OUP	$48,400
Transition development cost	7/1/07	6/30/08	$28,000	CREATE/OUP	$31,360
Implementation start up cost	7/1/07	6/30/08	$100,000	LAX Police	$112,000
AVATA Upgrade in 2014	1/1/14	1/1/15	$250,000	AVATA/LAX Pol	$257,500
AVATA annual fee for 3 years	1/1/14	12/31/16	$150,000	AVATA/LAX Pol	$154,500
Implementation cost (Other users)	n/a	n/a	n/a	n/a	n/a
TOTAL COST (Real and Inflation Adjusted)			**$938,000**		**$1,056,460**

Costs and benefits occurred in various past or future years for each TTKP. Future values were discounted at a rate informed by professional practice and Government guidance.[1,2,3,4,5] The base real rate of discount chosen was 3 percent with a range from 0 to 7 percent; where appropriate for uncertainty analysis, a triangular distribution was used.

While it is standard to apply a common discount rate across projects as above, retrospective practice is less clear as is the particular interest rate to be used. An investigation of real interest rates in the 2005 to 2016 period indicated that in many of these years the real rate was close to zero. The approach used throughout this project was to adjust nominal past costs or benefits to for purchasing power in 2017 using the Consumer Price Index[6] (CPI), but to use a zero retrospective real rate of interest across projects to compute the present value of historical costs and benefits as of 2017. Such a general index was used as each individual case had slight differences in cost components and it was thought that a general price adjustment would be the most transparent. Past costs and benefits were escalated at the rate of inflation using Table 6[7]. For example, the last column in Table 6 shows the costs of developing ARMOR between 2003 and 2016 expressed in present value 2017 dollars. Ultimately, all costs and benefits were estimated in present value terms for the 2017 base year.

Table 6: Inflation Multipliers Used for Past Costs and Benefits
(Source: Bureau of Labor Statistics, CPI inflation calculator from mid-year to mid-year[7])

Year	CPI Inflator to 2017
2005	1.26
2006	1.21
2007	1.18
2008	1.12
2009	1.14
2010	1.12
2011	1.09
2012	1.07
2013	1.05
2014	1.03
2015	1.03
2016	1.02
2017	1.00
Average	1.10

6. Benefits Analysis

Initially, we believed that monetized estimates would be extremely difficult to obtain and that many cases would resort to multi-attribute measures. However, we found that informative if at times simple values could be obtained for all the cases. The framework tended to be that of expected value, as from a decision-analysis between a base case and an alternative where the "value" used was often constructed from unit costs or benefits. The specific benefits of the TTKPs varied widely, both in the source of the benefits and their magnitude. The cases seemed to fall into the following categories:

1. Government Cost Savings, often by introducing a new technology, in which no additional security is achieved, or other actions taken
2. Cost Savings in which cost reductions are used for additional operational purposes, such as improving security or providing additional qualitative benefits
3. Redistributing Costs Over Time, thereby delaying costs and leading to lower net present values due to discounting
4. Improved Detection Performance, by either improving the detection rate or reducing the false alarm rate, or both

5. Increased Deterrence of terrorist attacks by better protection or intervention with attacks
6. Less Costly and/or Higher Quality Information, such that new technologies may make the same information available at a lower cost or improve the quality of the information.

Additional categories may develop over time and with additional cases.

The most straightforward benefits calculations were based on documented savings in staff time. For example, the use of ARMOR resulted in a reduction in the number of five-person teams for checkpoints from 4 teams to 2 teams, while maintaining the same level of protection.

Table 7 shows the benefit calculations for ARMOR. In this case all benefits are in the past. Since the benefits were the difference in staff costs before and after using ARMOR, we asked the Los Angeles Airport Police to provide the 2017 staffing costs for one checkpoint team. We then determined the 2017 difference in the cost of using four teams vs. two teams and applied this difference to the previous 10 years.

ARMOR also led to a moderate increase in seizures and guns. During the year prior to the implementation of ARMOR, there were 4 seizures of drugs and 5 seizures of guns. Table 7 shows the increase and their respective values after the implementation of ARMOR.

Table 7: Benefit Calculation of ARMOR

Variable	Base Case
Number of Years in Use (original: 2008-2013, AVATA from 2014-2017)	$10
Pre ARMOR Cost per Year for 4 Teams at RegularPay Rate	$5,390,028
Post ARMOR Cost per Year for 2 Teams at Regular Pay Rate	$2,695,014
Drug Seizures Value - Increase of 26 Seizures/Year at $5,000/Seizure	$130,000
Weapons Seizure Value - Increase of 15 Seizures/Year at $1,000/Seizure	$15,000
Pre ARMOR Cost per Year for 4 Teams at Overtime Rate	$8,085,042
Post ARMOR Cost per Year for 2 Teams at Overtime Rate	$4,042,521
Percent Overtime	25%
Annual Benefits	***$3,176,891***
Ten Year Benefits (2008 to 2017)	***$31,768,908***
Net Benefits (2017 Dollars)	**$30,712,448**
Return on Investment for 10 years of Use	**3274%**
Benefiit to Cost Ratio (10 years)	**33.9**

In other cases, the benefits were due to increased protection levels, while using resources of equal cost. For example, the PROTECT software used to schedule U.S. Coast Guard patrols in the harbors of Boston and New York had a demonstrable increase in the expected value of protecting potential targets. This was determined by assigning values to the targets (e.g., the Statue of Liberty or the Staten Island Ferry) and calculating the expected value of protection (the percent of time spent at or near these targets multiplied by the value of the targets, summed over targets) with and without the use of the PROTECT software. We then assumed that the effort to obtain the same expected value of protection without PROTECT would require additional staffing proportional to the expected value increase. For example, if PROTECT increases the expected value of protection by 50%, we assumed that the same could be achieved without PROTECT by adding 50% more staffing resources. The additional cost of the required resources to match the level of protection from the TTKP was used to estimate the TTKP benefit.

Deterring terrorists from launching an attack is another benefit. The HOAX call software, for example, can identify false emergency callers through voice print analysis. The software is now in use by the U.S. Coast Guard and convictions using the tool have been publicized. The current number of hoax calls is between 100 and 200 per year, leading to substantial costs in unnecessary search and rescue efforts. It is reasonable to assume that hoax callers are deterred from calling the U.S. Coast Guard emergency line if they are likely to be identified and successfully prosecuted. However, the precise reduction of hoax calls due to the new tool is uncertain. Due to this uncertainty, our analyses include deterrence effectiveness parameters, and they report extensive sensitivity and uncertainty analyses. We also included the benefits of increasing the conviction rates due to improved voice identification.

When benefits included saving statistical lives, a value of statistical life (VSL) was used in each study as informed by the large existing literature and practice at DHS.[8,9,10] The base case VSL used is $10 million in 2017 dollars with a range from $5 to $15 million.

7. Benefit-Cost Analysis (Base Case)

In the base case, the benefit-cost analysis (BCA) consists of calculating the Net Present Value (NPV) for ten years of use of the TTKP. In many cases, there are operating costs (e.g., training staff to use the TTKP on an annual basis), so the NPV is calculated using net benefits for each of ten years of use. Moreover, to determine net benefits in 2017 dollars, we subtract the investment cost in 2017 dollars from the NPV, i.e.,

Net Present Value (TTKP) = NPV (10 Years Use of the TTKP) – PV (Investments Costs).

The Benefit to Cost Ratio (BCR) is the ratio of the NPV and the present value of the costs of developing the TTKP.

BCR = NPV (Ten Years Use of the TTKP)/PV (Investment Costs).

The return of investment (ROI) is calculated as

ROI = 100[NPV (10 Years of Use of the TTKP)-PV (Investment Costs]/PV (Investment Costs*) (in %).

For example, the ARMOR software has a net ten-year benefit of $30.7 million, a BCR of nearly 34 and an ROI of about 3,300% in the base case analysis (see Table 7).

8. Sensitivity and Uncertainty Analysis

Break-Even Analysis. When the benefits are highly uncertain, one approach is to ascertain how much benefit (in NPV terms) would be required to justify the cost. For example, the development of the HOAX Calls software cost $183,000 according to COE records. The average cost of a search and rescue effort is about $50,000 according to the Coast Guard. Therefore, deterring three to four hoax callers from making a call would pay for the software development costs.

Similarly, ADCIRC, a software simulation model to predict hurricane wind speeds and storm surges, improves predictions over older models like SLOSH or P-SURGE. One benefit of these more accurate predictions is the avoidance of unnecessary evacuations and the associated costs. In one of our analyses we determined that an improved accuracy of 0.2% of predicting storm surge areas would justify the total OUP investment in ADCIRC. To recoup the $1 million investment in ARMOR, it would be sufficient to eliminate one of the four checkpoint teams for 6 months to achieve a break-even benefit.

Tornado Analysis. In most benefit-cost analyses there are some input variables that are highly uncertain. To examine how this uncertainty affects the results of the BCA, we first determined a reasonable lower and upper bound for each uncertain input variable. We then determined how the NPV would change as a result of varying each variable from its low to its high value, leaving all other variables at their base case value.[i] This analysis results in what is commonly called a tornado diagram. Table 8 illustrates this by showing the ranges of the input variables used for ARMOR. The results of the sensitivity analysis for ARMOR are shown as a Tornado diagram in Figure 1.

Table 8: Ranges of Uncertain Input Variables for ARMOR

Variable	Min	Base	Max
Years of ARMOR Operations	8	10	10
Percent OT	0%	25%	50%
Value/ Drug Seizure	$1,000	$5,000	$10,000
Value/Gun Seizure	$100	$1,000	$5,000

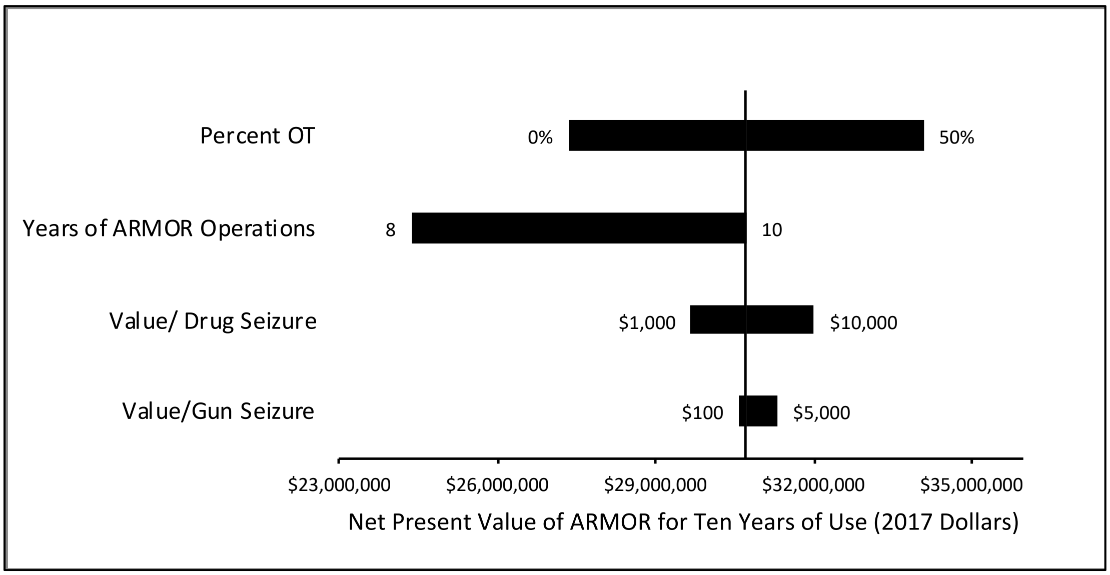


Figure 1: Sensitivity Analysis (Tornado Diagram) for ARMOR

The tornado diagram identifies the important input variables by the length of the bar that shows the range of net benefits defined by the minimum and maximum values for each input variable. Assuming a monotonic relationship between each input variable and net benefits, a large bar indicates an important variable, and a small bar indicates an unimportant variable. Note that the

[i] The Sensit software from Treeplan was used for this purpose

numerical low end of the input variable does not necessarily correspond to the low net benefits end.

9. Uncertainty Analysis

The sensitivity analysis described in the previous section can identify which input variables are important for the benefit-cost analyses. However, this analysis examines only one variable at a time. In a full uncertainty analysis, all variables are modeled with probability distributions and the resulting probability distribution of net benefits is calculated using standard probabilistic simulation software[ii].

The uncertainties about the input parameters were modeled with triangular probability distributions, using low and high values to define the range and the base-case as the mode (most likely) value. For example, in Table 6, the distribution for "Percent Overtime (OT) before ARMOR" was modeled with a triangular distribution with a minimum value of 0%, a mode of 25%, and a maximum value of 50%. We ran each simulation ten thousand times assuming independent (uncorrelated) input distributions and plotted the resulting histogram of net benefits. An example for ARMOR is shown in Figure 2, indicating that net benefits can vary between approximately \$22 million to \$34 million over ten years.

[ii] The SimVoi software from Treeplan was used to conduct the Monte Carlo simulation for the full uncertainty models.

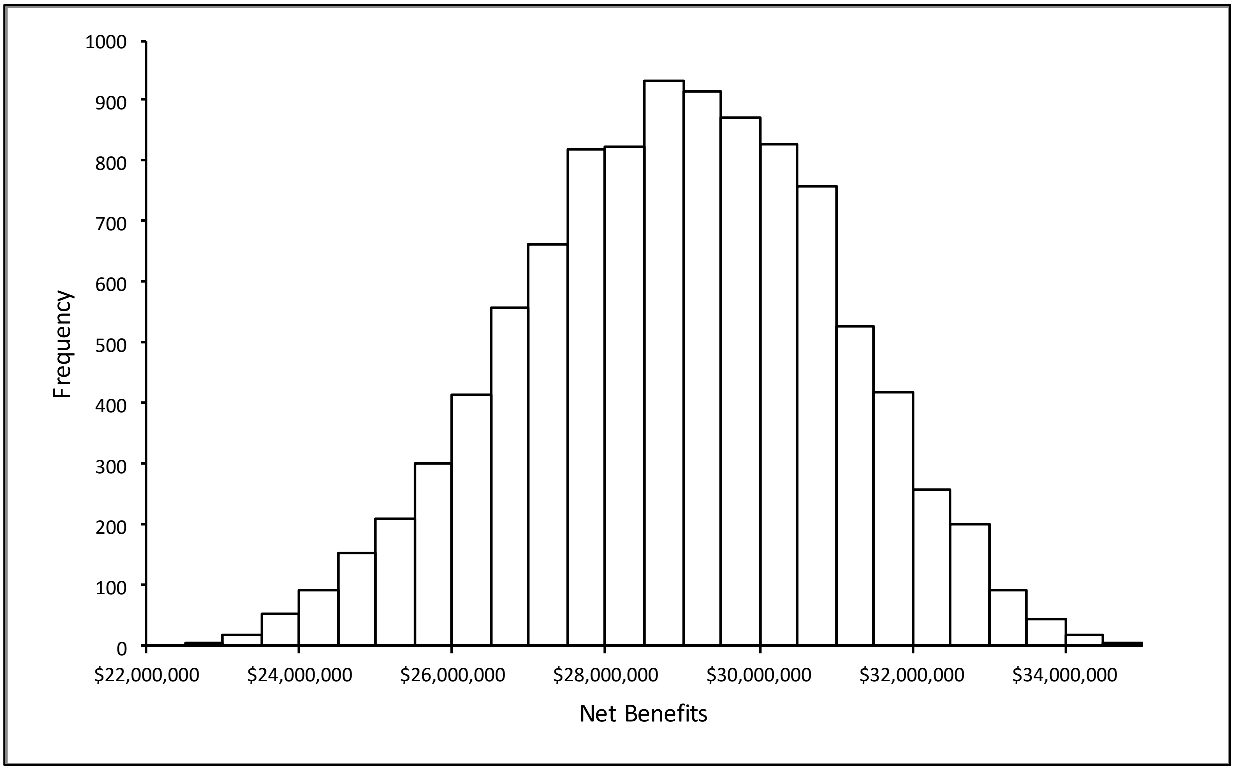


Figure 2: Results of the Simulation of Net Benefits for ARMOR

We summarize the results of the probabilistic simulations by providing the 5th, 50th and 95th percentile of the simulated distributions as well as other statistics. Table 9 illustrates the results for ARMOR.

Table 9: Statistics of the Simulation Output for ARMOR

Mean	$28,918,518
St. Dev.	$2,047,151
5th Percentile	$25,427,981
25th Percentile	$27,516,735
Median	$28,969,043
75th Percentile	$30,384,880
95th Percentile	$32,229,218

10. Summary Results for all TTKPs

Table 10 shows the net 5th, 50th and 95thn percentile of the net present value (NPV) of the benefits for all ten TTKPs. The sum of the median net benefits (NPV as defined above) is nearly $479 million.

Table 10: Costs, Medians and Ranges of Net Present Values for Ten TTKPs

Updated June 7, 2018		Ranges of Net Present Values (in 2017 $1000)			
Tool, Technolgy, or Knowledge Product (TTKP)	Cost (in 2017 $1000)	Low NPV (5th Percentile)	Median NPV (50th Percentile)	High NPV (95th Percentile)	Years of Use for Net Benefit Calculations
		TTKPs with Past Applications			
PROTECT	$710	$20,500	$35,505	$58,798	6 Past & 4 Future Years
ARMOR	$1,056	$25,428	$28,969	$32,229	10 Years, Past Use
CgSARVA	$803	$570	$5,247	$13,170	One Time (Sandy)
		TTKPs with Potential Future Applications			
ADCIRC	$7,095	$101,934	$286,209	$562,793	10 Years, Future Use
Engineered Swabs	$1,867	($77,597)	$22,528	$159,825	10 Years, Future Use
GeoXray	$273	$8,425	$18,404	$35,212	10 Years, Future Use
TraffiCop	$1,413	$3,214	$10,444	$24,562	10 Years, Future Use
Hoax Calls	$183	$1,731	$4,646	$9,442	10 Years, Future Use
BOARD	$1,018	$239	$2,435	$7,902	10 Years, Future Use
E-CAT	$945	($416)	$806	$2,603	10 Years, Future Use
TOTAL	**$15,363**	**$84,027**	**$415,193**	**$906,536**	

For most analyses, we used the ten-year NPV, calculated in 2017 dollars. There were three exceptions. For ARMOR, we used ten years of past benefits; for PROTECT, we used a mix of 6 past and 4 future years; and for CgSARVA, we could analyze only a specific but major use following one hurricane (Sandy), so that the net benefits constitute a lower bound over 10 years.

ADCIRC has by far the highest NPV, which was primarily due to the reduction of unnecessary evacuations during the hurricane season. ADCIRC was also used extensively by the U.S. Coast Guard to position assets or personnel in the hurricane season. For example, a decision was made in 2011, prior to hurricane Irene, to move the USCG headquarters from Portsmouth and Norfolk to St. Louis, based on ADCIRC projections of storm speeds and flooding. Prior to hurricanes Irma and Maria in 2017, ADCIRC predictions led the USCG to keep its helicopter fleet in Puerto Rico rather than diverting them away from the storm, thus avoiding delays in search and rescue operations after the storm. Similarly, ADCIRC predictions for the three major 2017 hurricanes led to more informed tactical decisions that resulted in more effective storm responses and reduced response time and costs in Florida (Irma), Texas (Harvey) and Puerto Rico (Maria).

Engineered Swabs, ARMOR, PROTECT, GeoXray and TraffiCop have median NPVs above $10 million. Of these, ARMOR and PROTECT have a relatively small range of NPVs, partially because they have been applied in the past and therefore benefits estimates were better grounded. Engineered Swabs have a high median net benefit, but also a huge range (from -$77.6 million to $159.8 million). The issue with Engineered Swabs is that detection of explosives materials at TSA checkpoints is improved (reduced false negatives), but at the expense of potentially increasing false alarms. At this time, both false negative and false positive rates are highly uncertain.

At the lower end of the net benefits are four TTKPs with net benefits of less than 10 million dollars. Of these, TraffiCop and HOAX calls still have significant benefits, even at the low end of the uncertainty analysis. CgSARVA, BOARD, and E-CAT have much lower net benefits especially at the low end of the uncertainty range.

11. Lessons and Limitations

The benefit-cost analyses conducted during this study should be interpreted cautiously in light of the uncertainty involved in estimating benefits for some of the TTKPs. While the development cost estimates were in most cases very solid (little or no uncertainty), the benefit estimates were, in some cases, quite uncertain. The uncertainty usually stemmed from a lack of knowledge about how successful the TTKP would be, once applied.

The best estimates (and therefore the lowest uncertainty band) were for TTKPs that were applied in the past, like ARMOR and PROTECT. Both tools were developed by the DHS Center of Excellence, and the National Center for Risk and Economic Analysis of Terrorism Events (CREATE), the COE awarded in 2004. Because of the early development of ARMOR and PROTECT, they had been applied for several years, with a total median net benefit of about $64.5 million.

For the TTKPS that have not yet been applied, the greatest uncertainty came from the variables that influenced the success of their implementation, and in some cases from the variables that characterized unintended consequences of their implementation. For example, the results of the

BCA of ADCIRC depended on the percent reduction of unnecessary evacuations. While ADCIRC provides unique prediction capabilities not available in other existing hurricane prediction models like SLOSH or P-SURGE, the extent to which decision makers will make evacuation decisions based on ADCIRC is unknown. To supplement the BCAs for ADCIRC, we are currently investigating examples of actual use by the U.S. Coast Guard to determine more tangible benefits resulting from documented tactical decisions related to past hurricanes.

Engineered Swabs is an example of a TTKP that has potentially large unintended costs due to the possible increase in the false positive rate. This is one of only two TTKPs that had, at the low end, a negative NPV. As a result of both uncertainties about increased detection rates (benefits) and increased false alarm rates (unintended costs) the Engineered Swabs TTKP BCA results span a very large range of NPVs.

In the process of conducting the BCAs for the ten TTKPs, we learned that the benefits of research resulting in TTKPs can come from a variety of sources:

1. Direct cost savings with the same or similar security risk level (e.g., ARMOR)
2. Increased security benefits at the same cost (e.g., PROTECT)
3. Improved ability to detect threats or to reduce false alarms (e.g., Engineered Swabs)
4. Improved information to support critical decisions (e.g., ADCIRC)
5. Improved ability to detect and convict criminals (e.g., TraffiCop)
6. Reducing threat by deterrence (e.g., HOAX Calls)
7. Delaying costs while keeping risk and efficiency the same (CGSARVA)

Of these sources of benefits, by far the hardest one to quantify is deterrence. HOAX Calls, for example, provides the ability to identify and prosecute a hoax caller based on the voiceprint they leave on the call. Once the technology is widely known and publicized, it is very likely that hoax calls will decrease due to callers fearing identification and conviction. In 2016, there were 167 hoax calls to the U.S. Coast Guard. It is uncertain whether the use of the HOAX call tool will reduce the number of call, but it is not unreasonable to assume some moderate deterrence effect.

In cases like these we made modest assumptions about the deterrence benefits (5% reduction in the base case with a range of 0% to 10%).

Each of the ten BCAs has its specific limitations. They are discussed at the end of each of description of the ten BCAs. As an overall note, the most important limitation of these analyses is the uncertainty in the benefits of several of the TTKPs that are in transition to application. In some cases, e.g., ADCIRC, there are applications, but not all are well documented. Our recommendation is to focus future BCAs on TTKPs that have a history of successful applications.

We recognize that due to these limitations, the actual BCA estimates are, in several cases, very uncertain. One of the major benefits of conducting the benefit cost and uncertainty analyses is to identify the information that should be collected, in order to reduce the uncertainty about benefits. In addition, more exact analyses could be conducted if TTKP developers included an evaluation component to their projects, in which benefits metrics are well defined a priori and relevant data collected in collaboration with TTKP users.

12. References

1. U.S. Office of Management and Budget (OMB), (1992). "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs" OMB Circular A-94, Washington, D.C.
2. U.S. Office of Management and Budget (OMB), (2017). Appendix C: Year 2017 and History of Rates. Accessed July 31, 2017 at https://www.whitehouse.gov/omb/circulars_a094/a94_appx-c.
3. U.S. Office of Management and Budget (OMB), (2003). "Regulatory Analysis" OMB Circular A-4, Washington, D.C.
4. Moore, M., Boardman, A., & Vining, A. (2013). The choice of the social discount rate and the opportunity cost of public funds. Journal of Benefit-Cost Analysis, 4(3), 401-409. doi:10.1515/jbca-2012-0008.
5. U.S. Council of Economic Advisers (2017). Discounting for Public Policy: Theory and Recent Evidence on the Merits of Updating the Discount Rate. Issue Brief. Available at https://obamawhitehouse.archives.gov/sites/default/files/page/files/201701_cea_discounting_issue_brief.pdf.
6. U.S. Bureau of Labor Statistics (2017). Consumer Price Index Calculator (mid-year to mid-year). Available at https://www.bls.gov/data/inflation_calculator.htm.
7. Ibid.
8. U.S. Department of Homeland Security (2014). Best Practices for the Treatment of a Statistical Life in U.S. Department of Homeland Security Regulatory Analyses. D. Hauser to Component Chief Economists. Available at https://homeport.uscg.mil/Lists/Content/Attachments/540/2014%20VSL%20Memo.
9. Viscusi, W. K. (2009). Valuing risks of death from terrorism and natural disasters. Journal of Risk and Uncertainty, 38(3), 191-213.
10. Hammitt, J. and L. Robinson (2011). The Income Elasticity of the Value per Statistical Life: Transferring Estimates between High and Low Income Populations. Journal of Benefit-Cost Analysis, 2(1), 1-29. Available at https://www.cambridge.org/core/journals/journal-of-benefit-cost-analysis.

APPENDIX A

Benefit-Cost Analyses of TTKPs with Past Applications

Table of Contents

Benefit-Cost Analysis of the Port Resilience Operational/Tactical Enforcement to Combat Terrorism (PROTECT) Software Tool

Developer: CREATE (USC), PI Milind Tambe
Analyst: Detlof von Winterfeldt, CREATE

1. Summary

Description of PROTECT. PROTECT is a software tool that creates a "smart" randomization schedule of US Coast Guard harbor patrols, taking into account the value of possible targets of terrorist attacks and the limited resources for patrolling. High value targets are protected more often than low value targets, and, subject to resource constraints, PROTECT maximizes the uncertainty about which target is protected at any given time. This keeps the attackers guessing about which target will be protected, even if they can observe the patrol schedule of the defender.

PROTECT is closely related to a similar software tool, called the Assistant for Randomized Monitoring over Routes (ARMOR).[1] The original development of ARMOR and its deployment in the Los Angeles International Airport (LAX) are described elsewhere. In the benefit-cost analysis of PROTECT we do not count these original development costs or the benefits accruing to LAX. Instead, both the costs and benefits are solely due to the adaptation and deployment of PROTECT to the Boston and New York harbor patrols.

Results. The total development and implementation costs of PROTECT were $710,000 in 2017 dollars. The main benefits of PROTECT were the increased protection value, estimated between 25% and 100% relative to the pre-PROTECT patrol schedule. The benefits of PROTECT can be measured by the cost of adding patrols in order to bring up the pre-PROTECT patrolling system up to the PROTECT level. Using this measure of benefits, we determined a total net benefit for 10 years of deployment (6 years past, 4 years future) at $31.6 million in the base case.

There is substantial uncertainty about the increase in protection value due to PROTECT, as well as some uncertainty about the hourly costs of patrols and other variables. We conducted sensitivity analyses on these variables and found that the net benefit could range from $20.5 million (5th percentile) to $58.8 million (95th percentile), with a median of $35.5 million. It is therefore worthwhile to collect additional information, especially on the increase in protection value. PROTECT is still used at the two harbors, accruing additional benefits.

2. Background

Problem Context. Security at major locations of economic or political importance is a key concern around the world, particularly given the threat of terrorism. Limited security resources prevent full security coverage at all times, which allows adversaries to observe and exploit patterns in selective patrolling or monitoring, e.g. they can plan an attack avoiding existing patrols. Hence, randomized patrolling or monitoring is important, but randomization must provide distinct weights to different actions based on their complex costs and benefits.

The PROTECT Tool. The PROTECT software tool was designed to provide a smart randomization of boat patrols in harbors. PROTECT determines a randomized schedule for the optimal level of protection, considering different values of the targets. Like its predecessor, ARMOR, PROTECT creates the highest possible level of uncertainty for the attacker, given resource constraints and target values, thus keeping the attacker guessing which target is protected at any given time. Unlike ARMOR it uses advanced quantal response models to randomize patrols. PROTECT was initially deployed to schedule US Coast Guard patrols in Boston Harbor in 2011. In 2012 PROTECT was also deployed in New York Harbor to protect the Staten Island Ferry, and it has been used in both harbors ever since.

3. Baseline Performance without PROTECT

Prior to the development and implementation of PROTECT, schedules for USCG harbor patrols were developed manually. There is some evidence that these manual schedules were not very effective in protecting multiple targets. For example, it has been reported[1] that two patrol boats accompanied one Staten Island Ferry, instead of spreading out the patrols between ferries. There is no evidence that the patrols were randomized in any way or took into account the differential values of targets.

Because we could not obtain exact information about the pre-PROTECT scheduling process, we benchmarked the baseline performance against a pure randomization strategy, which protects each target equally with a probability of 1/n. Given the fact that some targets were protected by two patrol boats, while leaving other target undefended, it is likely that the pre-PROTECT schedule had an even lower expected protection value than pure randomization.

The expected protection value of schedule s is defined as:

$$EPV(s) = \sum_{i=1}^{n} pi\ Vi,$$

Where n is the number of targets, p_i is the probability that a target is protected at a given time, and V_i is the value of the target. For a pure randomization strategy $p_i = 1/n$.

The baseline expected protection value was achieved using two patrol boats in Boston Harbor and four patrol boats in New York Harbor. There was no change in the number of boats or patrols, when PROTECT was deployed.[2] Therefore, the benefit of PROTECT is the increase in the expected protection value when using the value-weighted smart randomization instead of the pure randomization strategy.

4. Cost of PROTECT

Table 11 shows the cost of developing and implementing PROTECT at the Boston and New York harbors. There were some initial theoretical developments of the predecessor software, ARMOR, which were funded by the National Science Foundation.[3] These initial costs and the further application of ARMOR to schedule checkpoints and patrols at LAX are counted elsewhere.[4] The Office of University Programs (OUP) funded the major part of the development of PROTECT through CREATE, an OUP Center of Excellence. Oversight costs at CREATE and OUP are counted as well for the two years of development. In later stages, the Ports of New York and Boston funded the implementation of PROTECT to USC Coast Guard patrols. The total costs amounted to $710,350 in 2017 dollars.

Table 11: Costs for Development and Implementation of PROTECT

Cost Category	Start	End	Amount	Source	Amount in 2017 Dollars
Pre-project costs (COE)				CREATE/OUP	
Pre-project costs (other funding)				none	
Project costs (COE)	8/15/09	8/14/11	$100,000	CREATE/OUP	$112,000
Project costs (university cost share)	8/15/09	8/14/11	$15,000	USC	$16,350
Oversight cost at the COE	8/15/09	8/14/11	$25,000	CREATE/OUP	$26,750
Oversight cost at OUP	8/15/09	8/14/11	$40,000	OUP	$42,000
Transition development cost	7/1/09	6/30/11	$75,000	USCG	$77,250
Implementation start up cost	7/1/10	6/30/12	$400,000	USCG	$436,000
Implementation cost (User)			negligible	USCG	
Implementation cost (COE)			negligible	CREATE/OUP	
Implementation cost (Other users)			none	none	
TOTAL COST			$ 655,000		$ 710,350

5. Benefits of PROTECT

Table 12 shows the hourly costs of using a USCG boat, including crew.[5] There are several types of boats that can be used for patrolling. The most common one is the Response Boat (Small), used about 60% of the time at an hourly cost of $5,672 per hour. The Response Boat (Medium) is used about 25% of the time at a cost of $5,672 per hour. We use $1,500 as the base case, but consider a range of up to $2,900 per hour for a mix of the two types of boats.

Table 12: Hourly Costs of Patrol Boats with Crew
(Inside Government Rate)

Type of USCG Boat	Costs/Hour
Response Boat -Small	$1,500
Response Boat - Medium	$5,672

Using the Boston Harbor example, running a utility boat (Medium) for 2 hours a day for a year costs about $1,095,000.

Unlike the ARMOR application at LAX, PROTECT did not actually reduce the number of patrols or the time of patrolling in Boston and New York harbors. Instead, the smart randomization afforded by PROTECT increased the expected protection value, calculated as the percent of time a target is protected by a patrol boat multiplied by the value of the target, summed across targets. According to the authors of PROTECT, this increase can be as large as

100%. In this analysis, we assume a more modest base case of 50% using some of the PROTECT calculations of expected protection value increases.[6,7,8]

To assess the benefits of this increase in expected value, we consider the additional patrolling effort it would take to reach the same protection level. Assuming that the expected protective value increases proportionally with the patrolling effort and associated cost, this can be achieved by adding 50% more patrols. The assumption of proportionality is not unreasonable, since there are only a few patrols covering a large number of targets in both harbors and therefore there is substantial room for improvement in providing security. Given these assumptions, we estimate the benefits of using PROTECT as the difference between the cost of a patrolling effort at 150% of current effort (without PROTECT) and the cost of patrolling at the current level of effort (with PROTECT).

The detailed benefits calculations for PROTECT are shown in Table 13, which shows that the total annual benefits are about $3.3 million and total net benefits for ten years of use (six past years plus our future years) of using PROTECT are about $31.6 million. The return on investment (ROI) is 4,821% and benefit to cost ratio is 45.5.

Table 13: Benefits Calculations

Variable	Base Value
Hourly Cost of Patrol Boats with Crew	$1,500
Number of Patrol-Hours/Day (Boston)	2
Number of Patrol-Hours/Day (New York)	4
Number of Patrol-Hours/Day (SI Ferry)	6
Number of Days Patrolling/Year	365
Protection Value Increase with PROTECT	1.5
Number of Years (Past Use)	6
Number of Years (Future Use)	4
Total Cost of Patrolling/Year	$6,570,000
Cost of Matching PROTECT Protection Value	$9,855,000
Benefits/Year Past Use	**$3,285,000**
Benefit Past 6 Years	**$19,710,000**
Benefis Future 4 Years (Discounted)	**$12,576,988**
Ten Year Net Benefit	**$31,576,638**

6. Benefit-Cost Analysis – Base Case

Table 13 shows that the total net benefit for ten years of use is $31.6 million due to the increased expected value of protection. The corresponding return on investment is 4,821% and the benefit to cost ratio is 45.5.

7. Sensitivity and Uncertainty Analysis

Break-Even Analysis. One way to assess the cost-effectiveness of PROTECT is to determine how much the expected value of protection would have to increase relative to a simple (not value weighted) randomization strategy in order to pay back the cost of $710,000. Using this calculation, PROTECT would pay for itself if it can generate a 1.1% increase in expected value of protection. Of course, this also assumes that the same increase would occur if the patrol effort would be increased proportionally.

Sensitivity Analysis. There is little uncertainty in the cost calculations. The major uncertainty in the benefits calculation is the amount of increased protection value due to the use of PROTECT. There is no question that the expected value of protection is increased; for example, PROTECT schedules the two patrol boats protecting the Staten Island Ferry such that they protect different ferries as opposed to a system when both patrol boats protect the same ferry. In addition, PROTECT covers valuable targets more frequently than low value targets. The actual increase in expected value is, however, uncertain. In this analysis, we assumed a relatively conservative range of increases from 25% to 100%. There is also some uncertainty about the cost to the US Coast Guard of operating the patrols.

Table 14 shows the ranges of these uncertain variables and the resulting benefits calculation for their low, base case, and high values.

Table 14: Base Case and Ranges for Sensitivity Analysis

Variable	Low	Base Case	High
Hourly Cost of Boats with Crew	$1,500	$1,500	$2,900
Value Increase with PROTECT	1.25	1.5	2
Discount Rate	0%	3%	7%

Figure 3 shows a tornado diagram, which illustrates how the changes in each uncertain variable (from low to high values) impact on the net benefits. The increase in the expected protection value is the most important variable, followed by the hourly costs of patrolling and the discount rate.

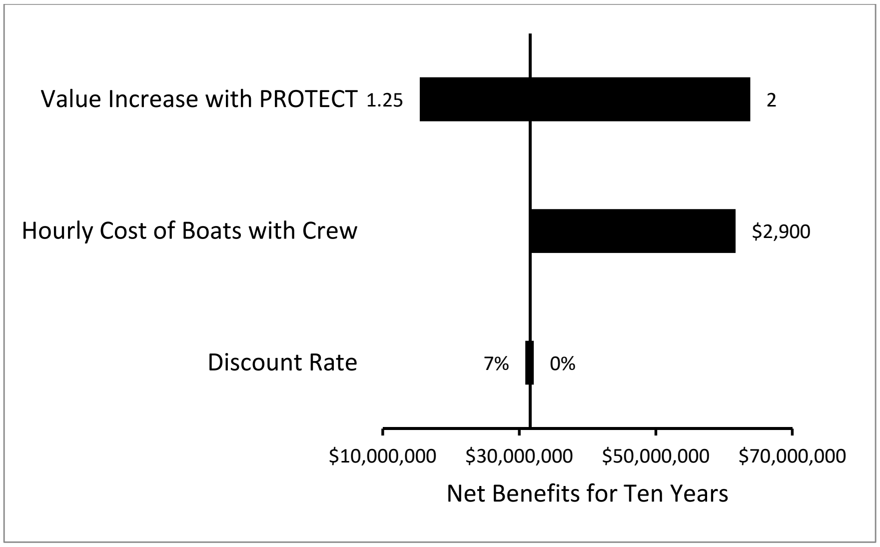


Figure 3: Net Present Value of PROTECT - Tornado Diagram

Uncertainty Analysis. In addition, we conducted a probabilistic simulation in which we assigned probability distributions to the three uncertain variables. For simplicity, we used triangular distributions with a minimum at the low end of the range shown in Table 14, the mode at the base case, and the maximum at the high end. We then ran 10,000 simulations resulting in a distribution of net benefits as shown in Figure 4. Table 15 shows the key statistics of this distribution; specifically, the 5th, 50th, and 95th percentile are $20.5 million, $35.5 million and $58.8 million, respectively.

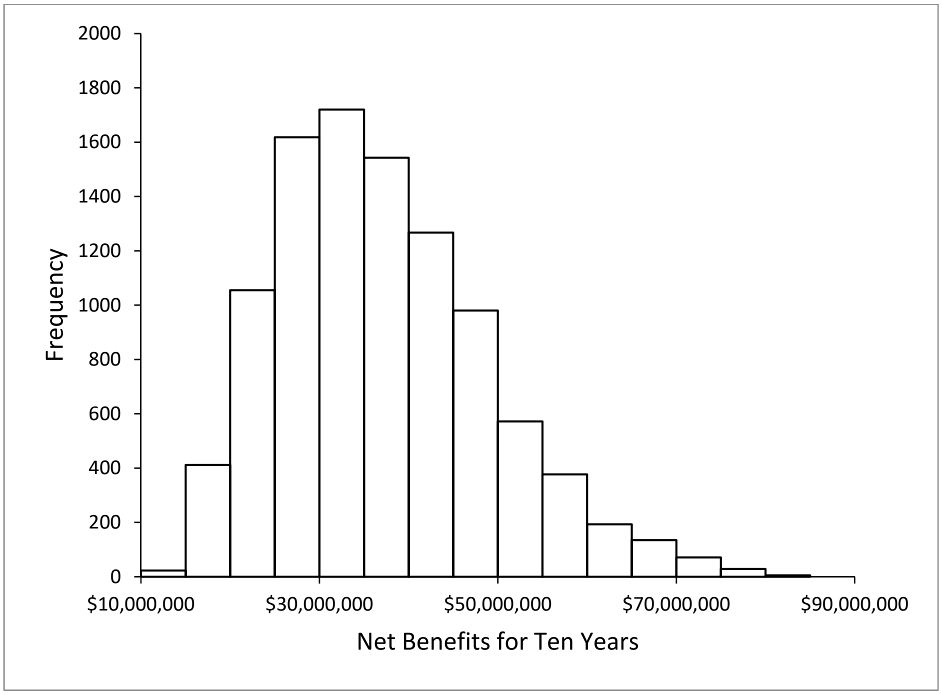


Figure 4: Net Present Value Distribution of PROTECT

Table 15: Statistics of the Net Benefits Distribution

Mean	$37,046,136
St. Dev.	$11,819,682
5th Percentile	$20,499,905
25th Percentile	$28,319,398
Median	$35,505,095
75th Percentile	$44,337,009
95th Percentile	$58,798,191

8. Assumptions and Limitations

The main limitation of this benefit cost analysis is the fact that there were no realized cost savings attributable to the use of PROTECT. In other words, the patrolling effort stayed the same, albeit with a higher protection value due to the use of PROTECT. We therefore had to assume that the same increase in protection value can be achieved with a proportional increase in effort using the current patrol system. We further assumed that the current patrol systems resembled a pure randomization strategy, which allowed us to compare the expected value of protection under the current system and under PROTECT.

Another limitation is the uncertainty about the actual increase in protective value. There is anecdotal evidence that PROTECT created a system that was observed as having deployed more boats on patrol at any given time. This is perhaps mostly due to the rescheduling of the patrol boats protecting the Staten Island Ferry, which was partly due to PROTECT and partly due to common sense re-scheduling (having only one boat accompany each ferry allowed the other boat to accompany another ferry).

9. Recommendations for Additional Research

On the benefit side, it would be useful to collect information of the actual protective value achieved with PROTECT, thus narrowing the 25%-to-100% range. It would also be useful to retrospectively gauge the actual protective value before the use of PROTECT. Barring this, we used a pure randomization strategy as a benchmark, which is often better than past practice, but occasionally may be improved upon by non-random scheduling of patrols.

Getting a better estimate of the actual hours of patrols and the types of boats used and their cost would allow us to narrow the cost estimate for patrolling, improving the benefits estimates. We did not have any information about the operational cost of using PROTECT on a daily basis, but we were informed by the USCG that this operational cost is minor, as PROTECT replaced a system that, while requiring no daily changes, also left the patrolling operation much more predictable.

10. References

1. Jain, M., Tsai, J., Pita, J., Kiekintveld, C, Rathi, S., Ordonez, F., and Tambe, M. (2012). Software assistants for randomized patrol planning for the LAX Airport Police and the Federal Air Marshals Service. Interfaces: Operations Research Management Science, 52, 1, 133.
2. Shieh, E. (May, 2017) Personal communication about the deployment of PROTECT.
3. Paruchuri, P. et al. (2008). Efficient Algorithms to Solve Bayesian Stackelberg Games for Security Applications. Proceedings of the Conference for the Advancement of Artificial Intelligence, pp.1559-1562.
4. von Winterfeldt, D. (2018) Benefit Cost Analysis of ARMOR. University of Southern California, CREATE.
5. US Coast Guard. (2017). Reimbursable Standard Rates. Department of Homeland Security, March, 2017.
6. Shieh, E. et al. (2015). PROTECT: An Application of Computational Game Theory for the Security of the Ports of the United States. Los Angeles, CA: Center for Risk and Economic Analysis of Terrorism Events, University of Southern California.
7. Tambe, M. (March, 2017). Personal communication regarding the development and deployment of PROTECT.
8. Shieh, E. (May, 2018). According to the developer of PROTECT, the range of values of targets and times of the day ranged from a high of 6,000 points to a low of 500 points, thus exceeding a ratio of 10. Since the actual value estimates are classified, we could not replicate the actual increase in expected protective value. However, we conducted some simple example calculations and found a 50-100% increase in expected protective value to be credible.

Benefit-Cost Analysis of the Assistant for Randomized Monitoring Over Routes (ARMOR)

Developer: Milind Tambe, CREATE Principal Investigator
Analyst: Detlof von Winterfeldt, CREATE

1. Summary

Description of ARMOR. The Assistant for Randomized Monitoring Over Routes (ARMOR) TTKP is a software tool that creates a "smart" randomization schedule of checkpoints and patrols, taking into account the value of possible targets of terrorist attacks. High value targets are protected more often than low value targets and, subject to resource constraints, ARMOR maximizes the uncertainty about which target is protected at any given time. This keeps the attackers guessing about which target will be protected, even if they can observe the protective actions of the defender.

The development of ARMOR was originally funded by the National Science Foundation in 2003.[1] In later years ARMOR was funded by the Office of University Programs at DHS and the Los Angeles Airport Police. In 2007 ARMOR was deployed for randomizing checkpoints and canine patrols in the Los Angeles International Airport (LAX).[2]

Results. By 2017, the total development and implementation costs were $1.1 million in 2017 dollars. The main benefits of ARMOR were staff savings of about $3.2 million per year. This was achieved by reducing the number of teams at checkpoints or on patrol, while maintaining the same level of protection. Other benefits include increased captures of drugs and guns. Sensitivity and uncertainty analyses revealed that the net present value (NPV) of the benefits of ARMOR range from about $25.4 million (5th percentile) to about $32.2 million (95th percentile) with a median estimate of $29.0 million. ARMOR is still used at LAX, accruing additional benefits.

2. Background

Problem Context. Security at major locations of economic or political importance is a key concern around the world, particularly given the threat of terrorism. Limited security resources prevent full security coverage at all times. This allows adversaries to observe and exploit patterns in selective patrolling or monitoring, e.g. they can plan an attack that avoids existing patrols. Hence, randomized patrolling or monitoring is important, but randomization must assign distinct weights to different actions based on their complex costs and benefits.

The ARMOR Tool. The ARMOR project team developed methods for creating randomized plans and processes for monitoring, inspection, patrolling, and security. Thus, even if attackers observe the plans, they cannot predict its progression. This provides risk reduction while guaranteeing a certain level of protection. The ARMOR system uses a game-theoretic method of providing such randomization of plans and processes. Casting the problem as a Bayesian Stackelberg game, ARMOR determines the optimal level of protection (percent of time a target is protected), considering different values of the targets. ARMOR creates the highest possible level of uncertainty for the attacker, given resource constraints and target values, thus keeping the attacker guessing which target is protected at any given time.

ARMOR was deployed at the Los Angeles International Airport (LAX) in 2007 and it has been in continued use since then. It was applied to randomize assignments to road checkpoints and to mobile canine patrols.[3]

3. Baseline Performance without ARMOR

Prior to the development and implementation of ARMOR, scheduling and locations of checkpoints and patrols were done without software support by officers of the Los Angeles Airport Police. It was not easy to determine how the scheduling process was conducted prior to the implementation of ARMOR ten years ago, but interviews and e-mail exchanges with the developers and early users of ARMOR suggests that the process considered several factors such as the traffic conditions, passenger volumes, and time of day without formally assigning a value to times and locations.[3] There also was no attempt at randomization, and it seems likely that the checkpoints and patrols were designed to be cyclical, moving in sequence from one location to another, thus making it possible for attackers to observe and predict times and locations of checkpoints and patrols.

Since we could not retrieve the exact pre-ARMOR scheduling process, we benchmark the baseline performance as a pure randomization strategy without considering differential values of times and locations. The expected protection value (EPV) is defined as

$$EPV(s) = \sum_{i=1}^{n} pi\ Vi,$$

where s is the scheduling strategy, p_i is the probability that a checkpoint or patrol is present at time and location i, and V_i is the value of a given combination of time and location. In the baseline (pure randomization) schedule, all p_is are equal to 1/n, where n is the number of possible time/location combinations. While this baseline definition may underestimate the protective value of unaided scheduling somewhat, this is counter-balanced by the fact that unaided scheduling does not have any element of randomization. ARMOR improves on this baseline performance by assigning values to times and locations and optimizing the schedule to achieve the highest expected protective value, subject to randomization and other constraints.

Another aspect of the baseline performance is the number of teams used for checkpoints and patrols. Prior to the implementation of ARMOR, the Los Angeles Airport Police had four teams staffing the checkpoints at several roads entering the Los Angeles International Airport, rotating between inbound roads.[4] Each time, there was one canine unit patrolling eight terminals. Here we report only the cost of staffing the checkpoints, which was provided by officers of the Los Angeles Airport Police[5]. The results for four teams are shown in Table 16. We also include the cost calculations for two teams, as the main benefit of ARMOR was the reduction of staffing costs from four teams to two teams, while maintaining the same expected protection value.

Table 16: Hourly and Annual Costs of Two and Four Teams for LAX Checkpoints

		Regular	Overtime
Lieutenant	per hour	$64	$96
Sargeant I	per hour	$55	$82
Sargeant 2	per hour	$52	$77
Police Officer 1	per hour	$45	$68
Police Officer 2	per hour	$48	$72
Total cost/hour		$264	$396
Cost/day with 2 shifts of 7 hours/each		$3,692	$5,538
Annual Costs for 2 Teams per Shift (ARMOR)		$2,695,014	$4,042,521
Annual Costs for 4 Teams per Shift (Before ARMOR		$5,390,028	$8,085,042

The is no evidence that the canine patrols and associated staffing costs were changed as a result of ARMOR. As a baseline we note that in the year preceding the implementation of ARMOR, there were four drug seizures and eight gun seizures. The benefits of ARMOR are the recorded increases in these seizures.

4. Cost of ARMOR

Table 17 shows the cost of developing and implementing ARMOR at LAX. There were some initial theoretical developments funded by the National Science Foundation.[5] Subsequently the Office of University Programs funded the major part of the development of ARMOR through CREATE, an OUP Center of Excellence. Oversight at CREATE and OUP is counted as well for the two years of development. In later stages, the Los Angeles Airport Police Department funded a major update and annual maintenance costs of ARMOR through a contract with AVATA, Inc., a commercial spin off of CREATE. The total costs of both development and implementation was $1,056,460 in 2017 dollars, including annual maintenance costs of $50,000 for the years 2014-2016.[6]

Table 17: Costs for Development and Implementation of ARMOR

Cost Category	Start	End	Amount	Source	2017 Dollars
Pre-project costs (COE)					
Pre-project costs (other funding)	7/1/03	6/30/05	$100,000	NSF	$126,000
Project costs (COE)	8/15/05	8/14/07	$200,000	CREATE/OUP	$242,000
Project costs (university cost share)	8/15/05	8/14/07	$30,000	USC	$36,300
Oversight cost at the COE	8/15/05	8/14/07	$40,000	CREATE/OUP	$48,400
Oversight cost at OUP	8/15/05	8/14/07	$40,000	OUP	$48,400
Transition development cost	7/1/07	6/30/08	$28,000	CREATE/OUP	$31,360
Implementation start up cost	7/1/07	6/30/08	$100,000	LAX Police	$112,000
AVATA Upgrade in 2014	1/1/14	1/1/15	$250,000	AVATA/LAX Pol	$257,500
AVATA annual fee for 3 years	1/1/14	12/31/16	$150,000	AVATA/LAX Pol	$154,500
Implementation cost (Other users)	n/a	n/a	n/a	n/a	n/a
TOTAL COST (Real and Inflation Adjusted)			**$938,000**		**$1,056,460**

5. Benefits of ARMOR

Before ARMOR was implemented at LAX, there were four teams of five officers each assigned to these checkpoints. These teams moved between the checkpoints according to a fixed schedule. When ARMOR was introduced, it was determined that two teams assigned to the four checkpoints with ARMOR was sufficiently protective of the LAX targets, thus reducing the need from four teams to two teams.

The protective value was based on the calculation of the expected value of a having a checkpoint or patrol at a specific target and a specific time, considering the value of the target. For example, the Bradley International terminal was assigned a higher value by Los Angeles Airport Police staff than all other terminals, due to the traffic and past attacks at that terminal. Thus, the expected value of protecting possible targets could be increased, roughly by a factor of 2, by implementing ARMOR's value-weighted schedule of checkpoints and patrols. Conversely, two teams could deliver the same protective value as four teams.

The reduction of the staff costs while maintaining the same protective value resulted in a substantial cost savings. Table 18 shows the hourly costs of staffing a checkpoint team and the resulting annual costs for four and for two teams.[7] Thus, the main benefit of ARMOR is the reduction in staffing costs ranging from $2,695,014 per year (at regular pay) up to $4,042,521 (at overtime pay).

The detailed benefit calculations are shown in Table 18. In addition to the cost savings due to reducing the staffing of checkpoints from four teams to two teams, there also were increases in seizures of drugs and guns. In the year following the implementation of ARMOR, drug seizures increased from 4 to 30, and gun seizures increased from 5 to 20. While the seizures in later years dropped somewhat, this drop may have been due to the publicity that ARMOR received in the local and national press. This may have led to fewer people bringing drugs and weapons to the airport, which also can be credited to ARMOR. While we use the first-year increase as a base case for the benefits, it turns out that these increases in drugs and weapons seizures made very little difference to the overall benefits. In the base case, we used a value of $5,000 for a drug seizure and a value of $1,000 for a gun seizure.

Since the protective value stays the same with two teams using ARMOR as with four teams using pure randomization, we would not expect a decrease in risk. However, it has been noted that there may be an additional deterrence effect, partially due to the publicity ARMOR received. This deterrence effect is very hard to measure and therefore we did not calculate the additional benefits due to risk reduction.

Table 18: Benefit Calculations

Variable	Base Case
Number of Years in Use (original: 2008-2013, AVATA from 2014-2017)	$10
Pre ARMOR Cost per Year for 4 Teams at RegularPay Rate	$5,390,028
Post ARMOR Cost per Year for 2 Teams at Regular Pay Rate	$2,695,014
Drug Seizures Value - Increase of 26 Seizures/Year at $5,000/Seizure	$130,000
Weapons Seizure Value - Increase of 15 Seizures/Year at $1,000/Seizu	$15,000
Pre ARMOR Cost per Year for 4 Teams at Overtime Rate	$8,085,042
Post ARMOR Cost per Year for 2 Teams at Overtime Rate	$4,042,521
Percent Overtime	25%
Annual Benefits	***$3,176,891***
Ten Year Benefits (2008 to 2017)	***$31,768,908***
Net Benefits (2017 Dollars)	**$30,712,448**

6. Benefit-Cost Analysis – Base Case

Table 18 shows that the total annual net present value (NPV) of benefits in 2017 dollars is about $3.2 million and the NPV of using ARMOR for ten years is about $31.8 million. The savings in staff costs represent the major portion of these benefits. Including past investment, upgrades and maintenance costs (inflated to 2017 dollars), the NPV is $30.7 million for 10 years of use. The benefit-to-cost ratio is 33.9 and the return on investment is 3,274%.

7. Sensitivity and Uncertainty Analysis

Break-Even Analysis. To recoup the $1 million cost of developing and implementing ARMOR, it would be sufficient to eliminate one of the four original checkpoint teams for about 9 months. At the overtime rate, this would be reduced to 6 months.

Tornado Analysis. The cost estimates for ARMOR are quite certain and were not subjected to a sensitivity or uncertainty analysis. However, several of the variables in the benefits calculations are uncertain. Table 19 shows the ranges of the variables used in the sensitivity analysis.

There was some uncertainty about the number of years that ARMOR has been implemented. This is partly due to the lack of precise data on when ARMOR was first used and to a short gap in the use of ARMOR between the end of USC/CREATE support and the major revision that AVATA implemented in 2014. Another key uncertainty is the amount of overtime required to staff the checkpoints. Los Angeles Airport Police staff told us that overtime is an essential part of their officers' pay, representing about 25% of their salaries.[8] However, to assure that we covered a wide range of overtime pay, we used a minimum of 0% overtime pay and a maximum of 50%.

Table 19: Base Case and Ranges for Sensitivity Analysis

Variable	Min	Base	Max
Years of ARMOR Operations	8	10	10
Percent OT	0%	25%	50%
Value/ Drug Seizure	$1,000	$5,000	$10,000
Value/Gun Seizure	$100	$1,000	$5,000

Figure 5 shows a tornado diagram, which illustrates how the changes in each uncertain variable (from low to high values) impact on the net present value. The percent overtime before and after implementation of ARMOR had a major impact, as has the number of years of ARMOR implementation. By comparison, the valuation of drug and weapons seizures have a relatively small impact.

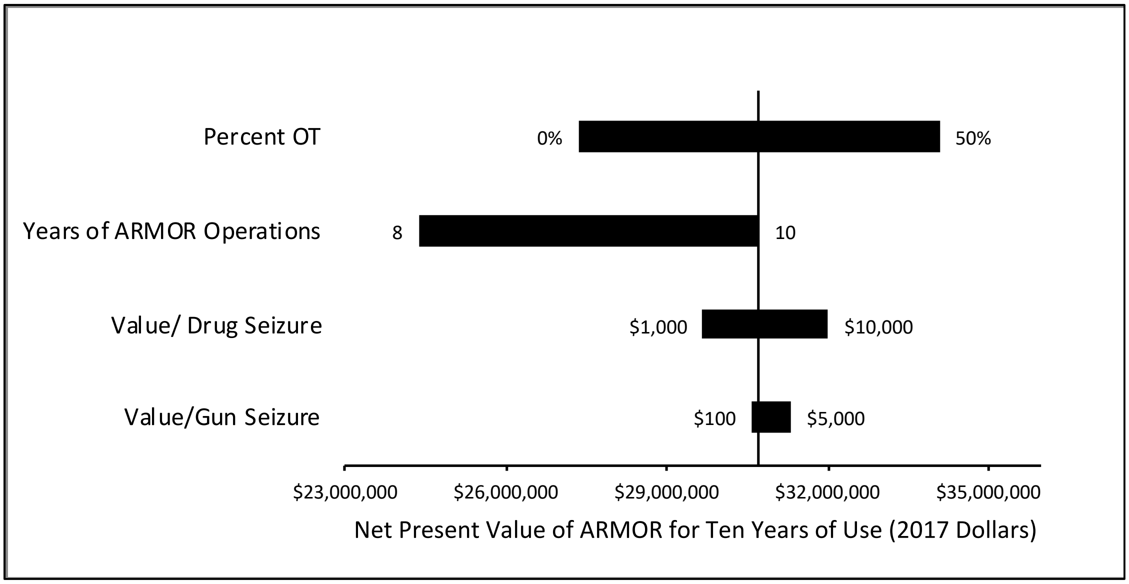


Figure 5: Net Present Value of ARMOR - Tornado Diagram

Uncertainty Analysis. In addition, we conducted a probabilistic simulation, in which we assigned probability distributions to each of the four uncertain variables. For simplicity, we used triangular distributions with a minimum at the low end of the range in Table 19, the mode at the base case, and the maximum at the high end. We then ran 10,000 simulations resulting in a distribution of net benefits as shown in Figure 6. Table 20 shows the key statistics of this distribution. In particular, the 5th, 50th, and 95th percentile are \$25.4 million, \$29.0 million, and \$32.2 million.

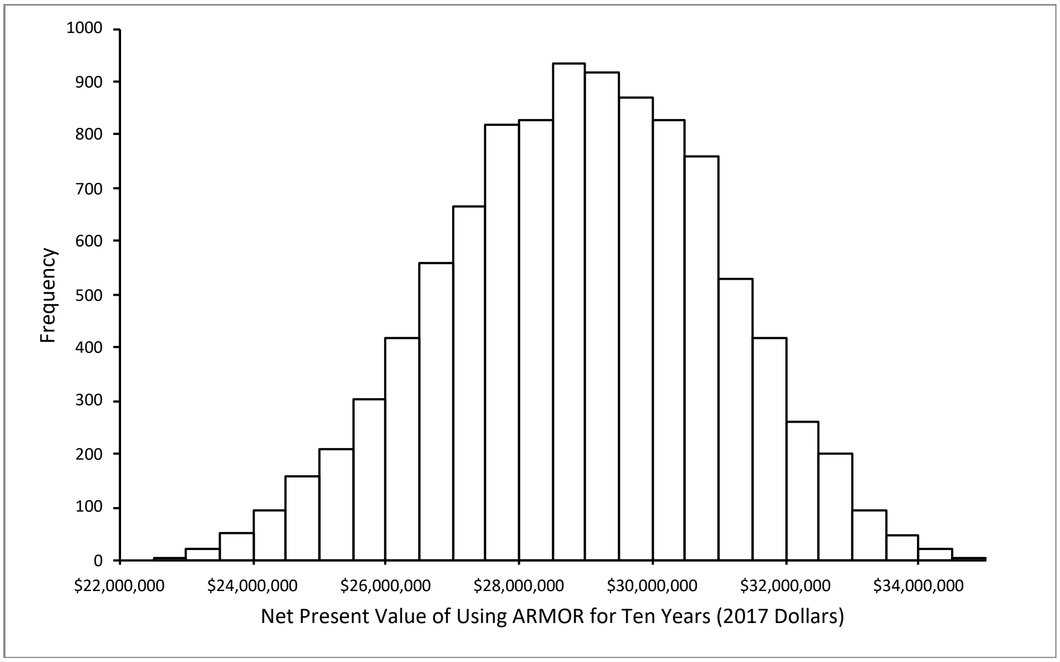


Figure 6: Net Present Value Distribution of ARMOR

Table 20: Statistics of the Net Benefits Distribution

Mean	$28,918,518
St. Dev.	$2,047,151
5th Percentile	$25,427,981
25th Percentile	$27,516,735
Median	$28,969,043
75th Percentile	$30,384,880
95th Percentile	$32,229,218

8. Assumptions and Limitations

A critical assumption was that the reduction of the checkpoint teams from four to two did not reduce the protective value. This was based on the calculation of the expected value of the protective value with and without ARMOR. Important inputs to these calculations are the values assigned by the Los Angeles Airport Police to the possible targets at LAX. For security reasons we cannot provide these values in this report, but we were assured that these values varied greatly between times and locations.[10] Had these values been the same, ARMOR would not have been able to increase the protective value over a simple randomization procedure.

The improvement of captures of drugs and guns was also uncertain. While there was a demonstrable increase in capture after ARMOR was implemented, we cannot attribute this increase to the use of ARMOR alone. However, as stated in the benefits analysis, the capture of drugs and guns contributed very little to the overall benefits, compared to the savings in staff costs.

The percent of overtime was also an important variable. We did not receive specific data on the percent of overtime, but we were told that overtime represents around 25% of salaries.[11] However, even without considering overtime pay, the benefits of ARMOR were substantial.

9. Recommendations for Additional Research

It would be valuable to continue to collect data on captures of drugs and guns to determine the trend over time after ARMOR. More importantly, additional evidence of the protective value is needed. For example, evidence of suspicious activities at the terminals at LAX could firm up the judgments by Los Angeles Airport police officers about the value of protecting one terminal vs. another. The percent of overtime pay could also be narrowed down by obtaining additional data from the Los Angeles Airport Police Department.

10. References

1. Paruchuri, P. et al. (2008). Efficient Algorithms to Solve Bayesian Stackelberg Games for Security Applications. *Proceedings of the Conference for the Advancement of Artificial Intelligence*, pp.1559-1562.
1. Tambe, M. (March, 2017). Personal communication regarding the development and deployment of ARMOR.
2. Jain, M., Tsai, J., Pita, J., Kiekintveld, C, Rathi, S., Ordonez, F., and Tambe, M. (2012). Software assistants for randomized patrol planning for the LAX Aiorpoprt Police and the Federal Air Marshals Service. *Interfaces: Operations Research Management Science*, 52, 1, 133.
3. Jain, M. (May and June, 2017). Personal communication regarding the implementation of ARMOR at LAX and the upgrades and annual maintenance costs of AVATA.
4. Jain, M. et al., ibid.
5. Bissell, P and Southers, E. (March, 2017). Personal communication providing cost and benefits estimates for ARMOR.
6. CREATE cost data and Jain, M., personal communication (March, 2017).
7. Bissell, P. and Southers, E. (March, 2017). Ibid.
8. Ibid.
9. Jain, M. (May, 2018). Personal communication.
10. Ibid.
11. Bissel, P. and Southers, E. Ibid.

Benefit-Cost Analysis of the CGSARVA Tool
(Coast Guard Search and Rescue Visual Analytics)

Developer: Visual Analytics for Command, Control in Interoperability Environments (VACCINE)
Analyst: Scott Farrow (UMBC/CREATE)

May 31, 2018

1. Summary

Description of the CGSARVA Tool. The Visual Analytics for Command, Control and Interoperability Environments (VACCINE) developed a computerized support tool to analyze Search and Rescue (SAR) cases and Coast Guard (CG) sorties. The CGSARVA (Coast Guard Search and Rescue Visual Analytics) tool evaluates the change in risk from a policy such as closing or rebuilding small boat stations, which changes the availability of rescue assets such as boats and personnel. Risk is primarily measured by response time and exceedances of the Coast Guard SAR target of taking less than 2 hours to be on the accident scene.[1] Additional metrics such as the CG cost for sorties can be included.[2] The tool was used to assess the impact on risk from reallocation of vessels or stations throughout the United States,[3], on the Great Lakes, or following Hurricanes Irene and Sandy.[4]CGSARVA remains in use today by the CG to inform ad-hoc resource allocation questions,[5] and further development is occurring for use in Hawaii.[6]

Results. CGSARVA potentially generates benefits and costs each time it is applied. This analysis focuses on one important historical use that helped prioritize CG rebuilding following Hurricane Sandy on the East Coast. A second historical use was its application as part of a nationwide study for potential future CG station closings. The benefits of using CGSARVA following Hurricane Sandy are suggested by information from the CG that CGSARVA helped maintain the baseline of SAR on-scene arrival times during a protracted time to rebuild stations damaged from the hurricane. The cost savings are estimated compared to a present value baseline cost of $159.9 million appropriated by Congress[7] that could also have maintained the baseline of SAR on-scene arrivals by immediate rebuilding. The estimated present value cost of CGSARVA is $ 0.8 million in 2017 dollars, which includes the cost of research and transition efforts at VACCINE, university overhead, and oversight cost by the Office of University Programs (OUP). Information was not provided on the cost of CG implementation.

As risks would be held constant by either immediate rebuilding--the baseline counter-factual--or the actual protracted rebuilding informed by CGSARVA, the change in net present value stems solely from a change in the present value of cost. A delay in construction of 2.5 years (30 months) with a 3 percent discount rate--the base case scenario-- yields a net present value of $5.2 million and a 652 percent rate of return. A 3-month delay in construction is sufficient to break-even, which just recoups the CGSARVA investment. Uncertainty analysis, using simulation, resulted in a mean net cost savings of $5.8 million with a 5th percentile of $0.6 million and a 95th percentile of $13.2 million.

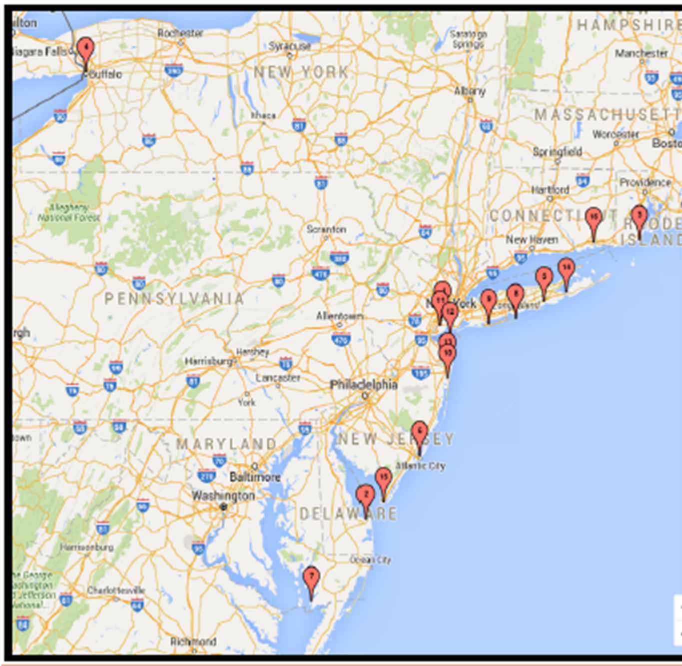
CGSARVA was also used in a planning exercise, which may generate net benefits in the future but has not generated benefits to date. Evidence and analysis from GAO suggests that CGSARVA was a key input identifying a potential for $269 million in present value savings from reducing SAR overlap and duplication in CG boat stations. Achieving such cost savings would require closing down stations and releasing those resources for other uses which has not occurred to date. What fraction of this potential value is allocable to CGSARVA is not known but would likely be a substantial amount, likely dominating the cost savings attributed to its use following Hurricane Sandy. The present value benefits reported in this case study omit the potentially large benefits based on the GAO review from the base closing study.

2. Background

Problem Context. The quantification of cost-saving from the application of CGSARVA to CG decisions following Hurricane Sandy is suggested by the following quote from Kevin Hanson, leader of an analytic team for the verification and validation of the tool for CG use:

> "The CGSARVA model formulation proved to be tremendously insightful for the Coast Guard as it began to prioritize the repair of its stations," (*following Hurricane Sandy*) says Commander Kevin Hanson, analysis team leader." [8]

This quotation suggests that value was created following Hurricane Sandy by prioritizing reconstruction and while maintaining SAR response goals. In contrast, use of CGSARVA as part of a nationwide analysis for potentially closing CG stations nationwide identified stations that are deemed unnecessary or duplicative to maintain SAR response goals.[9] The policy alternative following Hurricane Sandy is the order of reinvesting; the policy alternative for the nationwide analysis is which stations to keep open or to close even when not damaged. Figure 7, below, from Braxton[10] identifies the East Coast stations at which re-investment occurred.



#	Location	Award $
1	ANT NY, NJ	$3.1M
2	MSD Lewes, DE	$2.2M
3	STA Pt. Judith, RI	$5M
4	Sector Buffalo, NY	$8.8M
5	SFO Moriches, NY	$.125M
6	STA Atlantic City, NJ	$11.3M
7	STA Crisfield, MD	$2.5M
8	STA Fire Island, NY	$3M
9	STA Jones Beach, NY	$6.1M
10	STA Manasquan, NJ	$13.7M
11	STA New York, NY	$18.8M
12	STA Sandy Hook, NJ	$45M
13	STA Shark River, NJ	$2M
14	STA Shinnecock, NY	$11M
15	TRACEN Cape May, NJ	$8.3M
16	USCGA, CT	$18M
16	STA New London, CT	$1M

Figure 7: CG Reinvestment following Hurricane Sandy[11]

The CGSARVA Tool. VACCINE developed several desktop tools for the visual display of event data for the CG and others such as local police. CGSARVA focused on resource allocation issues related to small boat stations as stated in briefing documents to provide “Metrics for station demand, capability, and risk under current and hypothetical siting plans (e.g., pre- & post-closure values for risk & utility).” The tool integrates historical data on assistance calls to the CG with geographical information about stations and search and rescue assets while providing several risk and cost metrics. One use of CGSARVA allows the user to “shut down” stations and hence their SAR response capability and then to reallocate SAR responses to alternative stations and assets. Users can then explore how to maintain a risk response capability when a station is shut down either for rebuilding or for other purposes.

3. Baseline Performance without the CGSARVA Tool

Defining the baseline alternative for rebuilding following Hurricane Sandy is complex. The definition can be made clearer by comparing it to a baseline analysis for the nationwide study. GAO[1] reviewed the CG plan to potentially close stations which uses a baseline of the stations and assets currently operating along with a target SAR response time standard. That baseline is compared to an alternative that identified duplicative and unnecessary stations which if closed would still allow the CG to maintain its SAR response time. Closing the identified stations can generate present value cost savings from recurring and non-recurring costs avoided. Figure 8 below from GAO[11] shows the nation-wide overlap of SAR capability with excess capacity especially noteworthy in the Northeast and the Great Lakes.

In contrast, the baseline "status quo" following the sudden damage from Hurricane Sandy is less clear. One baseline might have been to leave the stations damaged or to close them, consistent with the nationwide analysis. However, Congress quickly made a decision to reinvest in the damaged stations. An alternative baseline that takes into account rebuilding might evaluate the change in risk and cost from a hypothetical baseline of what the CG might have done without the use of CGSARVA[i]. However, analysis of SAR responses in the Great Lakes[14] and CG stations nationwide[15] indicate that duplicative resources exist with the potential to maintain SAR mission goals of arriving on-scene within 120 minutes of notification[16] (90 minutes of departure) even with some stations shut or damaged. Consequently, an analysis that holds risks constant while only assessing costs is consistent with the objectives of the CG[17,] A counter-factual baseline that rebuilds all stations immediately, holds risk constant with the funding available from Congress. An immediate rebuilding plan may not have been exactly feasible but any other ad-hoc counter-factual plan may introduce changes in risk as well as present value cost. Consequently, the

[i] A first step in such a benefit analysis would be what the CG considers the change in a hazard function from longer times to on-scene arrival. The only publicly available information is the bright line mission objective to be on-scene within 90 minutes of departure (120 minutes of notification) which is not sufficient for a benefits analysis. Use of the CG's internal Probability of Survival Decision Aid (PSDA) estimator could possibly be used but was not available.

(counter-factual) baseline used here assumes immediate reinvestment using the entire congressionally allocated funds of $160 million[18] while maintaining the SAR risk response standard.

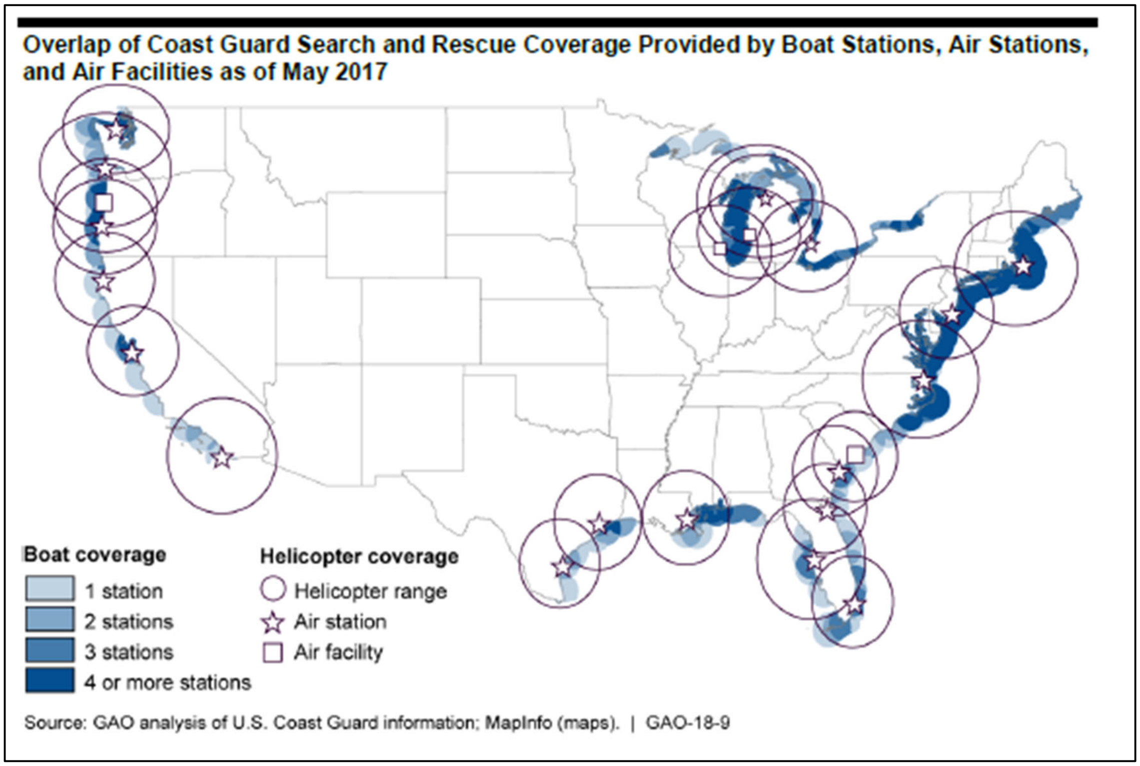


Figure 8: Coast Guard Station SAR Coverage

4. Cost of the CGSARVA Tool

The development and transition cost for CGSARVA is mainly but not entirely known. Costs are recorded and reported for VACCINE, some of which costs were part of a multi-project budget with a portion here allocated to CGSARVA[19], and with additional overhead costs allocated to DHS as consistently applied for this (Landscape) project. However, the CG costs to learn and apply CGSARVA are not available in general and for Hurricane Sandy in particular. The available cost information is reported in Table 21 where nominal (as spent) dollars are adjusted to present value 2017 dollars using the CPI index and assuming a zero real discount rate as discussed elsewhere. COE stands for the Center of Excellence that carried out the work and OUP stands for Office of University Programs, which funded the project.

Table 21: Development Cost of the CGSARVA Tool

Cost Category	Start	Cost (2017 $)	Source
Pre-project costs (COE)			
Pre-project costs (other funding)			
Project costs (COE)	2009	$ 99,740	VACCINE/OUP
Project costs (university cost share)			
Oversight cost at the COE		$ 112,140	VACCINE/OUP
Oversight cost at OUP		$ 130,000	OUP
Transition development cost			
Implementation start up cost	2010-2014	$ 460,960	VACCINE/OUP
Implementation cost (User)			
Implementation cost (COE)			
Implementation cost (Other users)			
Total Cost, 2017 dollars		$ 802,840	

5. Benefit of the CGSARVA Tool

The benefits of CGSARVA are slightly different in the station closing case reviewed by the GAO, and the reinvesting case following Hurricane Sandy. However, central to both analyses is that SAR risks are held constant in the baseline and the policy case because the CG response-time goal is achieved in both cases. While being "constant" is an approximation (for instance risks may be reduced if a CG boat is on-scene in 30 minutes instead of 45 minutes even though both meet the CG goal), it seems a reasonable to hold risks constant. When risks are constant, changes in present value between the baseline and the policy case result from changes in the present value of costs as evident in accounting or business textbooks and government guidance[20].

In the case of closing stations, cost savings (and hence the benefits) are based on reductions in recurring and non-recurring costs after resources have been re-allocated to achieve the SAR response-time standard21. This type of cost savings, which takes place over a span of years, is a clear reduction in the social cost (and CG expenditures) to achieve an objective. The present value cost savings (benefits) of station closure are estimated by the CG and GAO to be $269 million. Potential benefits from selling property are not included in the estimated present value.

The cost savings in the second case of re-investing following Hurricane Sandy depend entirely on the timing of the expenditures. The basic present value equation or discussion as presented in texts, Government guidance[22], regulatory proposals[23], and the professional literature[24] indicate that delaying expenditures reduces the present value cost of a given amount of funding. Consequently, to the extent that CGSARVA informed prioritization that held SAR risk constant but allowed expenditures to be delayed, the benefits are the present value cost savings between immediate and delayed expenditures.

The baseline assumes a present value cost equal to congressionally appropriated funds of $160 million as if expended immediately. Re-investment at the most expensive site, Sandy Hook, was anticipated to potentially continue from 2014 to 2019. The present value cost saving from delay is then a benefit and, in the Hurricane Sandy case, was attributed to the use of CGSARVA. Information necessary for the benefit analysis is the cost of rebuilding and the present value parameters of the discount rate and duration of the delayed construction.

Data are available on the congressionally allocated funding to the CG to rebuild and repair its stations following Hurricane Sandy. Similar data has not been found for Hurricane Irene or other decisions where CGSARVA was used, so that the cost-savings here may represent the largest but not the only benefits from using CGSARVA. The cost of rebuilding from Hurricane Sandy is based on supplemental disaster appropriations from Congress.[25,26] The CG provided a breakdown of those rebuilding costs in Braxton[27], with total costs of $159,925,000; sometimes rounded up to $160 million.

Benefits from the present value of cost savings are based on assumptions about the length of construction delay supported by the use of CGSARVA. The time delay to rebuild is not precisely known. The delayed construction path is assumed to spread the budgeted (nominal) cost of rebuilding evenly across the total time period, measured in months. For instance, a 36-month delay to complete rebuilding will assume that 1/36 of the rebuilding cost occurs each month. Combinations of time of delay and interest rates are then analyzed for differing amounts of cost savings and rates of return[ii].

Present value calculations are central to defining the benefits from delayed construction. Those calculations are importantly affected by interest (discount) rate and by the length of time. Neither are known exactly in this situation. As a lower bound, if discounting is not applied (a 0 percent rate of discount), then there are no cost saving benefits from delayed construction.

It is not known how many months of delayed construction CGSARVA facilitated by informing ways to maintain SAR efficiency. The Coast Guard[28] signed a memorandum of agreement regarding one station, Sandy Hook, putting a maximum time frame of five years from that date. In this analysis, the range of months of delay will be investigated from 0 to 60 (5 years) with a base case of 30 months (2.5 years), the mid-point of that range. If there is no delay (0 months), then there are no benefits from the use of CGSARVA.

The structure of the model and base case calculations are presented in Table 22 below. The present value of the benefit is $6,035,189.

[ii] Present value cost savings are numerically defined as PV(rebuild at once) - PV(rebuild over T months at interest rate r). The second term is computed as the PV of an annuity based on equal monthly payments of PV(rebuild at once)/T over T time periods using interest rate r.

Table 22: Estimated Base Case Benefits and NPV for Hurricane Sandy

PV cost of rebuilding from Sandy	$ 159,925,000
Number of months to rebuild (base 30)	30
Discount rate	3.0%
PV for 2017 of past project cost	$ 802,840
PV cost if rebuild immediately (PV Cost)	$ 159,925,000
PV if rebuild over months above given discount rate	($153,889,811)
Present Value of Benefits w/o Project Cost	$ 6,035,189
Net Present Value (after project cost)	$ 5,232,349
Rate of return--months above	652%
Break-even time, months	3

6. Benefit-Cost Analysis – Base Case

Given the base-case inputs and the present value (in 2017) of the costs and benefits from Tables 21 and 22, the net present value (NPV) of using CGSARVA following Hurricane Sandy is $5,232,349. This results in a base case return on investment (ROI) of 652 percent. These results can also be seen at the bottom of Table 22.

The base case in the nation-wide analysis of boat stations identifies $269 million net present value savings from closing CG boat stations with duplicative or overlapping SAR capability based on CG internal analyses. CGSARVA is highlighted[29] as one of the critical components of the sound process used by the CG to identify stations for closing, while recognizing that not all the cost savings may actually be realized, due to competing criteria for keeping bases open or in partial operation. Information is not available to conduct a sensitivity analysis of the reported net present value from potential station closings.

7. Sensitivity and Uncertainty Analysis

Breakeven analysis: The break-even outcome for the Hurricane Sandy application, defined as the delay time to break-even with the cost of CGSARVA, varies with the discount rate. At the base case of 3 percent rate of discount, the break-even delay time is 3 months; CGSARVA would have just paid for itself if it maintained SAR efficiency while spreading out construction for that amount of time.

Tornado and Sensitivity Analysis: Sensitivity analysis and later simulation are driven by assumptions for uncertain variables. Section 3 provided the reasoning on the uncertainty distributions for the discount rate and months of delay. The costs of developing and transitioning CGSARVA are relatively well-known, as are the appropriated costs for reinvesting in CG stations, although costs 10 percent larger and smaller than those used in the base case are investigated for their effects on the outcome. Table 23, below, summarizes the parameter values for these variables, noting that later simulation adds the assumption of a triangular distribution using the values below for the discount rate and the months of delay.

Table 23: Ranges of CGSARVA Inputs for Sensitivity Analysis

Parameter	Low	Base	High
Rebuild cost	$ 143,932,500	$ 159,925,000	$ 175,917,500
Months Delay	0	30	60
Discount Rate %	0	3	7
Project Cost	$ 722,556	$ 802,840	$ 883,124

The key determinants of the NPV are investigated using a structured sensitivity approach, employing the values in Table 23. Figure 9 presents these results as a "Tornado" diagram with the width of the bars representing the impact on the cost savings. Given these ranges of uncertainty, both the effective time of delay and the discount rate are seen to be key determinants of the cost savings. If the months of delay are increased from the base case, then the effect is always positive. If the discount rate goes as low as zero, then the net cost savings are negative; the cost of CGSARVA.

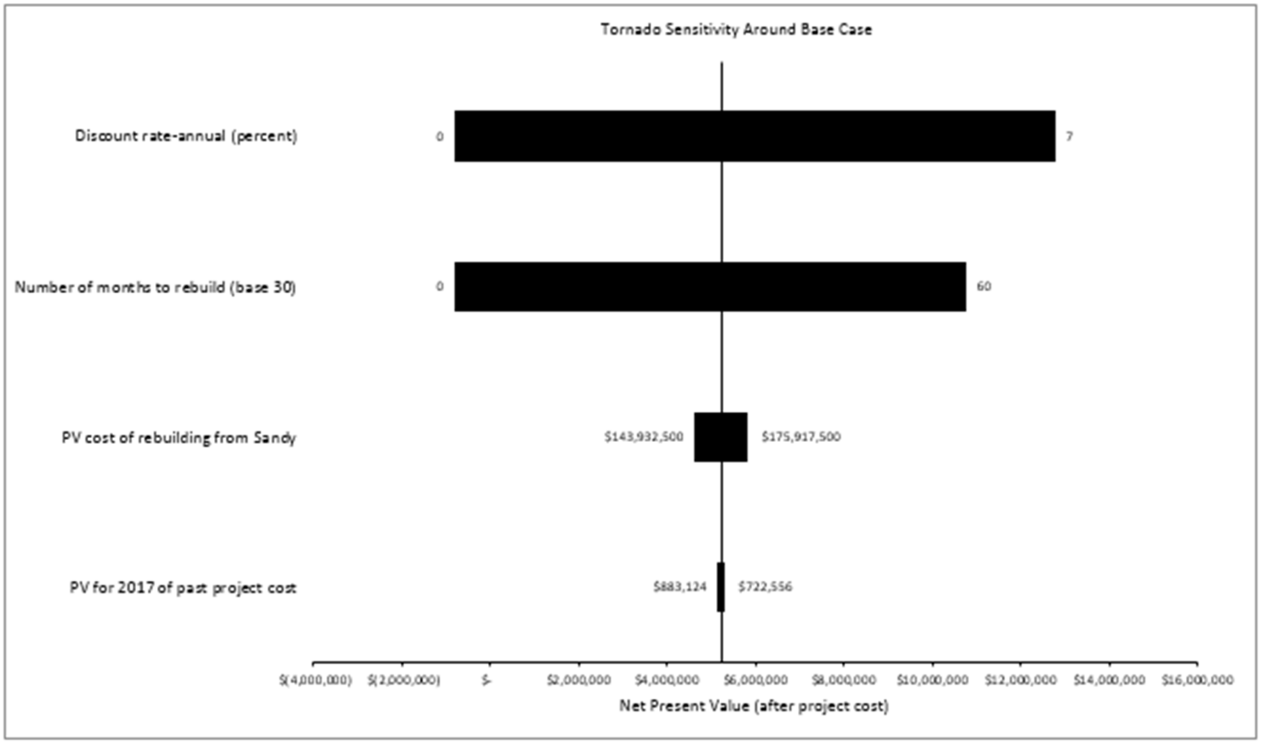


Figure 9: Tornado Diagram: CGSARVA

Sensitivity results are investigated in more detail in Table 24, which varies both the discount rate and the months of delay simultaneously while holding the rebuilding cost and the cost of CGSARVA constant. The break-even rate can be seen at the boundary of the red (in parentheses) and black values; around 6 months and less than 2 percent interest rate (or 12 months and a 1 percent rate). The dollar and percentage returns get very large, as either the time of delay expands or the interest rate is higher.

Table 24: Dollar and Percent Rate of Return for Time of Delay and Annual Discount Rates

NPV after project cost: 2 way table with months and discount rate											
$ 5,232,349	3	6	12	18	24	30	36	42	48	54	60
0	($802,840)	($802,840)	($802,840)	($802,840)	($802,840)	($802,840)	($802,840)	($802,840)	($802,840)	($802,840)	($802,840)
1%	($536,668)	($337,427)	$60,062	$456,230	$851,081	$1,244,622	$1,636,856	$2,027,788	$2,417,424	$2,805,768	$3,192,825
2%	($271,234)	$125,925	$916,289	$1,701,415	$2,481,342	$3,256,107	$4,025,751	$4,790,310	$5,549,823	$6,304,328	$7,053,860
3%	($6,534)	$587,227	$1,765,904	$2,932,897	$4,088,336	$5,232,349	$6,365,065	$7,486,608	$8,597,103	$9,696,673	$10,785,438
4%	$257,433	$1,046,490	$2,608,968	$4,150,853	$5,672,451	$7,174,063	$8,655,984	$10,118,506	$11,561,915	$12,986,493	$14,392,517
5%	$520,671	$1,503,727	$3,445,541	$5,355,458	$7,234,068	$9,081,949	$10,899,666	$12,687,776	$14,446,822	$16,177,338	$17,879,848
6%	$783,182	$1,958,947	$4,275,684	$6,546,886	$8,773,561	$10,956,691	$13,097,236	$15,196,134	$17,254,299	$19,272,626	$21,251,988
7%	$1,044,969	$2,412,163	$5,099,457	$7,725,307	$10,291,295	$12,798,958	$15,249,790	$17,645,245	$19,986,739	$22,275,646	$24,513,305
NPV rate of return: 2 way table with months and discount rate											
	Months										
652%	3	6	12	18	24	30	36	42	48	54	60
0%	-100%	-100%	-100%	-100%	-100%	-100%	-100%	-100%	-100%	-100%	-100%
1%	-67%	-42%	7%	57%	106%	155%	204%	253%	301%	349%	398%
2%	-34%	16%	114%	212%	309%	406%	501%	597%	691%	785%	879%
3%	-1%	73%	220%	365%	509%	652%	793%	933%	1071%	1208%	1343%
4%	32%	130%	325%	517%	707%	894%	1078%	1260%	1440%	1618%	1793%
5%	65%	187%	429%	667%	901%	1131%	1358%	1580%	1799%	2015%	2227%
6%	98%	244%	533%	815%	1093%	1365%	1631%	1893%	2149%	2401%	2647%
7%	130%	300%	635%	962%	1282%	1594%	1899%	2198%	2490%	2775%	3053%

Uncertainty Analysis. To further explore the uncertainties of some of the input variables, we assumed that these uncertainties can be characterized by triangular distributions, with a minimum being the low value in Table 23, the mode being the base case value, and the maximum being the high value. We used an Excel add-in, SimVOI31 to simulate the NPV, using these triangular distributions to characterize uncertainty in the input variables. The analysis assumes that all input variables are independent and thus uncorrelated with each other and is run for 10,000 iterations.

Table 25 presents results of the simulation for the NPV, while Figure 10 charts a more detailed histogram of those results. The mean, median, 5% and 95th percent NPV values are $5.8 million, $5.2 million, $0.6 million and $13.2 million respectively. Referring to Table 24, the mean dollar return could result from a number of different combinations of discount rate and timer periods. With a 3% discount rate, the period of reconstruction (delay) would be somewhat less than 3 years to return the mean rate; with a 7% discount rate, the reconstruction period would be somewhat over 1 year.

Table 25: Statistics of the CGSARVA NPV Distribution

Mean	$ 5,818,613
St. Dev.	$ 3,916,925
5th Percentile	$ 570,179
25th Percentile	$ 2,819,999
Median	$ 5,247,324
75th Percentile	$ 8,194,111
95th Percentile	$ 13,170,054

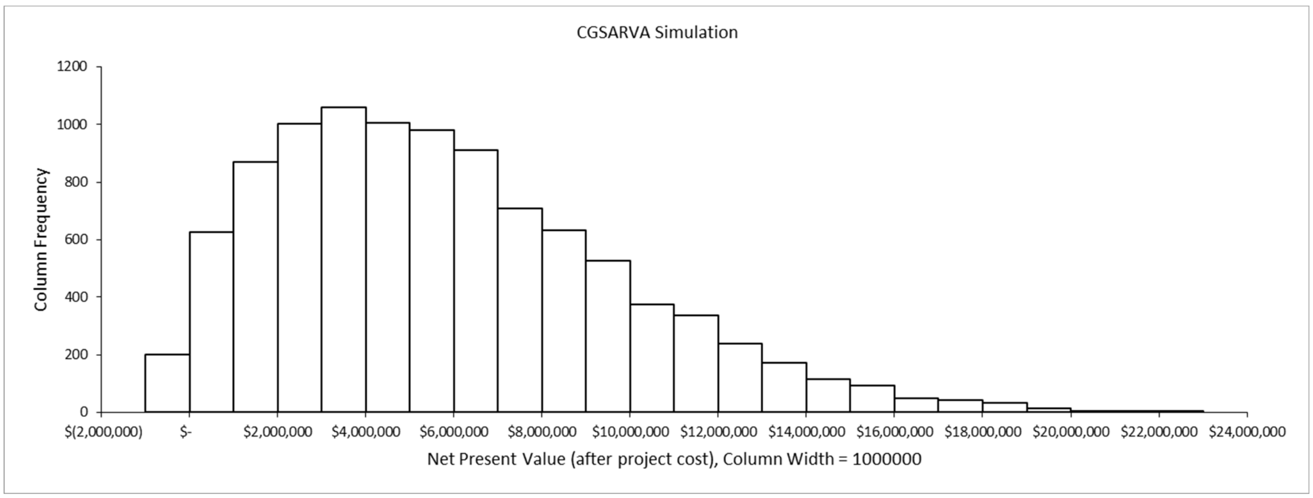


Figure 10: Simulation Results for the Present Value Net Cost Savings, in dollars[32]

8. Assumptions and Limitations

Support exists for the base case parameters and distributions of the several costs, discount rate, and duration of delay used in the Hurricane Sandy analysis, even if each is not known exactly. Of these assumptions, the most uncertainty is associated with the duration of delay. This uncertainty is in part driven by the inferential nature of the model; what might seem to be a risk problem constrained by costs, is instead investigated with its dual cost minimization constrained by achieving a target level of risk[33]. That risk target is explicitly recognized in planning documents. Second, actual implementation of congressionally directed reinvestment occurred with the support of CGSARVA. No documentation of a counter-factual alternative is available without the use of CGSARVA. In its place, the analysis uses a hypothetical rebuilding at time zero, which would also maintain the targeted risk level. The benefits stem from construction delays from an unknown time zero to a later time, with consequently lower present value costs, while holding SAR risks constant through the application of CGSARVA. This analysis allocates all the cost savings from delay to the use of CGSARVA, which may overstate the benefits. Other applications of CGSARVA are known to exist but lack the documentation available for Hurricane Sandy. Consequently, the value of CGSARVA for planning uses following other damaging storms such as Hurricane Irene or other applications is ignored. Finding other quantifiable cases of returns from using CGSARVA may increase the aggregate NPV that is here based solely actions following Hurricane Sandy.

Regarding the potential cost savings from station closings informed by CGSARVA analyses, the GAO[34] does not break down the contribution to the present value savings from different parts of the process. Nor is information provided that allows exploration of sensitivity or uncertainty. The contribution of CGSARVA to the cost-saving process is clearly significant, but bundled in a complex way with the entire potential station closing process used by the CG. Consequently, the analysis here focuses on the NPV from Hurricane Sandy. The analysis does, however, note that CGSARVA is also a central input into a potential base-closing process, which may yet generate substantial present value cost savings, although the exact value due to the use of CGSARVA is not known.

9. Recommendation for Additional Research

An improved evaluation of the NPV from the use of CGSARVA (all of which may add substantial time and cost to the analysis) could benefit from:

1. Estimates of the CG cost of implementation of CGSARVA,
2. Enumeration and evaluation of other applications of CGSARVA,
3. A method to allocate partial "credit" to different components of a concurrent process, as particularly occurred with the station closing analysis,
4. Improved documentation of the process that the CG would use if CGSARVA is not available,
5. Consideration of a "risks avoided" approach to net benefits, which would involve public or CG use of a SAR hazard function and SAR data, such as that which informs the CGSARVA tools.

10. References

1. USCG (2017). SAR (Search and Rescue) Program Information. Available at https://www.uscg.mil/hq/cg5/cg534/SAR_Program_Info.asp .
2. Ebert, David (2017). Purdue. Principal Investigator. Personal communication and training in CGSARVA from VACCINE personnel.
3. US GAO (2017). COAST GUARD: Actions Needed to Close Stations Identified as Overlapping and Unnecessarily Duplicative. GAO-18-9. Available at https://www.gao.gov/products/GAO-18-9 .
4. Purdue, Purdue Today (April 22, 2013). Coast Guard Accredits System. Available at https://www.purdue.edu/newsroom/releases/2013/Q2/u.s.-coast-guard-accredits-analytical-system-developed-at-purdue.html.
5. Baxa, Philip (2017). USCG. Personal communication.
6. Ebert, David (2017) Purdue. Principal Investigator. Personal communication.
7. Braxton, Mark, USCG, U.S. Coast Guard (USCG) Superstorm SANDY. Resiliency Reconstruction, presented at the Maritime Risk Symposium, November, 2016. http://coastalresiliencecenter.unc.edu/wp-content/uploads/2016/11/Braxton-MRS-Slides-web.pdf
8. Purdue, Purdue Today (April 22, 2013). Coast Guard Accredits System. Available at https://www.purdue.edu/newsroom/releases/2013/Q2/u.s.-coast-guard-accredits-analytical-system-developed-at-purdue.html.
9. US GAO (2017). COAST GUARD: Actions Needed to Close Stations Identified as Overlapping and Unnecessarily Duplicative. GAO-18-9. Available at https://www.gao.gov/products/GAO-18-9.
10. Braxton, Mark, USCG, U.S. Coast Guard (USCG) Superstorm SANDY. Resiliency Reconstruction, presented at the Maritime Risk Symposium, November, 2016. http://coastalresiliencecenter.unc.edu/wp-content/uploads/2016/11/Braxton-MRS-Slides-web.pdf
11. Ibid.
12. US GAO (2017). COAST GUARD: Actions Needed to Close Stations Identified as Overlapping and Unnecessarily Duplicative. GAO-18-9. Available at https://www.gao.gov/products/GAO-18-9.
13. Ibid.
14. Malik, A., R. Maciejewski, B. Maule and D. S. Ebert (2011), "A Visual Analytics Process for Maritime Resource Allocation and Risk Assessment," IEEE XPLORE. Available at https://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?punumber=6093899.
15. US GAO (2017). COAST GUARD: Actions Needed to Close Stations Identified as Overlapping and Unnecessarily Duplicative. GAO-18-9. Available at https://www.gao.gov/products/GAO-18-9 .
16. USCG (2017). SAR (Search and Rescue) Program Information. Available at https://www.uscg.mil/hq/cg5/cg534/SAR_Program_Info.asp.
17. Wainright, K. and A. Chiang (2005). *Fundamental Methods of Mathematical Economics*. McGraw-Hill Education, Columbus, Ohio.
18. Braxton, Mark, USCG, U.S. Coast Guard (USCG) Superstorm SANDY. Resiliency Reconstruction, presented at the Maritime Risk Symposium, November, 2016.

http://coastalresiliencecenter.unc.edu/wp-content/uploads/2016/11/Braxton-MRS-Slides-web.pdf
19. Ebert, David (2017) Purdue. Principal Investigator. Personal communication.
20. US EPA (2010, 2014). Guidelines for Preparing Economic Analysis. National Center for Environmental Economics. Available at https://www.epa.gov/environmentaleconomics/guidelines-preparing-economic-analyses .
21. US GAO (2017). COAST GUARD: Actions Needed to Close Stations Identified as Overlapping and Unnecessarily Duplicative. GAO-18-9. Available at https://www.gao.gov/products/GAO-18-9.
22. Office of Management and Budget (OMB), (1992). "Guidelines and Discount Rates for the Benefit-Cost Analysis of Federal Programs", OMB Circular A-94, including Appendix C updated annually and OMB, 2003. "Regulatory Analysis" OMB Circular A-4, Washington, D.C.
23. CMS (Centers for Medicare and Medicaid), (2006). Medicare and Medicaid Programs; Fire Safety Requirements for Long Term Care Facilities, Automatic Sprinkler Systems. Federal Register, October 27, 71(208):62957-62971.
24. Farrow, S., (1987). Lease Delay Rights: Market Valued Permits and Offshore Leasing, *Resources Policy*, June, 1987. p. 113-122.
25. Braxton, Mark, USCG, U.S. Coast Guard (USCG) Superstorm SANDY. Resiliency Reconstruction, presented at the Maritime Risk Symposium, November, 2016. http://coastalresiliencecenter.unc.edu/wp-content/uploads/2016/11/Braxton-MRS-Slides-web.pdf
26. Public Law 113-2 (2014). An Act Making Supplemental Appropriations for the Fiscal Year Ending September 30, 2013, To Improve and Streamline Disaster Assistance for Hurricane Sandy, and for Other Purposes.
27. Ibid.
28. USCG (2014). U.S. Coast Guard and New Jersey Memorandum of Agreement Regarding Sandy Hook. Dated July 20 through July 22, 2014.
29. Ibid.
30. TreePlan (2017). SensIt and SimVOI software. Available at www.treeplan.com
31. Ibid.
32. Ibid.
33. Wainright, K. and A. Chiang (2005). Fundamental Methods of Mathematical Economics. McGraw-Hill Education, Columbus, Ohio.
34. US GAO (2017). COAST GUARD: Actions Needed to Close Stations Identified as Overlapping and Unnecessarily Duplicative. GAO-18-9. Available at https://www.gao.gov/products/GAO-18-9 .

APPENDIX B

Benefit-Cost Analyses of TTKPs with Potential Future Applications

Table of Contents

Benefit-Cost Analysis of the Advanced CIRCulation (ADCRIC) Storm Surge Model

Developer: Rick Luettich, Coastal Resilience Center (CRC) Principal Investigator
Analyst: Richard S. John, CREATE

June 4, 2018

1. Summary

Description of ADCIRC. The ADCIRC software tool predicts flooding for coastal communities in terms of location, timing, and degree of inundation. ADCIRC uses forecasts about atmospheric pressure, wind, and precipitation to create models with greater forecast precision than currently used models. Enhanced precision allows identification of locations likely to become unsafe under particular storm conditions. ADCIRC allows for more cost effective mitigation and response planning prior to the occurrence of severe storms.

Results. Over the past 10 years (2008-2017), the DHS Office of University Programs (OUP) has invested a total of $7.1 million in 2017 CPI adjusted dollars. This cost calculation does not include other non-OUP ADCIRC funding since the early 1990s by numerous sources, including federal agencies, state agencies, and universities.

The primary benefit of ADCIRC is to provide more timely and accurate forecasts of coastal flooding, prior to severe storms. Such improvements in forecasting accuracy are expected to enhance both preparedness and response to severe storms, resulting in both reduction in evacuation cost, and reduction in loss of life and property damage. The benefit analysis is based on projected reductions in both evacuation cost and loss of life and property damage over a future 10-year period, 2018-2027. Annual base case benefit is ~$16.9 million, including ~$14.6 million reduction in evacuation costs, ~$1.5 million reduction in property damage, and ~$0.8 million in reduction in fatalities.

Base case future benefit projected over a 10-year period results in a discounted total benefit of about $144.4 million (2017 dollars, 3% discount rate). The base case NPV (benefit – cost),

including the past 10 years of OUP funding and 10 years of future use of the tool, is estimated to be about \$137.3 million in 2017 dollars. This results in a benefit-cost ratio (BCR) of 20.35, and a corresponding return on investment (ROI) of 1,935%, based on OUP investment for only the 10-year period; from 2008 to 2017. An uncertainty analysis of six key model parameters resulted in a wide NPV distribution; the 5th percentile, median, and 95th percentile are estimated (in 2017 dollars), respectively, at \$101.9 million, \$286.2 million, and \$562.8 million.

Our analysis indicates that ADCIRC has the potential to provide substantial benefit over the next 10 years. Although a net benefit of over \$100 million over ten years may seem quite large, the problem that ADCIRC addresses is in the tens of billions of dollars for a single storm. For 2017 alone, named storms cost the US over \$200 billion dollars, so even a small improvement will lead to a large expected benefit.

2. Background

Problem Context. Accurate and timely forecasts of storm surge are critical for effective storm planning and response. The effectiveness of levees and other storm mitigation structures depends on accurate modeling of storm surge. Flood insurance risk assessment also depends heavily on accurate storm surge modeling. Severe storm response planning is highly dependent on accurate forecasts of storm surge in order to maintain continuity of operations.

The efficacy of previous severe storm forecasts has been attenuated by substantial uncertainty and short lead times, which make it difficult for decision makers to execute evacuation plans in a timely manner. There is a potential for a more accurate storm surge model, such as ADCIRC, to reduce the costs from unnecessary evacuations, and from losses resulting from hasty and failed evacuations due to extremely short lead times.

The ADCIRC software tool. Rick Luettich, Coastal Resilience Center (CRC) PI, was one of two initial developers of the ADCIRC coastal circulation and storm surge model, originally funded by the Army Corps of Engineers in the early 1990s. ADCIRC has been applied in numerous storm surge studies, including the following:

- Updating the National Flood Insurance Program coastal inundation maps (FEMA)
- Designing new hurricane protection systems and structures based on forensic studies of levee performance during Hurricanes Katrina and Rita (U.S. Army Corps of Engineers)
- Preparing and responding to immediate hurricane threats, e.g. Gustav and Ike (Louisiana Governor's Office of Homeland Security and Emergency Preparedness),
- Planning responses to severe storms (National Weather Service and the North Carolina Div. of Emergency Management)
- Preparing and responding to impending Nor'easters (National Oceanic and Atmospheric Agency [NOAA])
- Planning for USCG deployment and operations during Hurricane Irene (USCG)
- Modeling oil spill movement near the coastline, during and following BP Deepwater Horizon oil spill

ADCIRC is under continuous development, with new enhancements rolled out at regular intervals (currently on upgrade 53). A Hurricane Sandy supplemental recently funded a major upgrade of the software to Version 2.0. A (boot camp) training conference is held annually for new users.

3. Baseline Performance

Annual Evacuation Baseline Cost Estimates. Baseline is defined as the current cost of severe US coastal storms. While ADCIRC has been run since 2011 for all hurricanes reaching landfall in the U.S., NOAA (parent of the National Weather Center and the National Hurricane Center) has not used ADCIRC to issue evacuation warnings. Thus, annual cost estimates from pre-2017 are the relevant comparison baseline. Costs are partitioned into 3 categories: (1) evacuation costs, (2) property damage, and (3) fatalities. Table 26 summarizes key assumptions related to the cost of evacuation based on data from Regneir (2008)[1]. Annual US coastal storm evacuation costs are estimated at nearly $1.5 billion, of which approximately 75% were unnecessary, resulting in about $1.1 billion in potentially avoidable cost.

Table 26: Baseline Annual Evacuation Cost Estimates from Hurricanes

Annual Cost of Unnecessary Evacuations	
Storms with hurricane warnings (annual average)	3.5
Miles of coastline evacuated (average per storm)	417
Miles of coastline evacuated (annual average)	1459.5
Evacuation cost per mile (estimated)	$ 1,000,000
Total annual evacuation cost	**$ 1,459,500,000**
Current "False Alarm" Rate	75 %
Unnecessary evacuations per storm (miles)	312.75
Cost of unnecessary evacuations	**$ 1,094,625,000**

Annual Property Damage Baseline Cost Estimates. Table 27 summarizes property loss calculations based on data from 35 hurricanes, each with over $1 billion in property losses, over a 38 year period.[2] This results in a lower bound on average annual costs of $566 billion in property losses, given that hurricanes under $1 billion in property losses are not included. Conservatively, we estimate that 1% of these property losses are due to hurricane hits on unprepared coastline, attributable to short lead-time and inaccuracy in tracking. That is, approximately $149 million in annual property losses are attributable to forecasting errors that could be reduced with a more accurate forecasting tool.

Table 27: Baseline Annual Property Loss Calculations from Hurricanes

Misses (False Negatives) Property Damage	
Total of 35 Hurricanes 1980-2017	$ 566,000,000,000
(each greater than $1B in property losses)	
Annual property losses per year (lower bound does not include <$1B Hurricanes)	**$ 14,894,736,842**
Percent of Property Losses from Hurricane Hits	*1.00 %*
on unprepared Coastal Regions attributable to	
short lead time and inaccuracy in tracking	
Total Annual Property Losses from Hurricanes	**$ 148,947,368**
on unprepared Coastal Regions attributable to	
short lead time and inaccuracy in tracking	

Annual Fatality Baseline Cost Estimates. Table 28 summarizes assumptions and calculations related to loss of life based on the same historical data from 35 hurricanes over the past 38 years, with greater than $1 billion in property losses.[3] A total of 85 persons are killed from hurricanes annually. Using a $10 million valuation on each life lost, the total cost of lives lost from hurricanes is nearly $845 million annually. As a baseline, we estimate that 10% of all fatalities from severe storms result from unprepared coastal areas, due to imprecise storm forecasts and short lead-times. Consequently, $84.5 million of the annual loss of life is due to forecast deficits that could potentially be improved by more accurate and timely evacuation warnings.

Table 28: Baseline Annual Loss of Life Calculations from Hurricanes

Misses (False Negatives) Loss of Life	
Total deaths of 35 Hurricanes 1980-2017	3210
(each greater than $1B in property losses)	
Annual Lives Lost from Large Hurricanes	84.47
(lower bound does not include <$1B Hurricanes)	
Value of a Statistical Life (VoSL)	$ 10,000,000
Annual Value of Lives Lost	**$ 844,736,842**
Percent of Life Loss from Hurricane Hits	*10.00%*
on non-Evacuated Coastal Regions due to	
short lead time and inaccuracy in tracking	
Total Life Loss Cost of Hurricanes attributable	**$ 84,473,684**
to unprepared Coastal Regions due to	
short lead time and inaccuracy in tracking	

4. Cost of ADCIRC

Investments in the ADCIRC tool from the DHS Office of University Programs (OUP) are summarized in Table 29. The ADCIRC model and software have been funded since the early 1990s by numerous sources, including federal agencies, state agencies, and universities. We make no attempt to calculate the total funding for ADCIRC, but instead focus on funding from the Office of University Programs (OUP) beginning in 2008. The $5.4 million estimate includes $3.4 million in funding from DHS through the Coastal Hazards Center (CHC) COE from 2008 thru 2014, and $2.0 million in funding from DHS through the Coastal Resilience Center (CRC) COE starting in 2015. These estimates do not include funding from the US Army Corps of Engineers, FEMA, NOAA, or any other federal or state agency, nor the Hurricane Sandy supplemental, nor any costs to run and interpret the results of the ADCIRC model. In addition, we have assumed oversight costs at each COE of 20% of the direct funding amount ($1,080,000) total, and $20,000 per year oversight cost at OUP ($200,000) total. The total OUP cost of ADCIRC development is calculated to be $6,680,000; using the actual CPI, this results in an adjusted total cost of $7,094,771 in 2017 dollars.

Table 29: OUP Costs for Development of ADCIRC

Cost Category	Start	End	Amount	Source
Pre-project costs (COE)				
Pre-project costs (other funding)				
Project costs (COE)	2008	2017	$5,400,000	CHC &CRC
Project costs (university cost share)				
Oversight cost at the COE			$1,080,000	CHC &CRC
Oversight cost at OUP			$200,000	OUP
Transition development cost				
Implementation start-up cost				
Implementation cost (User)				
Implementation cost (COE)				
Implementation cost (Other users)				
TOTAL COST			**$6,680,000**	
TOTAL COST 2017 Dollars			**$7,094,771**	

5. Benefits of ADCIRC

We estimated benefits in the form of reduced costs due to more timely and accurate storm surge forecasts using ADCIRC compared to forecasts using current technology. These estimates are based on more timely and accurate forecast performance that would be realized following routine application of ADCIRC for making real time forecasts that are utilized as inputs to storm preparation and response planning. Benefits (summarized in Table 30) are estimated as reductions in the baseline severe storm costs computed in Tables 1-3.

Evacuation cost reduction. For evacuation cost, the baseline estimate is that ADCIRC provides more timely and accurate forecasts of storm surge, which results in a reduction of false positive forecasts (from 75% to 74%). This equates to a cost reduction of 1% of the total annual evacuation cost (~$14.6 million).

Unprepared Coastline Cost Reduction Benefit Estimates. We use a baseline estimate that ADCIRC provides more timely and accurate forecasts, which results in more trustworthy information for evacuation. Improved accuracy of ADCIRC forecasts are expected to both reduce "misses", and to promote greater compliance with evacuation orders, resulting in a 1% reduction in annual avoidable losses from property damage (1.5 million) and loss of life ($0.8 million).

Table 30: Summary of Annual Total Costs, Avoidable Costs, and ADCIRC Cost Reduction

Summary of Annual Baseline Cost Estimates	Annual Total Cost	Annual Avoidable Cost	Annual Cost Reduction (ADCIRC Benefit)
Evacuation Costs	$ 1,459,500,000	$ 1,094,625,000	$ 14,595,000
Property Damage	$ 14,894,736,842	$ 148,947,368	$ 1,489,474
Loss of Life	$ 844,736,842	$ 84,473,684	$ 844,737
Total Baseline	**$ 17,198,973,684**	**$ 1,328,046,053**	**$ 16,929,211**

Thus, improved ADCIRC forecasts are estimated to produce a total reduction in cost from unprepared coastlines of ~$2.3 million. ADCIRC forecasts are also estimated to result in a total annual cost reduction of ~$16.9 million annually due to reduced costs from unnecessary evacuations (~$14.6 million), and reduced costs of property damage and loss of life due to unprepared coastlines (~$2.3 million).

6. Benefit-Cost Analysis - Base Case

A benefit-cost analysis was conducted using actual costs over the previous 10 years (2008-2017) summarized in Table 29, and projected benefits over the next 10 years (2018-2027) are summarized in Table 30. The CPI-adjusted total cost is $7,094,771 in 2017 dollars. The annual base case benefits ($16.9 million) are discounted at 3% over the next 10 years, resulting in a discounted total benefit for 10 years of $144,409,600 in 2017 dollars. Thus, NPV (benefit – cost) over the next 10 years is estimated to be $137,314,828 in 2017 dollars. This results in a BCR = 20.35, and an ROI of 1935%, based on OUP investments only over the previous 10-year period, 2008-2017.

7. Sensitivity and Uncertainty Analysis

Break-Even Analysis. A break-even analysis was conducted, assuming benefits associated with improvement only in reducing unnecessary evacuations (false alarms), i.e., no improvement assumed in improved forecast to avoid property damage and lives lost. Note that of the 417 miles of coastline evacuated (per storm) on average, approximately 75% (313 miles) are false alarms that, in retrospect, would not have been required if the consequences of the storm were fully known ahead of time. Break-even improvements are calculated for a 10-year horizon of benefits (2017-2026). The break-even point is the reduction in the number of miles of coastline not evacuated due to a more accurate (and timely) forecast by ADCIRC. Percent improvement is calculated in comparison to the 313 miles of false alarm evacuations per storm, for an average of 3.5 storms per year. The break-even point for ADCIRC benefits equaling the DHS costs detailed above is a 0.047% improvement, which is about 0.15 miles of coastline per storm over 10 years (35 expected storms).

Tornado Analysis. A sensitivity analysis was conducted on the NPV estimate of $137 million described in Section 6 above. A total of 6 key uncertainty parameters in the benefit calculation were varied across a plausible range around the baseline values defined in Section 5 above. Table 31 summarizes the ranges utilized for each of the 6 parameters in this sensitivity analysis. Two parameters are related to ADCIRC effectiveness in improving forecasts: (1) to reduce unnecessary evacuations (reduction in "false alarms"), and (2) to reduce costs associated with unprepared coastline by providing more trustworthy forecasts with longer lead times. Two other key parameters varied relate to the extent to which any improved forecast can reduce losses from (1) property damage, and (2) loss of life. These parameters explicitly capture the fact that most of the property damage and loss of life in a severe storm in not avoidable, even with a perfect (clairvoyant) forecast of storm surge. The last two parameters varied, (1) future discount rate, and (2) value of a statistical life (VoSL) are not directly related to either the hurricane problem context or the ADCIRC tool. Future discount rates depend on the economy and are uncertain. Similarly, societal VoSL changes over time and is therefore also uncertain.

Table 31: Ranges of ADCIRC Benefit Input Parameters for Sensitivity Analysis

Input Variable	*Low*	*Base Case*	*High*
ADCIRC Reduction in Unnecessary Evacuations (Reduction in False Alarms)	0.0%	1.0%	5.0%
ADCIRC Reduction in Unprepared Coastline (Reduction in Misses)	0.0%	1.0%	5.0%
Percent of Property Losses Avoidable with Perfect Storm Surge Forecast	0.0%	1.0%	5.0%
Percent of Loss of Life Avoidable with Perfect Storm Surge Forecast	0.0%	10.0%	20.0%
Future Discount Rate (2018-2027)	0.0%	3.0%	7.0%
Value of a Statistical Life (VoSL, 2018-2027)	$ 5,000,000	$ 10,000,000	$ 15,000,000

Figure 11 is a Tornado Diagram that displays graphically the results of the sensitivity analysis described above. The vertical line represents the base case of $137,314,828 in discounted net benefits, when all 6 parameters are set equal to their base case values. Each horizontal bar represents the range of possible total NPV from varying the identified parameter over the plausible ranges defined in Table 31, assuming that all other parameters are held at their base-case level. The sensitivity analysis clearly demonstrates that the most critical parameter is the percent reduction in unnecessary evacuations of coastlines afforded by improved ADCIRC forecasts. Note that NPV is relatively insensitive to avoidable loss of life percentage and VoSL.

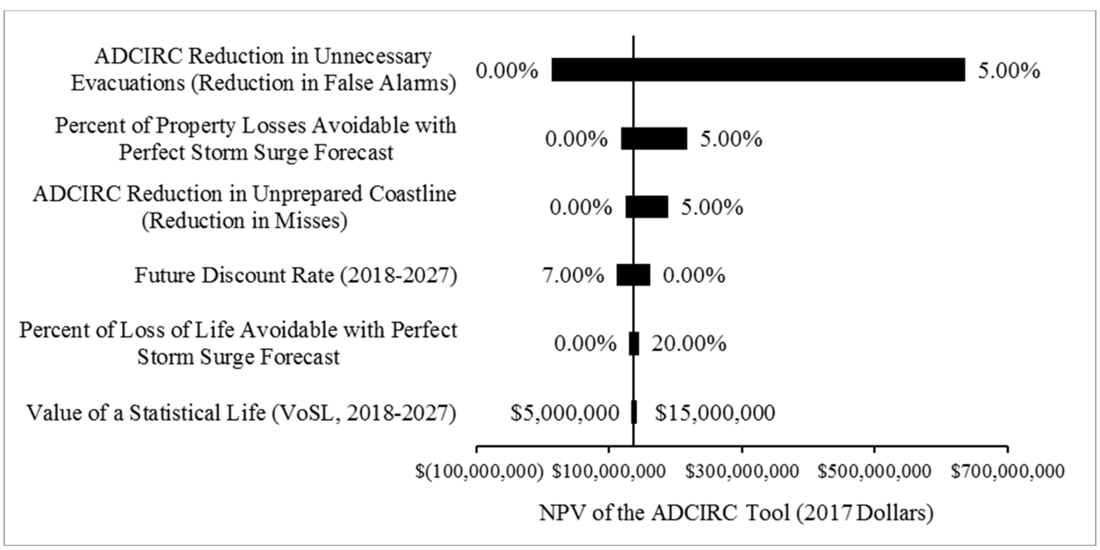


Figure 11: Tornado Diagram for the NPV of the ADCIRC Tool

Uncertainty Analysis. An uncertainty analysis was conducted on NPV using a Monte-Carlo simulation assuming single-peaked (triangular) probability distributions for each of the 6 uncertain model parameters identified in Table 31. The simulation analysis is based on input parameter distributions defined over the same ranges identified in Table 31. The input distributions for the 6 model parameters are assumed to be independent. A total of 10,000 iterations were run using Latin-Squares sampling.

Figure 12 is a histogram of the uncertainty analysis results for NPV over 10 years. The distribution accounts for uncertainty in all 6 input model parameters defined in Table 31. Because the benefits of the ADCIRC tool are projected for the next 10 years, there is substantial uncertainty in the benefit resulting from cost reductions due to improvements in storm surge forecast performance. The distribution is single peaked and right skewed. The right skew is due to the skewed input distributions for 3 of the 6 input parameters (ranging from 0 to 5%, mode = 1%), which results in the expected outcome: Mean > Median > Base Case.

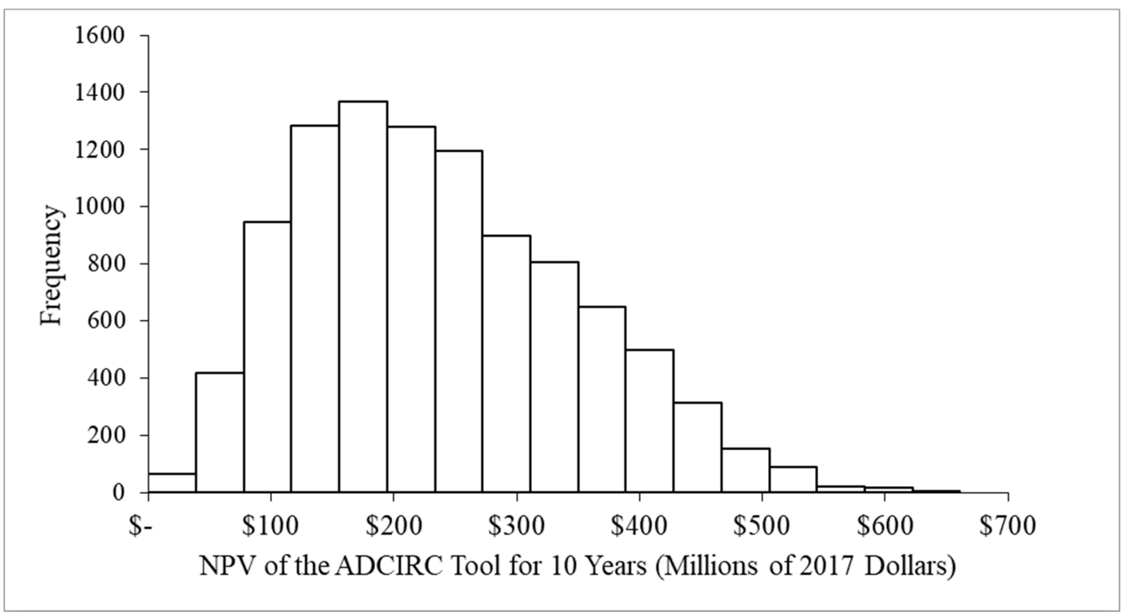


Figure 12: Net Present Value Distribution

The mean NPV of the ADCIRC tool is estimated to be \$ 303,857,203. The median (50th percentile) is \$ 286,208,890. Discounted net benefit ranges from \$101,933,686 (5th percentile) to

$ 562,793,233 (95th percentile). Summary statistics for NPV frequency histogram displayed in Figure 12 are presented in Table 32.

Table 32: NPV Uncertainty Analysis Summary Statistics

Mean	$ 303,857,203
St. Dev.	$ 143,278,923
5th %-tile	$ 101,933,686
25th %-tile	$ 192,369,742
Median	$ 286,208,890
75th %-tile	$ 402,572,361
95th %-tile	$ 562,793,233

8. Limitations and Assumptions

There is great uncertainty about the four model parameters related to avoidable cost evacuations, property damage, and fatalities, and ADCIRC improvements in timely and accurate storm surge forecasts to reduce avoidable costs. Base case estimates are roughly based on preliminary reports from limited use of the ADCIRC tool during the 2017 hurricane season. The base case estimates suggest substantial benefits from using the ADCIRC tool for storm preparation and response planning. Both the sensitivity analysis and the uncertainty analysis indicate great uncertainty in the NPV for the next 10 years of ADCIRC use, based on the ranges and triangular distributions used for the 6 uncertain input parameters. The most critical input parameter, related to the effectiveness of the ADCIRC tool to reduce unnecessary evacuations, has a substantial effect on NPV.

9. Recommendations for Collecting Additional Information

Uncertainty about the four benefit-related input parameters could potentially be reduced by a closer study of the use of ADCIRC since 2011, particularly during the 2017 hurricane season. Specifically, we propose to conduct a VOI (Value of Information) analysis of actual decisions made prior to storms since 2011 in which ADCIRC was used. For this, we would need expert judgments to identify decisions, quantify uncertainties about storm outcomes, and estimate costs for the outcomes of different scenarios. This would allow us to better estimate the effectiveness of ADCIRC with respect to the primary benefit of reducing costs through a more targeted approach to evacuation that avoids worst case assumptions.

10. References

1. Regneir, E. (2008). Public evacuation decisions and hurricane track uncertainty. *Management Science, 54*(1), 16-28. https://doi.org/10.1287/mnsc.1070.0764
2. Ibid.
3. Ibid.

Benefit-Cost Analysis of Engineered Swabs

Developer: ALERT Center of Excellence
Analysts: Jonathan Eyer and Detlof von Winterfeldt (USC/CREATE)

June 3, 2018

1. Summary

Description of the Engineering Swabs Tool. The research team at the ALERT COE is developing an advanced swab designed for collecting explosive residue. The swab can used for explosive detection systems that use ion mobility spectrometer (IMS). Rather than performing research to improve the IMS technology, ALERT is attempting to improve IMS explosive detection by improving the swab design for the collection of residue from testing surfaces. This will decrease the frequency of false negative results (misses) from IMS swabs, thus leading to a decrease in the risk of explosives attacks, especially on airplanes. However, there is a potential increase in the frequency of false positives, imposing delays on travelers.

Results. The costs of funding this project was $1.87 million (2017 dollars), including the direct funding to the ALERT COE from the DHS Office of University Programs, OUP oversight costs and testing. The benefits of the ALERT swabs project can be decomposed into two components. First, the improved swabs will reduce the likelihood of a successful explosives-based terrorist attack on an airplane. This benefit can be determined by multiplying the damages from a terrorist downing of an airliner by the change in the probability that an attack is thwarted due to more effective swabs. On the other hand, the new swabs will pick up more residues from materials carried by regular travelers as well. These travelers will be diverted into secondary screening and the value of their wait-time leads to additional costs. The balance of these benefits and costs as well as the development costs were considered in this study to determine the net benefits of using the improved swabs.

Under the baseline parameters, the ALERT swabs result in approximately $26.6 million (in 2017 dollars) in net benefits over a ten-year time period of use, easily justifying the $1.87 million development cost. However, these results are highly sensitive to several inputs, and the

associated data is often either non-existent or classified. An uncertainty analysis indicates that there is even a 35% chance that the net benefits could be negative. Testing and evaluating of swabs in order to more firmly establish the false negative (miss) rates and the false positive (alarm) rates can reduce this range substantially and lead to more conclusive results.

2. Background

Problem context. Explosive detection swabs can reduce the likelihood that explosives are smuggled through airport security by detecting residue from explosives on passengers' hands and clothing. While these swabs can detect explosives they also result in a number of false positives. These false positives lead to wasted time both for inconvenienced passengers and for TSA agents who are diverted from other tasks. Improving the accuracy of the swabs will convey two benefits. First, lowering the false negative rate for explosive detection swabs will reduce the likelihood of a successful attack on an airplane. Lowering the false positive rate will allow TSA agents to work on more productive tasks and avoid inconvenience for passengers.

The Engineering Swabs Tool. The research team at the ALERT COE is developing an advanced swab designed for collecting explosive residue, which can used for explosive detection systems that use ion mobility spectrometers (IMS). Rather than performing research to improve the IMS technology, ALERT is attempting to improve IMS explosive detection by improving the swab design for the collection of residue off testing surfaces. The new swabs have not yet been deployed and ALERT is finalizing the new product. Given that the swabs are not finished, it is uncertain if there will be additional manufacturing or training costs but it is relatively unlikely that costs will change substantially because the application of the swab will be the same and the physical cost of the swabs themselves are low.

3. Baseline Analysis Without the Engineered Swabs Tool

Explosive detection swabs reduce the likelihood of a successful terrorist attack on an airplane. In our baseline analysis, we focus on the current expected losses from a terrorist attack on an airplane under the existing explosive detection swab technology, and the costs associated with delayed passenger time due to false alarms.

Table 33 shows the baseline parameter assumptions. Based on the number of domestic travelers in 20161 and federal guidance on the value of wait-time[1] as well as an assumption that 5% of travelers are swabbed and 7.5% of swabbed passengers result in false positive explosive detection signals, we find baseline costs from false positives of $31.9 million per year. We assume that there are 0.25 attempted explosive-based attacks per year, that the chance that an attempted attack is thwarted through means other than the swab is 25%, and that a successful attack results in losses due to behavioral effects[3], we find expected losses from false negatives of $58.6 million per year.

Table 33: Baseline Analysis Without the Engineered Swabs Tool

Input Variable	Base Case Value
Number of Travelers/Year (Millions)	719
Number of Attack Attempts Per Year	0.3
Detection Probability w/o Swabs	0.250
Swabbing Percentage	0.050
Current False Positive Rate	0.075
Current False Negative Rate	0.250
Time in Secondary (Min)	15
Cost of One Minute of Wait Time	$0.79
Cost of One Minute of TSA Time	$0.27
Cost of a Successful Attack (Millions of 2017 Dollars)	$25,000.0
Current Cost of False Positives (Millions of 2017 Dollars)	**$42.9**
Current Cost of False Negatives (Millions of 2017 Dollars)	**$70.3**

4. Cost of the Engineered Swabs Tool

Table 34 shows the cost of developing the improved engineered swabs, including direct project costs, COE overhead, and OUP oversight cost. Most costs are associated with the initial project development and associated oversight. Around 20% of total costs are associated with the implementation of the advanced swabs. The additional cost of training TSA staff to use the new swabs is not counted. Application of the new swabs is largely comparable to the application of the existing swabs, so additional training and implementation costs are likely to be small. We do not, however, account for the change in staffing requirements associated with follow-up screening for passengers who result in a false positive swab. Other costs like the costs of false alarms are counted in the benefits analysis framework.

Table 34: Development Cost of the Engineered Swabs Tool (in 2017 Dollars)

Cost Category	Amount	Source
Pre-project costs (COE)		
Pre-project costs (other funding)		
Project costs (COE)	$ 1,276,990	COE/OUP
Project costs (university cost share)		
Oversight cost at the COE	$ 251,732	COE/OUP
Oversight cost at OUP	$ 83,600	
Transition development cost		
Implementation start up cost		
Implementation cost (User)	$ 255,000	NDOE Nat'l Lab
Implementation cost (COE)		
Implementation cost (Other users)		
Total Cost (2017 dollars)	**$1,867,322**	

5. Benefits of the Engineered Swabs Tool

The primary benefit of the engineered swabs is the improved probability of detecting true explosive materials. Because swabs are primarily associated with air travel, we focus on the benefits associated with changes in the probability of detecting explosive material on aircraft. This increases the likelihood of detecting terrorist attempts to enter an airplane with explosives, and thereby reduces the potentially very large consequences of a successful attack that may bring down one or more airplanes. While the swabs also convey a benefit by allowing easier prosecution of terrorists who are caught attempting to bring explosives onto an aircraft, this benefit is difficult to value. Similarly, while ALERT is producing a generalized framework for evaluating future IMS swabs advancements, we do not attempt to place a value on the framework itself.

In our analysis we assume that, in the absence of the updated swabs, the likelihood of a successful attack is determined by the efficacy of the incumbent swab technology. Similarly, the costs associated with false positives are determined by the frequency with which the current swabs technology results in an erroneous signal of explosive detection. The benefits (and costs) of the enhanced swabs are determined by the changes in these false negative and false positive rates and the associated change in passenger wait-time and successful attacks.

The benefits of the swabs can be broken down into two components. The first component reflects the change in expected damages from the reduced likelihood of a successful explosive-based attack on an airliner. The second component reflects the value of the change in passenger wait-time due to the updated swabs. Note that the wait-time component could be either a societal benefit or a social cost. If the improved swabs can be tested more quickly than the existing swabs, TSA lines will be shorter, and passengers' wait-time can be reduced. Similarly, if the updated swabs reduce the likelihood of a false positive, there will be fewer passengers who are diverted to time-consuming secondary screening. On the other hand, if the new TSA swabs increase processing time or increase the frequency of false positives, passengers will experience greater wait-times and TSA will require additional staffing to oversee the passengers who are sent to secondary screening.

We specify the annual value of the ALERT swab by two components: the first component is due to improved detection capability (reduction of false negatives); the second component is due to the change of false alarms. The first component is calculated as follows:

$$A * (1 - I) * F * (Po - Po * P1) * D,$$

where A is the expected number of attempted explosives attack per year (highly uncertain, but low range, 0.1-0.5). I is the probability of interdicting the attempt by means other than swabbing (uncertain, but perhaps as high as 25%). F is the percentage of passengers selected for swabbing (around 5%). Po is the false negative (miss) rate with the current swabs (relatively high, around 10-30%). $P1$ is the reduction of the false negative rate with the new engineered swabs (claimed to be around 10-50%[1]). D is the damage due to a successful attack.[3]

The second component captures the negative value of false alarms due to swabs. Ideally improved swabs reduce both the false negatives and the false alarms. Unfortunately, it is well known in signal detection theory that decreases in false negatives are usually accompanied by increases in false alarms. Thus, while the developers are confident that the new swabs will decrease false negatives, there also exists some evidence that they may lead to an increase in false alarms. The (negative) value of the new swabs due to an increase in false alarms can be captured by the following equation:

$N * F * \mathrm{T} * (\mathrm{VT} + \mathrm{W})$*(Qo+Q1*Qo),

where N is the number of passengers per year (719 million in 2016). F is the percentage of passengers that are swabbed (close to 5%). T is the time required to resolve a false alarm through secondary inspection (10-20 minutes). VT is the value of time of the waiting passenger (around $50/hour according to DOT). W is the cost of TSA wages associated with secondary screening (between $11-$21 according to Glassdoor) Qo is the false alarm rate with current swabs (between 5-10%). Q1 is the increase in the false alarm rate with the new swabs (could be as high as 50%).

Again, many of the key parameters underlying this analysis are classified. We therefore use conservative assumptions about the baseline parameters and provide sensitivity analyses across a wide range of potential parameter values. Parameter values are shown in Table 34 and some of the key parameters are discussed below.

Probability of an Attempted Attack with Explosives. Since 9/11 there were two known attacks that were foiled on planes (the shoe bomber and the underwear bomber), and at least one attack that was foiled before the attackers entered a plane (the Heathrow liquid bomb attack). These three attempts in 18 year suggest an annual probability of between 0.1 and 0.2 attacks per year. To account for uncertainty in the attack rate, we use a range from 0.1 to 0.5/year and adopt a baseline frequency of 0.3 for the sake of symmetry.

Damages from a Successful Attack. A successful explosive attack on an airliner will result in substantial costs. These costs are due to a range of factors, including the value of the airplane itself, the value of the lives lost in the attack, as well as GDP losses due to changes in consumer behavior. Blomberg and Rose (2009) summarized several studies that estimated the GDP loss due to the 9/11 attacks to be close to $100 billion. This loss was driven in large part by the economic impacts of reduced air travel due to the psychological effect of the attack resulting in fear of flying. A single explosives attack that brings down an airplane is likely to have an impact that is a fraction of the 9/11 attack. We therefore used a wide range from $10 billion to $50 billion for this parameter. While engineered swabs would not have prevented a 9/11-type attack, our damage estimates are largely based on the concept of business interruption and psychological effects due to a downed airliner. Still, damages are likely to be large even if psychological responses are small. The replacement cost of a downed airliner would likely be in the hundreds of millions and the loss of life would be valued in the low billions.

Value of Waiting Time. Following the Department of Transportation's (2015) most recent value of travel time-savings memorandum, we use a value of waiting time on intercity travel of $50/hour for personal air travel. In our sensitivity analysis, we allow this to vary from $30 (approximately the DOT's value of personal time for surface travel) to $60 per hour (the DOT's value of business time for air travel).

Wage Rate. TSA agents are not on the GS pay scale so it is not possible to identify the costs of TSA agent time with certainty. Instead, we use the Glassdoor range of reported hourly wage rates for TSA agents. This ranges between $11/hour and $21/hour with a central estimate of $16/hour.

Probability of False Negatives. While data on false negative (miss) rates for swab technologies are generally unavailable and confidential, ALERT (2016) notes that existing swab technology may fail to capture 30% of residue on surfaces. The 30% miss rate is likely high and applicable only to a subset of testing circumstances, so we are using a range from 10% to 30% with a base case value of 20%.

The updated ALERT swabs have not yet been tested, and the false negative rate for these swabs will likely be classified even after testing. We assume that the ALERT swabs reduce the false negative rate relative to existing swab designs because the ALERT swabs focus on increasing the amount of residue that is captured from swabbed surfaces. In the base case, we assume that ALERT swabs reduce false negatives by 20% with a range from 10% to 30%.

Probability of False Positives. There is no available data on the frequency with which current or ALERT swabs will result in false positives. Indeed, one portion of the ALERT project that we do not evaluate is the creation of a framework to identify false positive rates for existing and potential technologies. There is an important distinction to be made about what constitutes a false positive. While a passenger with baby wipe residue on his hands may not constitute a false positive in the sense that the IMS technology is designed to identify the irregularity of such residue, it is a false positive in the sense that an innocuous passenger is inconvenienced.

Based on consultation with a former TSA agent, we use a relatively large false positive rate for existing swabs: 7.5%. Because the ALERT swabs will increase the amount of residue that is obtained but will not increase the distinction between explosives and innocuous chemicals, we assume that the ALERT swabs will increase the false positive rate by 25% with a range from 10%-30%.

Table 35 presents the annual benefit of the engineered swabs under the base case parameters.

Table 35: Annual Benefit of the Engineered Swabs Tools

Input Variable	Base
Number of Travelers/Year	719,000,000
Number of Attack Attempts Per Year	0.3
Detection Probability w/o Swabs	0.25
Swabbing Percentage	5.0%
Current False Positive Rate	7.5%
Current False Negative Rate	25%
ALERT Increase in False Positives Rate	25%
ALERT Decrease in False Negatives Rate	20%
Time in Secondary (Min)	15
Cost of One Minute of Wait Time	$0.79
Cost of One Minute of TSA Time	$0.27
Cost of a Successful Attack	25,000,000,000
Number of Passengers Swabbed/Year	35,950,000
ALERT False Positive Rate	9%
ALERT False Negative Rate	20%
Current Cost of False Positives	$ 42,870,375
Current Cost of False Negatives	$ 70,312,500
ALERT Cost of False Positives	$ 53,587,969
ALERT Cost of False Negatives	$ 56,250,000
Discount Factor	0.030
Total Value of Swabs/Year	**$ 3,344,906**
Total Net Benefits for Ten Years	**$ 26,665,407**

6. Benefit-Cost Analysis – Base Case

Under the base parameters, the annual benefit of the ALERT swabs is $3.3 million. The parameter values associated with the base case are presented in Table 36. While the annual costs of false positives using the ALERT swabs increases from $42.8 million to $53.6 million, the expected losses from a successful attack on an airliner are reduced from $70.3 million to 56.3 million, because of the reduction in the likelihood of a false negative resulting in a successful attack. If the enhanced swabs were to be implemented, the base case net present value (NPV) (subtracting the costs of development from the ten-year benefit) over a period of ten years is $26.7 million assuming a 3% annual discount factor starting from the time of implementation. The key parameters driving this result are the damages from a successful attack ($25 billion), the number of attempted attacks per year (0.25), the change in the false positive rate (25%) and the change in the false negative rate (-20%). The base case benefit-cost ratio (BCR) is 15 and the return on investment (ROI) is 1,400%.

7. Sensitivity and Uncertainty Analysis

Break Even Analysis. The engineered swabs tool will likely both increase the false positive rate and decrease the false negative rate. Holding all other parameters constant, the engineered swabs tool will break even (i.e., result in an NPV of zero) if the increase in the false positive rate were 32% or if the reduction in the false negative rate was 15%. Similarly, the tool would break even at the level of 0.23 attempted attacks per year, holding all other variables constant.

Tornado Analysis. The net benefits associated with the engineered swabs project are highly sensitive to the assumed parameters. This is due, in part, to the wide range of some of the key parameters. Table 36 shows the range of input parameters in the sensitivity analysis. As shown in the sensitivity analysis, many parameters cause this wide range and research. While some of these ranges cannot be narrowed substantially (e.g., probability of an attempt), there will be great value in narrowing the ranges for false positives and false negatives, which can be established through testing. Figure 13 presents a “tornado diagram” showing how changes in the underlying parameters affect the value of the ALERT swabs.

Table 36: Ranges for the Engineered Swabs Analysis

Input Variable	Min	Base	Max
Number of Travelers/Year	719,000,000	719,000,000	719000000
Number of Attack Attempts Per Year	0.1	0.3	0.5
Detection Probability w/o Swabs	0	0.25	0.5
Swabbing Percentage	2.5%	5.0%	7.5%
Current False Positive Rate	2.5%	7.5%	10%
Current False Negative Rate	10%	25%	30%
ALERT Increase in False Positives Rate	0%	25%	50%
ALERT Decrease in False Negatives Rate	10%	20%	30%
Time in Secondary (Min)	10	15	20
Cost of One Minute of Wait Time	$0.50	$0.79	$1.00
Cost of One Minute of TSA Time	$0.18	$0.27	$0.35
Cost of a Successful Attack	10,000,000,000	25,000,000,000	50,000,000,000

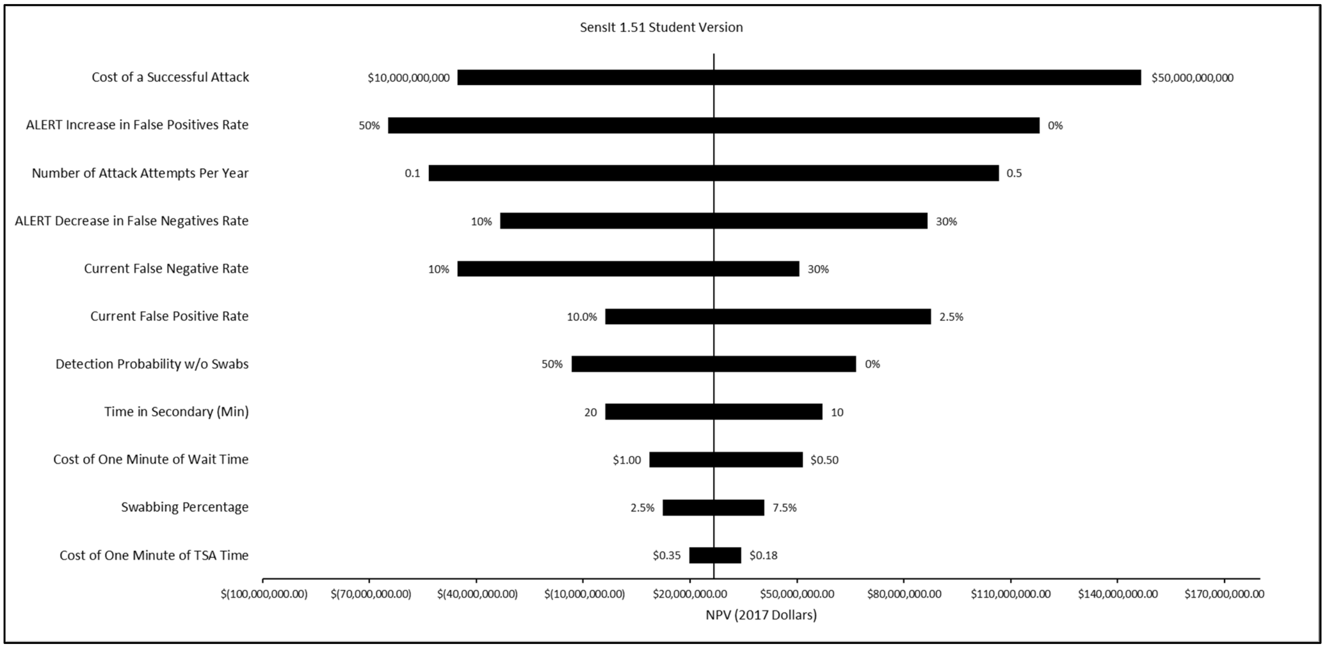


Figure 13: Tornado Diagram for the NPV of the Engineered Swabs Tool

The greatest uncertainty in the valuation of the new swabs is the number of attempted attacks/year (i.e., the annual attack frequency) and the damages from an attack. At the lowest level of damages – in which we assume that the damages from an attack are limited to the value of the airliner and the value of the lives lost plus no more than 5% of the 9/11 GDP loss), the safety benefits of the swabs do not exceed the increased waiting time due to false positives. At the upper level, however, the swabs produce over one hundred millions dollars in value. The effectiveness of the new ALERT swabs (high reduction in false negatives and low increase in false alarms) is also important. On the other hand, the number of passengers, (which is well known), the swabbing percentage, the valuation of time, and the time in secondary have less impact on the results.

Uncertainty Analysis. We consider a formal sensitivity analysis of the value of the new engineered swabs by varying each of the parameters and recalculating the value of the swabs. We assessed probability distributions for each of these parameters and evaluate the value of the swabs at various points along the distribution. For most parameters, we assume a triangular distribution between the low, base case and high value. These parameter values are shown in

Table 34. For the current false negative and false positive rates, we assume normal distributions that are negatively correlated. Thus, a high current false negative rate is associated with a low current false positive rate and vice versa. Using probabilistic simulation software, we ran 10,000 simulations of the expected net ten-year benefits with the results shown in Figure 14.

While most of the density (the most frequently observed outcomes) are in the tens of millions of dollars range, it is notable that the tails are very large. The median ten-year net benefit is $22.5 million. The 5th percentile of the distribution is -$77 million due to a large increase in false positives and a high value of passenger time, while the 95th percentile is $159 million due to a large reduction in false negatives and a large number of threats. The mean 10-year discounted net benefits are $30 million. The probability of a negative net benefit is about 35%.

8. Assumptions and Limitations

This model relies on a number of decisions about the structure of attacks. Most notably, we hold the number of potential attacks constant. If terrorists believe that updated engineered swabs are likely to prevent them from successfully attacking a plane with a detectable explosive, they will likely either switch to an undetectable type of explosive or switch targets. This behavior would reduce the impact of the engineered swab.

We also assume a 10-year time horizon for benefits. While the efficacy of the engineered swabs is unlikely to change over time, the set of alternative explosive detections available to TSA may change. If, for example, non-swab based technologies are developed in year 5 that are preferable to the swabs, there will be no benefits associated with the swabs in subsequent years.

Many of the input parameters are relatively uncertain. In particular, the number of attempted attacks per year is known only to the terrorist organizations planning the attempts. Many other parameters such as the false negative rate of existing swabs are classified. In these cases, we attempted to provide “conservative” estimates (low NPV values) by assuming parameter values that minimized the benefits of the engineered swabs.

The primary limitation of this analysis is the large amount of uncertainty surrounding the likelihood of a potential attack. Because this is a key driver of the total benefits of the engineered swabs, this results in a large distribution of expected net benefits. We also ignore changes in the swabs on other behavior. Such behavioral changes could affect the adversary (through changes in attack vectors) or security personnel (by re-allocating time away from other tasks).

Table 37: Statistics of the Engineered Swabs NPV Distribution

Mean	$ 29,983,631
St. Dev.	$ 73,609,032
5th Percentile	$ (77,597,125)
25th Percentile	$ (16,746,439)
Median	$ 22,528,347
75th Percentile	$ 69,320,476
95th Percentile	$ 159,825,039

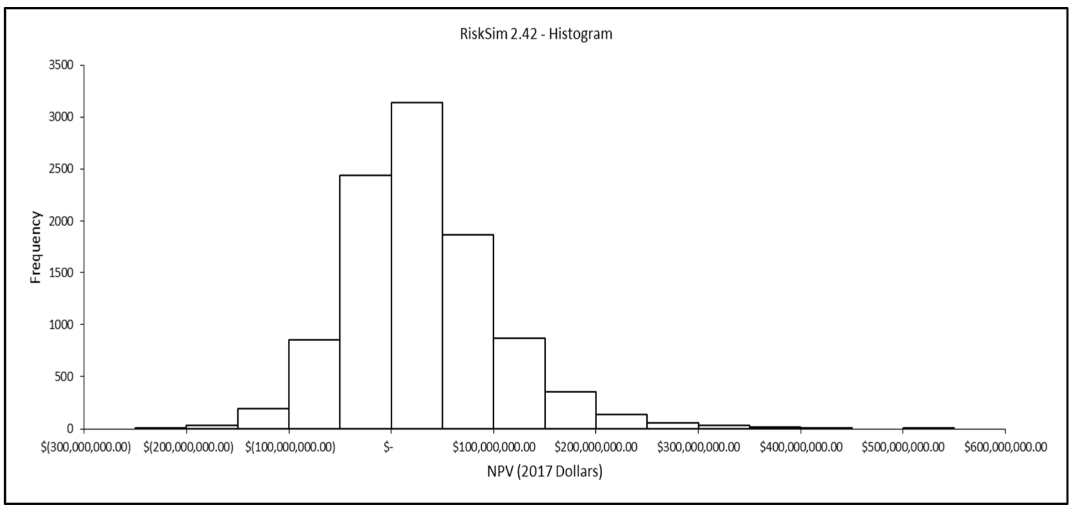


Figure 14: Net Present Value of Using Engineered Swabs for Ten Years (2017 Dollars)

9. Recommendations for Additional Research

There are several potential pathways to improve the precision of the engineered swabs analysis. Many of the variables that are most important in the parameterization of the value of the swabs are not publicly available. If classified information could be obtained on these parameters, uncertainty in the benefits would be substantially reduced. The key variables to be collected are:

1. False negative rate of current swabs
2. False Positive rate of current swabs
3. False Negative rate for ALERT swabs
4. False Positive rate for ALERT swabs
5. Number of attempted explosive-based terror attacks per year

10. References

1. Bureau of Transportation Statistics. “2016 Annual and December U.S. Airline Traffic Data.” https://www.bts.gov/newsroom/2016-annual-and-december-us-airline-traffic-data, Last Accessed: 5/9/2018
2. Beaudoin, Stephen P., and Bryan Boudouris. R2-A.1: Improved Swab Design for Contact Sensing. Rep. N.p.: ALERT, 2016. Print.
3. Blomberg, B. and Rose, A.Z. The economic impacts of the September 11, 2001 terrorist attacks. Peace Economics, Peace Science and Public Policy Volume 15, Issue 2, 2009.
4. Department of Transportation. “Revised Departmental Guidance on Valuation of Travel Time in Economic Analysis.” https://www.transportation.gov/sites/dot.gov/files/docs/2015%20Revised%20Value%20of%20Travel%20Time%20Guidance.pdf . Last accessed: 5/9/2018

Benefit-Cost Analysis of GeoXRay

Developer: CCICADA, TerraGo
Analyst: Jonathan Eyer (USC/CREATE)

June 4, 2018

13. Summary

Description of the GeoXRay. GeoXRay is a product developed by the CCICADA COE. It provides a visualization of geospatially-coded information and allows users to query open-source and confidential data sources for key words and phrases.[1] The results are maps that present a spatial representation of locations where key words or phrases have appeared in communications. Security assets can hypothetically be better deployed by taking into account the intelligence information displayed by GeoXRay. GeoXRay has not been operationalized by the government and is currently operated and maintained by TerraGo.[1]

Results. The value of GeoXRay is derived in the context of value of information. The likelihood of detecting and stopping terrorist attacks is higher with GeoXRay than without it, and the value of GeoXRay is calculated by comparing the change in expected costs. The value of GeoXRay likely exceeds the relatively small associated costs, even if large events are removed from the analysis. The baseline estimate of the net present value of 10 years of GeoXRay information ranges from \$8.4 million (5th percentile) to \$35.3 million (95th percentile) 2017 dollars with a median estimate of \$18.4 million, when large events are excluded from consideration. These results are sensitive to a number of model assumptions, most notably the relative change in interdiction likelihood, the underlying probability that an attack is successful and the number of potential attacks each year.

14. Background

Problem context. Increased social connectivity means that there is a growing amount of data related to threats. If this data can be effectively parsed, the data can be used to interdict potential attacks. Data from specific geographic markets present an additional potential benefit, because communications that are embedded with locational information provides an increased ability to identify threats. Security forces could identify an area at risk for a terrorist attack based on geographically-clustered areas of intercepted terrorist chatter. While geographically-encoded data provides additional information, it can be more difficult to analyze than traditional text-based data.

The GeoXray Tool. GeoXRay is a tool developed by CCICADA that maps geospatially-coded information. It can interface with a number of publicly facing data sources (e.g., news reports) as well as proprietary geo-located data. Users can define keywords and date restrictions, and GeoXRay places data points on a digital map related to each geo-located entry. Pertinent data points can be accessed via the map to show the full set of information associated with an observation. GeoXRay is not currently operated by the government and is maintained and operated by TerraGo.

15. Baseline Performance Without the GeoXRay Tool

Geographically-coded information can be used to inform security responses and interdict or prevent attacks. There is, however, a large amount of geographically-coded information, most of which has no security value. In our baseline, we assume that there is no benefit associated with this information (i.e., security agencies are unable to actionalize geo-coded data). As a result, the damages from attacks are simply the magnitude of damage when attacks take place multiplied by the probability of a successful attack. There is no interdiction opportunity. Note that this assumption can be viewed in a more relaxed form by viewing the existing use of GeoXRay as being incorporated into the baseline probability that an attack is successful.

Table 38 shows the baseline parameter assumptions. Based on an expectation that there will be 17 potentially detectable events per year, and that the likelihood that an attack is successful, we find expected annual damages of $7.2 million. We assume that a small attack results in $15 million in damages while a medium event results in $94 million in damage. These values are derived from the median and 90th percentile damage associated with lone-wolf attacks in the United States (assuming $10 million per fatality and $100,000 per injury). If large damages that result in substantial behavioral impacts are included, expected losses without GeoXRay rise to $15 million per year.

Table 38: Baseline Analysis Without the GeoXRay Tool

Input Variable	Base Case Value
Probability of Successful Attack	0.106
Number of Potential Incidents	17
Discount Factor	0.03
Damage from Medium Attack (Millions of 2017 Dollars)	94.3
Damage from Small Attack (Millions of 2017 Dollars)	15.5
Probability of Medium Attack	0.021
Probability of Small Event	0.129
Expected Damages No Geoxray (Millions of 2017 Dollars)	**$7.2**

16. Cost of the GeoXRay Tool

GeoXRay resulted in total costs of $273,000 in 2017 dollars. These costs are detailed in Table 39. The costs of GeoXRay were exclusively associated with project costs and the associated oversight. There were no substantial pre-project costs incurred in the development of GeoXRay and because GeoXRay was not implemented by the government, there were no implementation or follow-up costs. If the government chose to utilize GeoXRay, additional implementation costs would likely be small because GeoXRay is software that existing analyst employees could utilize. It is unlikely that there would be additional staffing requirements.

17. Benefits of the GeoXRay Tool

GeoXRay allows decision-makers to more effectively allocate resources by better identifying threats and understanding their locations. The value of GeoXRay can be calculated in a value of information context in which the expected outcomes without the new information (GeoXRay) are compared against expected outcomes with the new information. In each case, decision-makers are assumed to act rationally, given the information available to them, and expected outcomes are calculated based on these optimal rational responses.

Table 39: Development Costs of the GeoXRay Tool (in 2017 Dollars)

Cost Category	Amount
Pre-project costs (COE)	
Pre-project costs (other funding)	
Project costs (COE)	$190,240
Project costs (university cost share)	
Oversight cost at the COE	$38,048
Oversight cost at OUP	$44,800
Transition development cost	
Implementation start up cost	
Implementation cost (User)	
Implementation cost (COE)	
Implementation cost (Other users)	
TOTAL COST	**$273,088**

Figure 15 presents a decision tree outlining the series of actions and outcomes with and without GeoXRay, abstracting from the spatial nature of the tool. Without GeoXRay we assume that there is no additional intervention possible, and that a successful attack occurs based on existing security measures. With GeoXRay, there is some probability that this tool provides information that an attack is being planned, and security forces can then choose whether or not to attempt an intervention. If an attack is attempted and the government intervenes, the probability of a successful attack declines. In the case of either signal (an attack being either imminent or not imminent), there is some probability that the signal is correct and some probability it is incorrect. The expected value with GeoXRay is the consequence of each potential outcome (e.g. a successful attack, given that intervention was attempted), weighted by the probability that that outcome occurs. The expected value without GeoXRay is the consequence of each potential outcome (e.g. a successful attack, no attack) weighted by the probability that each outcome occurs. The value of GeoXRay is the difference in these expected values.

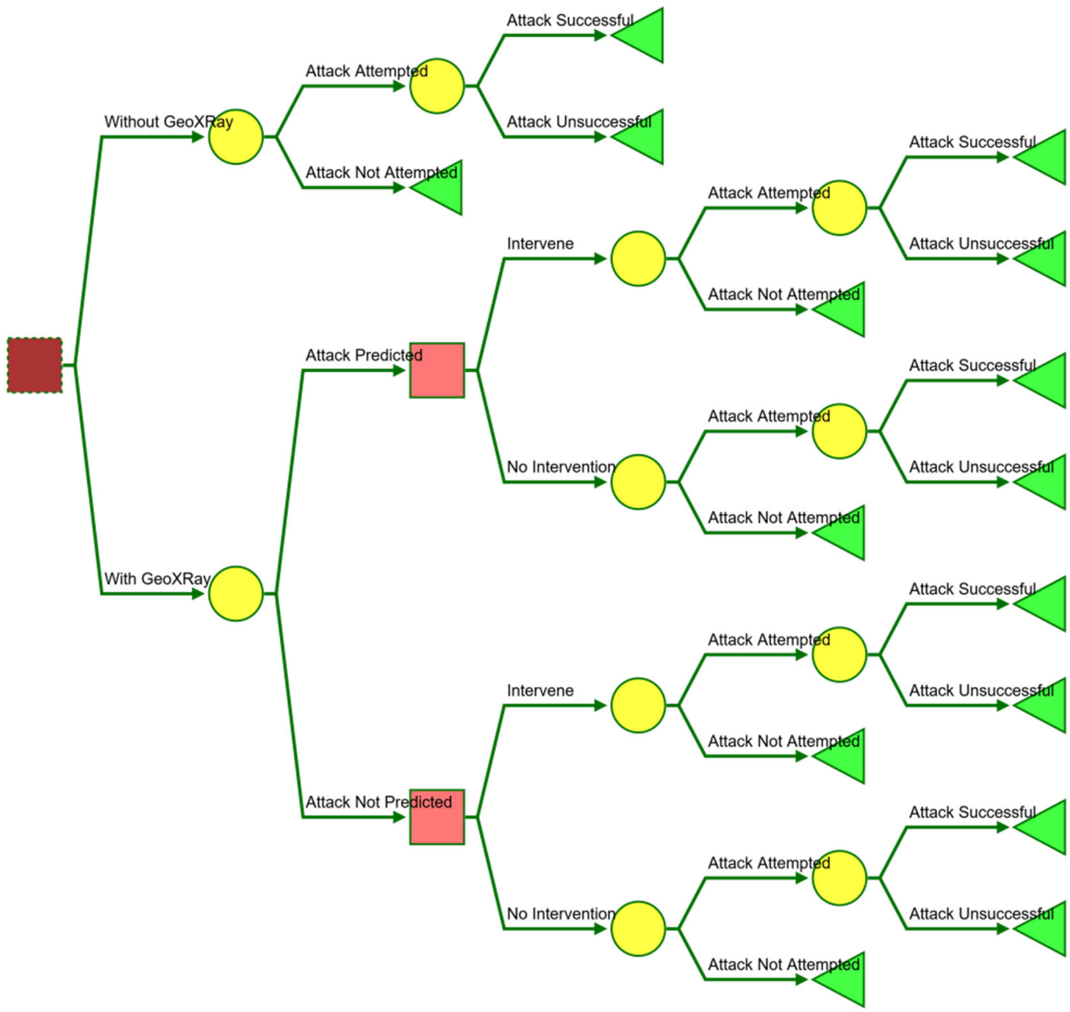


Figure 15: GeoXRay Decision Tree

In the following, we discuss some of the key variables influencing the benefits of using GeoXray.

Damages from Successful Attacks. We consider the costs of three potential attack magnitudes that could result from a relatively isolated lone-wolf style attack that GeoXRay is likely to be most effective at detecting.

Because there tends to be relatively little property damage from lone-wolf attacks, we focus on the monetary value of the casualties and injuries in the small and medium attack cases. Data on the number of fatalities and injuries from lone wolf attacks since 2002 are available from the University of Maryland's Global Terrorism Database (GTD). We calculate the losses from each attack assuming that the value of a statistical life is $10 million and the value of a statistical injury is $100 thousand.[3] We assume that a small attack results in damages equal to the median-level of losses for successful lone wolf terrorist attacks, and that a medium attack results in damages equal to the 90th percentile level of historic losses.

We also consider the possibility of a large, successful terrorist attack that results in behavioral impacts (e.g. reductions in international travel from tourists concerned about U.S. safety, see Rose et Al 2009).[4] Such behavioral impacts could result in substantially larger economic impacts than just property damage or fatalities associated with a lone-wolf style attack.

Probability of Attack and Number of Potential Signals. We base the probability of a small and medium attack attempt on the frequency with which successful attacks in the GTD database resulted in a given magnitude of damages in each year, and the relative frequency of those attacks. For example, because we assume that a medium-sized attack is one that results in damages equal to the 90th percentile of successful attack damages, we assume that medium-sized attack attempts occur approximately 10% of the time.

Similarly, we calculate the number of potential attack signals that could be detected by GeoXRay by adjusting the number of successful attacks each year by the ratio of successful attacks to total attacks. Since 2001, approximately 80% of terrorist plots in the United States have been thwarted or intercepted, the total number of potential attacks each year is five times the average number of successful attacks.[5]

We also calibrate the probability of a successful attack given an attempt based on the frequency with which successful attacks have resulted in damages, and the ratio of thwarted attacks to successful ones. This baseline success probability captures other (non-geocoded) interdiction and detection efforts. Finally, we assume that in an intervention attempt due to GeoXRay reduces the probability of a successful attack by one half. There is little or no data publicly available data on the effectiveness of geospatial data in interdiction so we focus on a central point that allows a wide range in the sensitivity analysis.

Under the baseline assumptions, GeoXRay results in annual expected benefits of $2.5 million. This is primarily driven by the fact that GeoXRay is cutting the number of expected successful attacks each year in half, due to the assumed efficacy of intervention after a potential attack is identified. If the most damaging events – which are primarily driven by behavioral responses – are included, the benefits increase to $6.8 million. There would need to be about 0.25 potential attacks per year that could be detected by GeoXRay in order to achieve break-even benefits.[i]

Table 40 presents the annual benefit of the GeoXRay tool under the baseline parameters.

[i] This assumes that total expenditure on GeoXRay development was the $273,000 spent by the federal government (i.e. there was no additional private investment by TerraGo).

Table 40: Annual Benefit of the GeoXRay Tool

Input Variable	Large Events Included	No Large Events
Probability of Successful Attack	0.106	0.106
Relative Probability with GeoXRay	0.5	0.5
Number of Potential Incidents	17	17
Damage from Large Attack (Millions of 2017 Dollars)	$1,000.0	$0.0
Probability of Large Attack	0.005	0
Discount Factor	0.03	0.03
Damage from Medium Attack (Millions of 2017 Dollars)	$94.3	$94.3
Damage from Small Attack (Millions of 2017 Dollars)	$10.5	$10.5
Probability of Medium Attack	0.021	0.021
Probability of Small Event	0.129	0.129
Expected Damages No Geoxray (Millions of 2017 Dollars)	$15.1	$6.1
Prob with Interdiction	0.053	0.053
Number of Positive Signals Large	0.09	0.00
Number of Positive Signals Medium	0.36	0.36
Number of Positive Signals Small	2.19	2.19
Number of Negative Signals	14.36	14.45
Number of True Signals Large	0.08	0.00
Number of True Signals Medium	0.35	0.35
Number of True Signals Small	2.08	2.08
False Positive Signals	4.31	4.33
True Negative Signals	10.06	10.11
False Negative Signals Large	0.00	0.00
False Negative Signals Medium	0.02	0.02
False Negative Signals Small	0.11	0.11
Interdiction Cost	$0.4	$0.4
Cost of Large Attacks (Millions of 2017 Dollars)	$4.7	$0.0
Cost of Medium Attacks (Millions of 2017 Dollars)	$1.9	$1.9
Cost of Small Attacks (Millions of 2017 Dollars)	$1.3	$1.3
Expected Damages with Geoxray (Millions of 2017 Dollars)	$8.3	$3.6
Total Value of GeoxRay / Year (Millions of 2017 Dollars)	**$6.8**	**$2.5**

18. Benefit-Cost Analysis – Base Case

Assuming a 3 percent discount rate and 10 years of benefits, the net present value of GeoXRay is approximately $20.8 million. If costs associated with large attacks are included this value increases to $57.6 million. In each case, we assume that there are no additional operation costs associated with maintaining GeoXRay over time. The key parameters driving this result are the reduction in the likelihood that an attack is successful if GeoXRay is used (50% reduction), the baseline probability that an attack is successful (10%), and the potential number of attacks each year (17). The base case benefit-cost ratio (BCR) is 77, and the return on investment (ROI) is

7,600%. Each of these values is associated with the conservative case in which large, behavioral costs are ignored.

19. Sensitivity and Uncertainty Analysis

Break Even Analysis. Holding all other parameters constant, the GeoXRay tool will break even (i.e., result in an NPV of zero) if there are 0.25 potential attacks per year, if the GeoXRay tool reduces the likelihood of a successful attack by 10%, or if the baseline probability of a successful attack is 1.5%. In each case, the values that would result in a negative ROI for GeoXRay are substantially different than the baseline assumptions and the sensitivity analysis range.

Tornado Analysis. Next, we consider a formal sensitivity analysis of the value of GeoXRay by varying each of the key parameters and recalculating the value of GeoXRay. The range of input parameters for the sensitivity analysis is shown in Table 41. The results of this valuation are sensitive to the parameter assumptions underlying the model. Figure 16 presents a "tornado diagram" showing how changes in the underlying parameters affect the value of GeoXRay.

Table 41: Ranges of GeoXRay Inputs for Sensitivity Analysis

Input Variable	Min	Base	Max
Probability of Successful Attack	0.05	0.106	0.15
Relative Probability with GeoXRay	0.25	0.5	0.75
Number of Potential Incidents	10	17	24
Damage from Large Attack (Millions of 2017 Dollars)	$750.0	$1,000.0	$1,250.0
Probability of Large Attack	0.0025	0.005	0.0075
Discount Factor	0	0.03	0.07
Damage from Medium Attack (Millions of 2017 Dollars)	$47.3	$94.3	$141.3
Damage from Small Attack (Millions of 2017 Dollars)	$5.5	$10.5	$15.5

The model suggests that GeoXRay is sensitive to the input parameters. As the baseline probability of terrorist success rises (i.e. intelligence mechanisms other than GeoXRay are less effective), the value of GeoXRay rises. This occurs because terrorist attacks are relatively more likely without GeoXRay's information. Similarly, as the reduction in the likelihood of terrorist success due to intervention rises, the value of GeoXRay increases because security forces are able to interdict a greater number of attacks identified by GeoXRay. As the number of potential events that can be detected by GeoXRay increases, the value of GeoXRay increases as well. Finally, as the probability and magnitude of attacks increase, the value of GeoXRay increases.

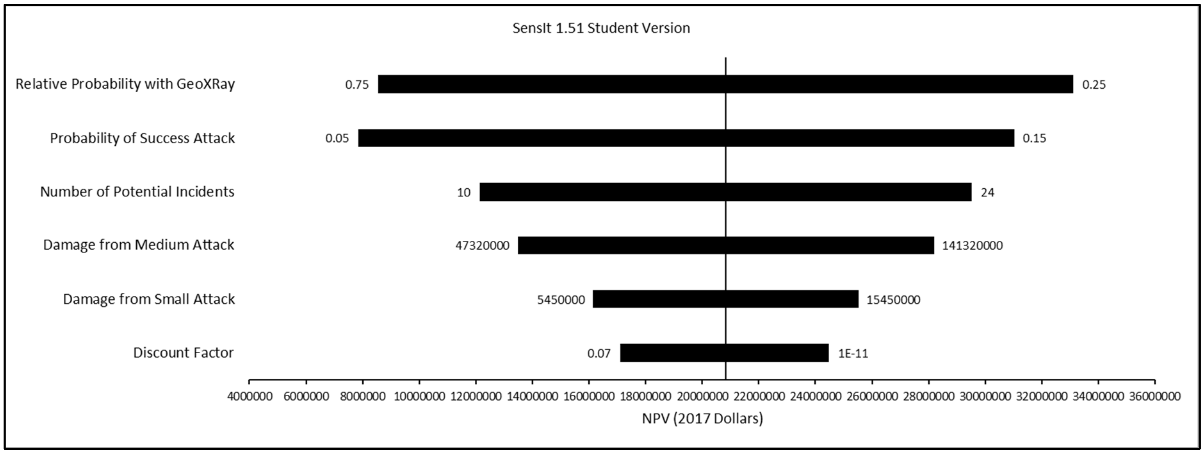


Figure 16: GeoXRay Tornado Analysis

Uncertainty Analysis. In Figure 17, we present the distribution of the imputed value of GeoXRay across each of these scenarios. In Figure 18, we show a comparable distribution of valuations if the effects of large attacks are removed. A summary of 10-year discounted net present benefits are presented in Table 42. If discounted benefits accumulate over a 10-year period, the net benefits range from $8.4 million to $35.2 million with mean and median net benefits of $19.6 million and $18.4 million, respectively.

Table 42: Statistics of the GeoXRay NPV Distribution (Millions of 2017 Dollars)

	Large Events	No Large Events
Mean	$54.1	$19.6
St. Dev.	$21.9	$8.4
5th Percentile	$24.6	$0.0
25th Percentile	$38.3	$13.5
Median	$50.9	$18.4
75th Percentile	$66.8	$24.4
95th Percentils	$94.9	$0.0

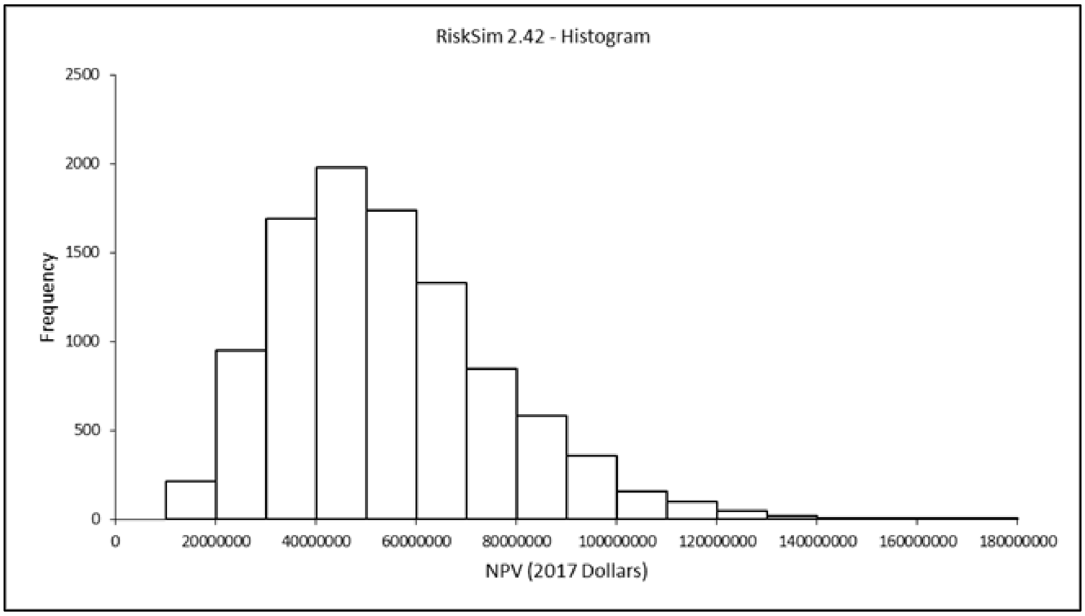


Figure 17: Uncertainty Analysis with Large Events

(in 2017 Dollars)

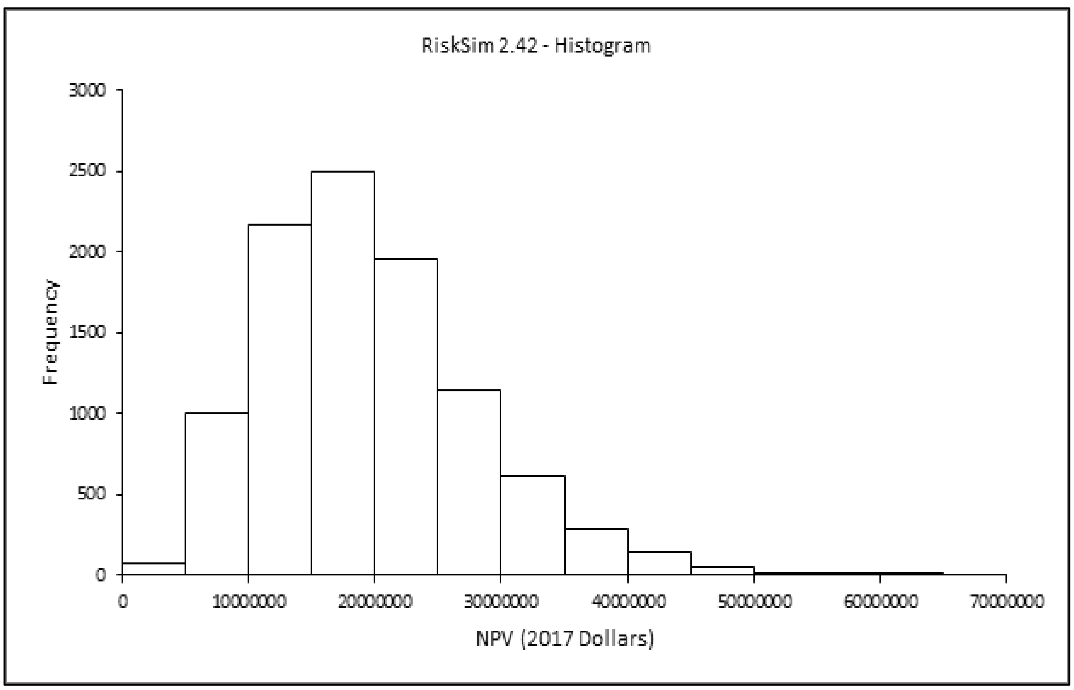


Figure 18: Uncertainty Analysis without Large Events

20. Assumptions and Limitations

This analysis relies on a number of decisions about attack interdiction. Most notably, we hold the number of potential attacks and the efficacy of interdiction constant. If GeoXRay resulted in multiple interdicted attacks, terrorists would likely shift their means of communication so that it could not be as easily detected. Similarly, terrorists might shift to attacks that are not geographically located (e.g., cyber-attacks). In this case, GeoXRay would reduce risks along one dimension, but increase them in other sectors.

We also assumed that the efficacy of GeoXRay was consistent across attack types. If GeoXRay is more able to detect large attacks than small ones, security forces may not attempt interdiction on frequent, small events because they are more likely to result in unnecessary expenditures.

The primary limitation of this valuation relates to the uncertainty in disaster frequency and the potential for interdiction. The number of potential attacks that can be detected with GeoXRay is one of the key determinants of its value. Given that GeoXRay hasn't been implemented, however, it is impossible to determine just how frequently attacks would be detectable by the software. The model also does not allow for variation in confidence in GeoXRay's signals. Because GeoXRay would likely be operated by experienced analysts, there would likely be the potential for separating "high quality" information from "low quality" information and making independent decisions about whether or not to pursue interdiction.

This analysis was limited in scope to potential terrorist attacks. GeoXRay could, of course, provide similar improvements in interdiction for other law enforcement situations. If GeoXRay were used as a proof-of-concept for other risks, the societal benefits would rise.

Finally, it is unclear to what extent GeoXRay duplicates existing technologies among intelligence agencies. It is highly possible that geospatially-encoded data on key words related to risks is already incorporated. If this is the case, the efficacy of GeoXRay in reducing the likelihood of a successful attack is likely overstated.

21. Recommendations for additional research

There are several potential pathways to improve the precision of the GeoXRay analysis. Many of the variables that are most important in the parameterization of the value of GeoXRay are not publicly available. If classified information could be obtained on these parameters, uncertainty in the benefits would be substantially reduced. The key variables to be collected are

1. Interdiction costs
2. Number of potential annual terror threats
3. Success rates of non-interdicted terror threats
4. Efficacy of interdiction

22. References

1. TerraGo. "TerraGo GeoXRay". Available at: http://www.terragotech.com/products/terrago-geoxray, Last Accessed: 5/9/2018
2. Blomquist, G. C. Review *of Economics of the Household*. "Self-Protection and Averting Behavior, Values of Statistical Lives, and Benefit Cost Analysis of Environmental Policy", 2:2004.
1. Ibid.
3. Rose, A., Oladosu, G., Lee, B. and Beeler-Asay, G. *Peace Economics, Peace Science, and Public Policy*. "The economic impacts of the terrorist attacks on the World Trade Center: A computable general equilibrium analysis", 15:2009.
4. Strom, Kevin J., Hollywood, John S., and Pope, Mark. R*AND Working Paper*. "Terrorist Plots Against the United States: What We Have Really Faced, and How We Might Best Defend Against It", 2015.

Benefit-cost Analysis of TraffiCop

Developer: Command, Control, and Interoperability
Center for Advanced Data Analysis (CCICADA)
Analysts: Heather Rosoff and Detlof von Winterfeldt, CREATE

1. Summary

Description of the TraffiCop. CCICADA developed a social media search tool to identify sex trafficker websites to support law enforcement in identifying both perpetrators of sex trafficking and their victims. The tool, called TraffiCop, was developed in cooperation with subject matter experts at the California and New York Offices of the Attorney General and the FBI.

Results. We estimated the cost of developing TraffiCop at $1.3 million. This estimate only includes the development and implementation cost of the tool. In addition, there are costs for using the tool, which we estimate at $200,000/year, if 20 investigators use it for 100 hours per year. These costs are counted in the net benefit calculations.

The benefits of using TraffiCop are twofold: Saving victims from sex trafficking and convicting sex traffickers. In the base case we estimate that the net benefits from using TraffiCop for ten years by 20 investigators for 100 hours per year is $7.9 million. Due to the uncertainty of several input variables entering the benefits calculation, this base case estimate has a range from $3.2 million (5th percentile) to $10.4 million (median) to $24.6 million (95th) percentile.

2. Background

Problem Context. "Sex trafficking is a form of modern slavery that exists throughout the United States and globally. Sex traffickers use violence, threats, lies, debt bondage, and other forms of coercion to compel adults and children to engage in commercial sex acts against their will. Under U.S. federal law, any minor under the age of 18 years induced into commercial sex is a victim of sex trafficking—regardless of whether or not the trafficker used force, fraud, or coercion." [1]

Some statistics on sex trafficking:

- About 5,600 cases of sex trafficking were reported in the U.S. in 2016, a number that is steadily rising.[2]
- In spite of this large number of cases, the number of prosecutions of sex traffickers is only in the low hundreds per year.[3]
- The conviction rate remains at about 50%.[4]

The Trafficop TTKP. TraffiCop is a social media search tool to identify sex trafficker websites to support law enforcement in identifying both perpetrators of sex trafficking and their victims. TraffiCop was developed by CCICADA researchers in cooperation with subject matter experts at the California and New York Offices of the Attorney General and the FBI. TraffiCop has the dual purpose of identifying and rescuing victims of sex trafficking and of increasing the prosecution and conviction rates of sex traffickers.

3. Baseline Performance without TraffiCop

Prior to using TraffiCop, investigators at the FBI and at prosecutors' offices in New York and San Francisco examined information about potential sex traffickers by personally visiting websites and reviewing sex advertisements. This is both a laborious and imprecise process, which can take many weeks for a single investigator in order to identify a single case of sex trafficking. We did not estimate the success rate or time spent by investigators in New York and San Francisco, though the rate of prosecutions is low compared to the numbers of cases reported and the conviction rate is only 50%. Instead, we used as a baseline the case in which no investigator uses TraffiCop and determined the additional numbers of arrests and convictions per hour of use of TraffiCop.

4. Cost of TraffiCop

Table 43 shows the cost of the TraffiCop project. The table only includes the development and implementation costs of the tool. In addition, there are costs for using the tool, which we estimate at $200,000/year, if 20 investigators use it for 100 hours per year. These costs are counted in the net benefit calculations.

Table 43: Cost of the TraffiCop Project

Cost Category	Start	End	Amount	2017 Dollars	Source
Pre-project costs (COE)					
Pre-project costs (other funding)					
Project costs (COE)	1/1/2010	12/31/2010	$300,000	$336,000	CCICADA
Project costs (university cost share)					
Oversight cost at the COE	1/1/2010	12/31/2012	$60,000	$67,200	CCICADA
Oversight cost at OUP	1/1/2010	12/31/2010	$20,000	$21,800	OUP
Transition development cost					
Implementation start up cost					
Implementation cost (User)	1/1/2011	12/31/2012	$800,000	$864,000	FBI
Implementation cost (COE)					
Implementation cost (Other users)	7/1/2014	6/30/2015	$120,000	$123,600	CBP
TOTAL COST			**$1,300,000**	**$1,412,600**	

5. Benefits of TraffiCop

Table 44 shows the input numbers for the base-case benefit calculations. This analysis is anchored on experiences with a similar tool developed at the Information Sciences Institute (ISI) of USC. In one case evaluation, the developers determined that 100 hours of an investigator's time of using the tool would result in the identification of one case of sex trafficking, leading to the arrest of the trafficker and the release of the victim from the abuse. In the benefits analysis we assume that 20 case study officers work in a similar fashion for 100 hours per year, leading to one successful identification and rescue per 100 hours.

We do not consider it a certainty that this effort always leads to rescuing the victim and arresting and convicting the trafficker. Instead, we assign probabilities to these events.

Other important inputs into this benefit calculation are the value of saving a victim from further abuse ($100,000 in the base case) and the value of convicting a sex trafficker ($50,000 in the base case). The value of convicting a sex trafficker is low, because saving the victim is already counted. Of course, some sex traffickers have many victims, but, to be on the conservative side, we only assumed that each trafficker is involved in a single case of trafficking.

Table 44: Base Case Analysis of the Benefits of the TraffiCop Tool

Variable	Base Case
Cost of one additional investigator using TraffiCop for one year	$200,000
Work hours/year	2000
Cost per hour	$100
Number of investigators using Trafficop	20
Number of hours/year of using TraffiCop per investigator	100
Number of sex traffic victims Identfied per 100 hours of use of TraffiCop	1
Probability of victim rescued after identification	50%
Probability of trafficker caught after victim identified	50%
Probability of conviction after being caught with Trafficop	50%
Value of saving one victim	$100,000
Value of convicting one trafficker	$50,000
Discount Rate	3%
Total annual cost of using TrafficCop	$200,000
Benefits, Year 1 for saving victims	$1,000,000
Benefits, Year 1 for convicting traffickers	$125,000
Benefit in 2017 dollars	**$1,125,000**
Ten Year Benefits	**$9,884,373**
Ten Year Net Benefits	**$6,445,573**

6. Benefit-Cost Analysis – Base Case

The ten-year net present value in discounted 2017 dollars is $6.5 million in the base case. The benefit-to-cost ratio is about 7.0, and the return on investment is about 460%.

7. Sensitivity and Uncertainty Analysis

Cost-Effectiveness Analysis. The TraffiCop tool will likely lead to additional identification of victims and traffickers. While it is difficult to put a value on rescuing a person from sex trafficking, a lower bound is the avoidance of one year of life-loss from other causes, which has been estimated at $100,000. Thus, to break even, the TraffiCop tool would have to save at least 13.2 victims from trafficking over ten years, or roughly one victim per year.

Tornado Analysis. There is little uncertainty in the calculations of the costs for the development and implementation of TraffiCop. The costs of using TraffiCop depends on the number of hours spent investigating per investigator per year. Using the example of one investigator, we use 100 hours per year in the base case. This is a conservative estimate. Increasing the number of hours will increase the costs somewhat, but the benefits will also increase.

The major uncertainties are about the "soft" input estimates:

1. The number of investigators using TraffiCop
2. The number of hours each investigator uses TraffiCop
3. The probability of a victim being rescued after a TraffiCop identification
4. The probability that a trafficker is caught and arrested after the victim is identified
5. The probability that a trafficker is convicted after being caught with TraffiCop

We used the ranges in Table 45 for further sensitivity analysis.

Table 45: Ranges of TraffiCop Inputs for Sensitivity Analysis

Variable	Low	Base Case	High
Cost of one additional investigator using TraffiCop for one year	$200,000	$200,000	$200,000
Work hours/year	2000	2000	2000
Cost per hour	$50	$100	$150
Number of investigators using Trafficop	10	20	30
Number of hours/year of using TraffiCop per investigator	50	100	200
Number of sex traffic victims Identfied per 100 hours of use of TraffiCop	0.5	1	2
Probability of victim rescued after identification	40%	50%	60%
Probability of trafficker caught after victim identified	40%	50%	60%
Probability of conviction after being caught with Trafficop	40%	50%	60%
Value of saving one victim	$50,000	$100,000	$200,000
Value of convicting one trafficker	$25,000	$50,000	$100,000
Discount Rate	0%	3%	7%

Figure 19 shows a tornado diagram, which illustrates how the changes in each uncertain variable (from low to high values) impact the net benefit. The most important variables in this diagram have the largest range (bar), from the benefit calculated with the low value, versus the benefit calculated with the high value. The most important variables are the number of sex traffickers identified per 100 hours of using TraffiCop, the value of saving one victim, and the number of investigators using TraffiCop.

Uncertainty Analysis. To explore the effect of uncertainty on the ten-year benefit, we conducted a Monte Carlo simulation. We assume triangular probability distributions for all variables, with the low value being the minimum of the triangular distribution, the base case being the mode, and the high value being the maximum. We then ran 10,000 simulations resulting in a distribution of net benefit as shown in Figure 19. Table 46 shows the key statistics of this distribution. In particular, the 5th, 50th, and 95th percentiles are \$3.2 million, \$10.4 million and \$24.6 million, respectively.

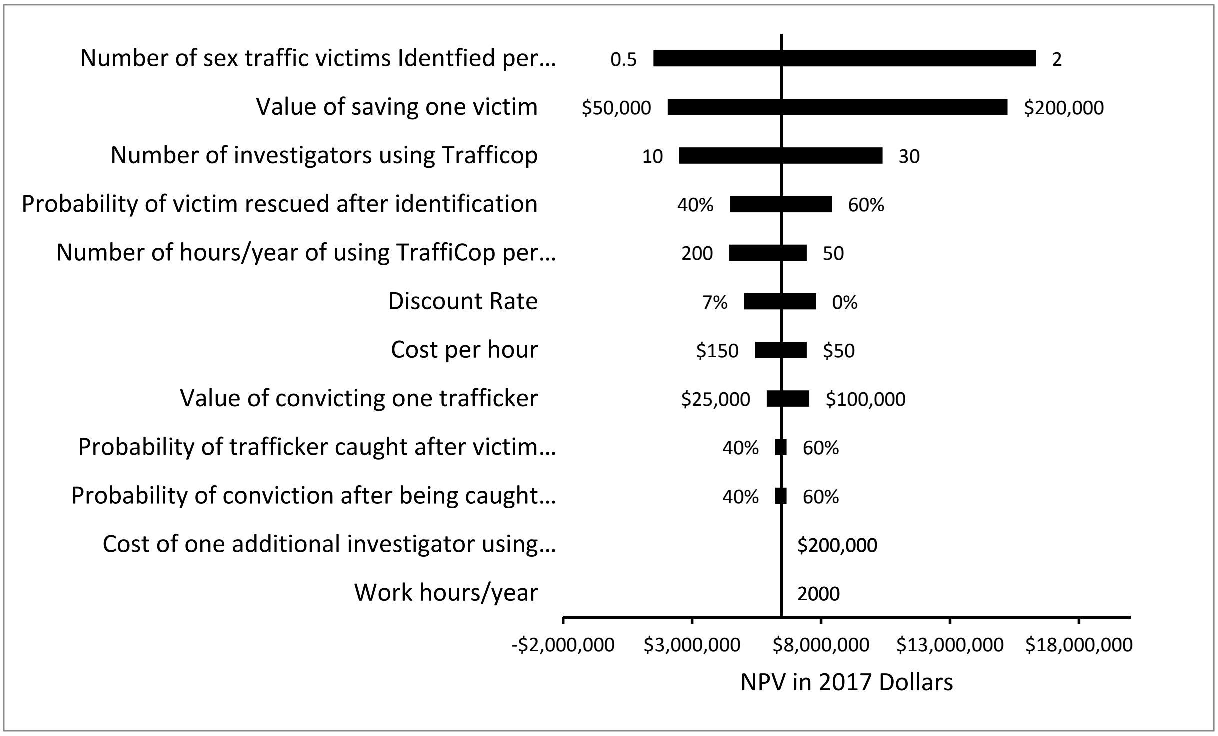


Figure 19: Net Present Value of Using TraffiCop for Ten Years

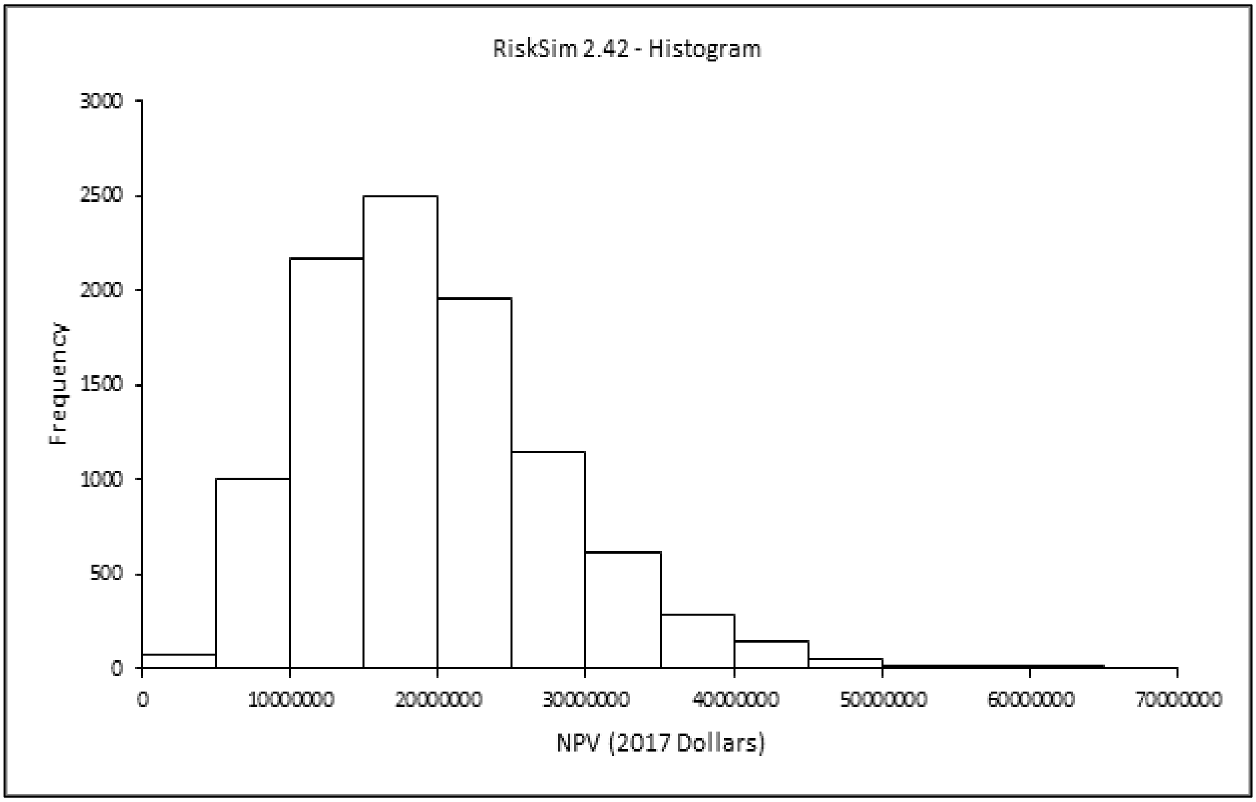


Figure 20: Net Present Value Distribution

Table 46: Statistics of the Net Present Value Distribution

Mean	$11,754,865
St.Dev.	$6,636,528
5th Percentile	$3,213,544
25th Percentile	$6,928,931
Median	$10,443,892
75th Percentile	$15,263,211
95th Percentile	$24,561,910

8. Assumptions and Limitations

Several of the most important inputs to the benefits calculations are also the most uncertain:

1. The number of investigators using TraffiCop
2. The number of hours of use of TraffiCop/Investigator per year
3. The number of victims identified using TraffiCop per 100 hours of use

The combination of these variables at the low end (few investigators, few hours, and low rate of victim identification) actually can lead to a negative net benefit.

Another issue is the competition of tools that are similar to TraffiCop. We assumed that the rate of convictions is based on not using any tools at all. However. The FBI and district attorneys' offices around the country are using increasingly sophisticated tools. This makes it hard to establish a baseline against which the use of a single tool can be evaluated.

Finally, there is very little research on the value of saving a victim or of convicting a trafficker. We used a wide range for both, with the value of saving a victim making a substantial difference to the benefits.

9. Additional Research

To further evaluate benefits of TraffiCop and similar web-based tools, it would be useful to establish a baseline rate of identifying victims and traffickers, ideally in terms of hours of investigator efforts. If possible, a side-by s-de comparison of investigators working with and without the tool should be carried out.

It would also be interesting and useful to conduct research on the value of saving a victim from further abuse. We used a range from $50,000 to $200,000, anchored at the value of one life-year saved. These values may be at the low end, considering that some victims are abused for many years and suffer permanent physical and psychological damage.

10. References

1. Polaris (2017). Polaris Project. www.polarisproject.org/sextrafficking. Last accessed on October 20, 2017.
2. Ibid.
3. U.S. Department of Justice (2917) https://www.justice.gov/crt/human-trafficking-prosecution-unit-htpu#cas. Last accessed on October 20, 2017.
4. Nolan Brown, E. (2016). Sex trafficking arrests are on the rise, but conviction numbers are still small. http://www.purchased.org/news/2016/02/23/general. Last accessed on October 20, 2017.

Benefit-Cost Analysis of the HOAX Call Tool

Developer: Command, Control, and Interoperability Center for Advanced Data Analysis (CCICADA)
Analysts: Richard John and Detlof von Winterfeldt, CREATE

May 8, 2018

1. Summary

Description of the HOAX Call Tool. The Command, Control, and Interoperability Center for Advanced Data Analysis (CCICADA) developed a computerized voice print recognition tool to identify callers who request a rescue by the U.S. Coast Guard (USCG), even though they are not in jeopardy. In 2016 the U.S. Coast Guard received 161 of these so called "hoax calls." The HOAX call tool helps the U.S. Coast Guard to identify features of hoax callers and to prosecute them successfully, once identified and arrested.

Results. The baseline analysis shows that the USCG loses about $10,000,000 per year due to unnecessary responses to hoax calls, while receiving only about $200,000 per year in restitution. The low restitution amount is due to the fact that a hoax caller first has to be identified (low probability), arrested and convicted (medium probability), and that restitution is received (medium probability). There are two types of benefit from the HOAX call tool: First, it will likely deter some hoax callers, once the use and effectiveness of the tool is known. Second, the tool helps with the conviction of suspected hoax callers by identifying key characteristics of the caller and the call environment.

We estimated the cost of the HOAX call project at $182,934 (in 2017 dollars), which includes the cost of the research at CCICADA, university overhead and oversight cost by the Office of University Programs, as well as some travel cost by USCG staff.

The base case analysis considered a ten-year future use of the tool, starting in 2017, resulting in a net present value (NPV) of $5.1 million. When subtracting the investment cost (inflated to 2017 dollars), we arrive at a total NPV of $4.9 million. There is substantial uncertainty about some of

the inputs to the benefit calculations. Using a probabilistic simulation, we estimated a range of the NPV from $ 1.7 million (5^{th} percentile) to $ 4.6 million (Median), to $ 9.4 million (95^{th} percentile). Thus, even at the low end, the HOAX call tool's net benefit far outweighs its cost. For the base case, the benefit cost ratio (BCR) is 28 and the return on investment is 2,695%.

2. Background

Problem Context. In 2016 The U.S. Coast Guard executed 16,343 search and rescue missions per year, saving thousands of lives and avoiding millions of dollars in property losses[1]. Depending on the situation, a search and rescue operation can cost between $15,000 and $250,000, with a median value of about $50,000[2,3]. In addition, some rescue operations endanger the safety USCG personnel and divert important resources from other operations. Therefore, avoiding unnecessary rescue operations can save substantial amounts of money and potentially save lives.

Rescue callers usually use the Coast Guard's VHF radio channel 16, which some call the "Mariner's 911" number. Most of these calls come from individuals who are truly in distress. Of the 16,343 calls received in 2016, 161 turned out to be hoax calls with an increasing trend[4]. The U.S. Coast Guard launches a search and rescue operation, even if they suspect that a call is a hoax.

If a hoax caller is identified and successfully prosecuted, he or she face a prison term of up to six years, a $250,000 criminal fine, a $5,000 civil fine, and a reimbursement of the USG cost for the search and rescue operation initiated by the call[5].

The HOAX Call Tool. CCICADA, in collaboration with Carnegie Mellon University, developed a tool that uses the recorded voice to create a "voiceprint" of the caller. These voiceprints can be used to identify hoax callers and help in their prosecution and conviction. For example, voiceprints can be used to identify several characteristics of the caller as well as of the background noise and the location of the call. At later stages, it may also be possible to identify repeat hoax callers with voice prints and avoid unnecessary rescue operations and/or deter callers from making the hoax call. One benefit of the voice print tool is the increased likelihood to convict hoax callers and to receive restitution for the cost of the rescue operation. Once the use and effectiveness of the tool is widely known, it may also serve as a deterrent to hoax callers, thus reducing the number of hoax calls.

3. Baseline Performance Without the HOAX Calls Tool

Hoax calls cause the USCG to waste precious resources, put the safety of USCG personnel and assets at risk, and possibly divert assets from important search and rescue operations[6]. In our baseline analysis, we focus on the current performance of the USCG's response to hoax calls considering the frequency of the hoax calls, the cost of responding to the hoax calls, the rate of identifying a hoax caller, the rate of convicting a hoax caller, and the amount of restitution received from a convicted hoax caller. Other performance aspects, such as endangering USCG personnel and missed opportunities for more important search and rescue operations are much harder to quantify and are considered qualitatively.

Table 47 shows the input numbers for the base line calculations. The annual number of rescue operations per year is about 20,000. According to the U.S. Coast Guard records, rescue cost can vary widely, at the low end several thousands of dollars and some rescues costing in excess of $200,000[7]. Based on data[8] and interviews[9] we used $50,000 as the median cost estimate.

There were 161 calls in 2016, with a rising trend. To take this trend into account, we used 200 estimated hoax calls in 2017. The arrest rate of 10% was estimated at 10% and the conviction rate without the HOAX calls tool at about 40%, based on expert judgement.

Not all convictions lead to a ruling of restitution and in some cases the convicted individual will not be able to pay the amount of restitution. To account for this in the base case, we assume a 50% success rate in collecting the cost of the search and rescue operation through restitution. We assume that restitution is paid by half of the convicted hoax callers.

Table 47: Baseline Analysis Without the HOAX Call Tool

Rescue operations per year	20,000
Average cost per rescue operation	$50,000
Hoax calls/year	200
Arrest rate	10%
Conviction rate w/o HOAX Calls Tool	40%
Restitution collection rate	50%
Annual cost due to haox calls	$10,000,000
Total annual expected cost recovery	$200,000

4. Cost of the HOAX Call Tool

Table 48 shows the development cost of the HOAX call tool. The NPV (2017 dollars) of the cost of the HOAX call project is $182,934, using the Consumer Price Index (CPI) to adjust for inflation.

According to U.S. Coast Guard, the ongoing cost of maintaining and using the HOAX calls tool are very small and there may even be some cost savings, as the analysis of voice prints will be automated. Therefore, we attribute all costs of the HOAX calls tool to its development.

Table 48: Development Cost of the HOAX Call Tool (in 2017 Dollars)

Cost Category	Amount	Source
Pre-project costs (COE)		
Pre-project costs (other funding)		
Project costs (COE)	$ 71,070	CICCADA/OUP
Project costs (university cost share)		
Oversight cost at the COE	$ 14,214	CICCADA/OUP
Oversight cost at OUP	$ 41,000	OUP
Transition development cost	$ 56,650	Supplement
Implementation start up cost		
Implementation cost (User)		
Implementation cost (COE)		
Implementation cost (Other users)		
Total cost (2017 dollars)	**$ 182,934**	

5. Benefit of the HOAX Calls Tool

Table 49 shows the base case inputs for the benefit calculation. There are two types of potential benefit of the HOAX calls tool. The first is the deterrence effects of the tool once publicized and used in court. In other words, it is likely that some potential hoax callers will reconsider possible consequences before making the call and some will not make the call at all. We use a 5% reduction of the 200 hoax calls every year. This benefit alone adds to $500,000 per year of reduction in hoax calls (product of 10 hoax calls avoided and $50,000 per hoax call).

The second benefit is the increase in the conviction rates of suspected hoax callers. In the base case, we assume that there is a 50% increase (from 40% to 60%) in the conviction rate, due to the improved ability to match the hoax callers' voice prints to the suspects. This benefit amounts to an annual increase of $100,000 in collected restitution (50% of $200,000).

Table 49: Annual Benefit of the HOAX Calls Tool

Input Variable	Base Case
Rescue operations year	20,000
Average cost per rescue operation	$50,000
Hoax calls/year	200
Arrest rate	10%
Conviction rate w/o HOAX Calls Tool	40%
Restitution collection rate	50%
Deterrence effect	5%
Increase of conviction rate	50%
Annual savings due to deterrence	**$500,000**
Annual increase in amount of restitution	**$100,000**

6. Benefit-Cost Analysis – Base Case

Given the base-case inputs in Tables 48 and 49, the total estimated annual benefit is $600,000. The 10-year net present value (NPV) of this future stream of $600,000/year sums to $5,118,122. Subtracting the NPV of the investment cost incurred through 2017, we determined a total NPV of $ 4,934,988. The base-case benefit-cost ratio (BCR) is 28, and the base-case estimate of return on investment (ROI) is 2,695%.

7. Sensitivity and Uncertainty Analysis

Break-Even Analysis. The HOAX call tool will likely lead to additional convictions of hoax callers and recovery of search and rescue cost through restitution. Assuming an average restitution amount of $50,000 (the average cost of a search and rescue operation), four additional convictions with restitution over the 10-year period would exceed the cost of the project. Similarly, deterrence of four hoax calls over the 10-year period would also pay for the cost of the project.

Tornado Analysis. There is little uncertainty in the cost calculations. For the inputs to the benefit calculations and the benefit-cost analysis, we used the ranges displayed in Table 50.

Table 50: Ranges of HOAX Call Inputs for Sensitivity Analysis

Variable	Low	Base Case	High
Rescue operations year	15000	20000	25000
Average cost per rescue operation	$25,000	$50,000	$75,000
Hoax calls/year	100	200	300
Reduction of hoax calls (Deterrence)	0%	5%	10%
Arrest rate	5%	10%	20%
Conviction rate w/o HOAX	30%	40%	50%
Conviction rate multiplier w/ HOAX	25%	50%	75%
Restitution collection rate	25%	50%	75%
Future Discount Rate	0%	3.00%	7%

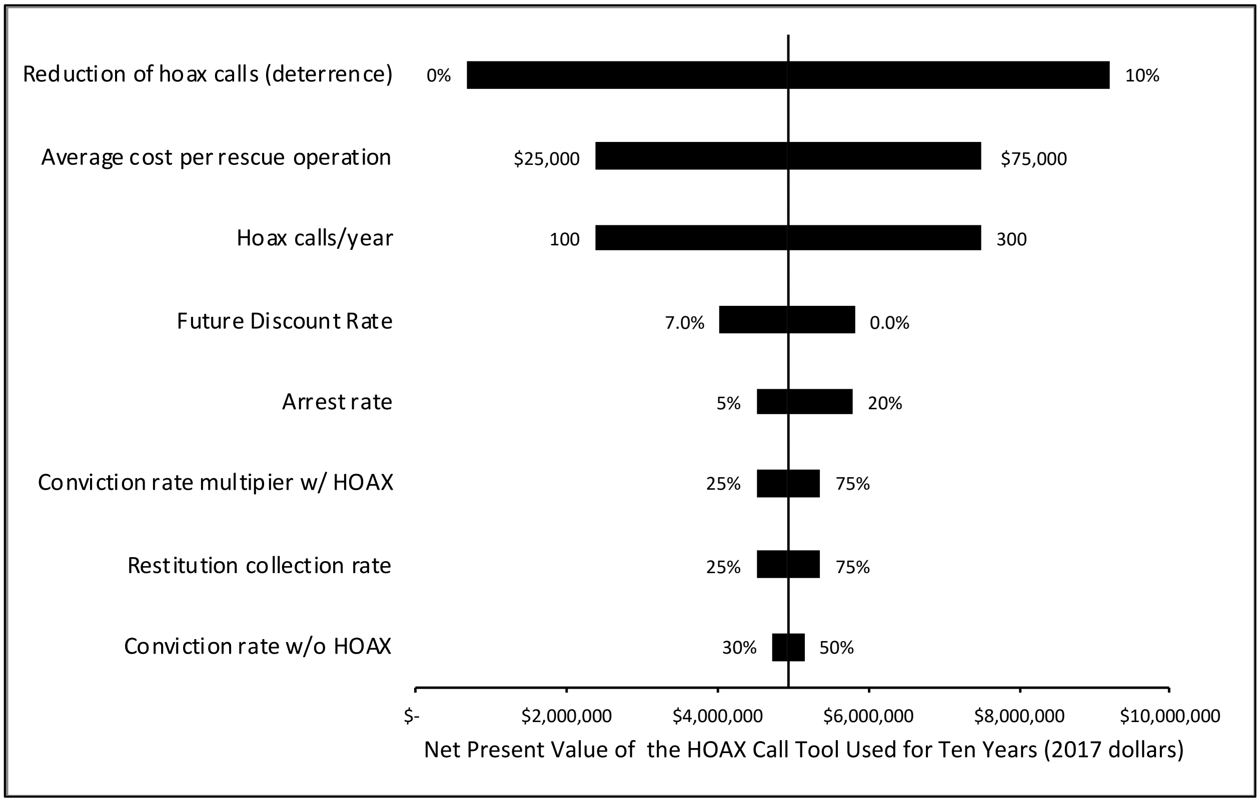


Figure 21: Tornado Diagram for the NPV of the HOAX Call Tool

Figure 22 shows a tornado diagram, which illustrates how the changes in each uncertain variable (from low to high values) impact the NPV. The most important variables in this diagram have the largest range (bar) from the benefit calculated with the low value vs. the benefit calculated with the high value. The three most important variables are the percent reduction of hoax calls due to deterrence, the average cost per search and rescue mission, and the number of hoax calls per year. Of these, the only "soft" number is the one related to the deterrence effect. The other variables are less important and have only a moderate or minor influence on the net benefit.

Uncertainty Analysis. To further explore the uncertainties of some of the input variables, we assumed that these uncertainties can be characterized by triangular distributions with a minimum being the low value in Table 50, the mode being the base case value, and the maximum being the high value. We used an Excel add-in (SimVoi[10]) to simulate the NPV using these triangular distributions to characterize uncertainty in the input variables. The analysis assumes that all input variables are independent and thus uncorrelated with each other and is run for 10,000 iterations.

Figure 22 presents a histogram of the simulated 10,000 NPV calculations for HOAX call tool future use over 10 years (2018-2027). The NPV is the sum of the NPV of future benefit and the NPV of past cost (all calculated in 2017 dollars). Table 51 shows the key statistics of this distribution, showing a median (50th percentile) of \$ 4,645,692, and ranges from \$ 1,734,132 (5th percentile) to \$ 9,417,717 (95th percentile).

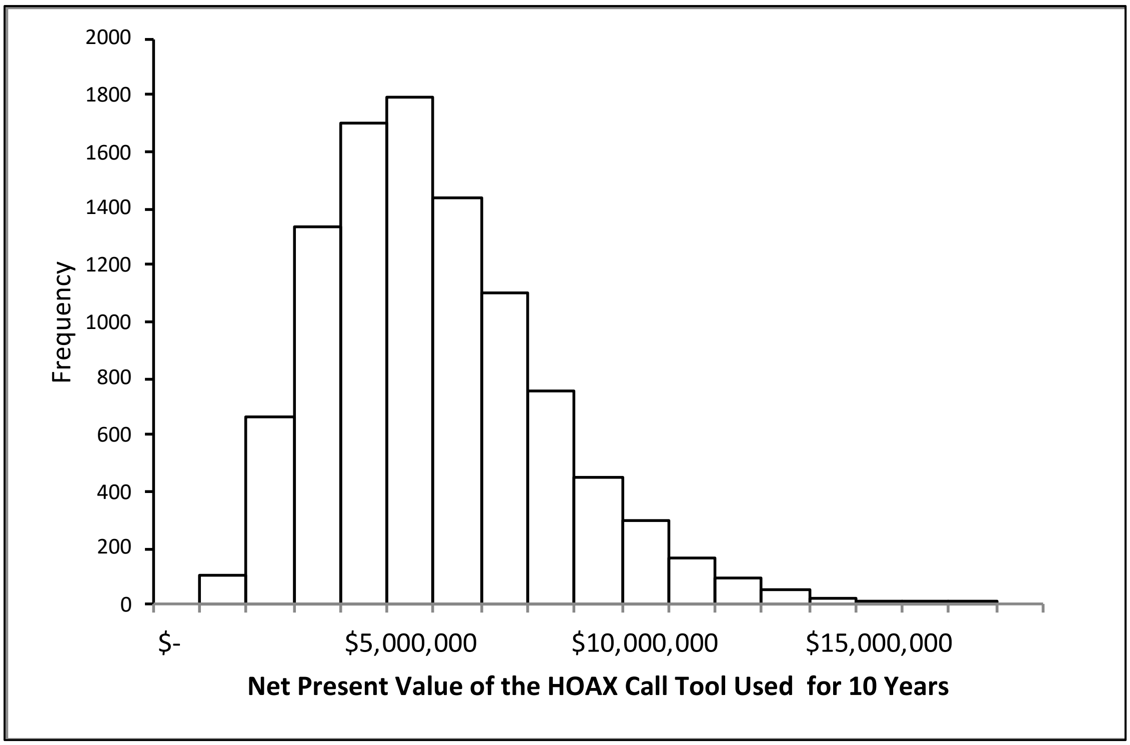


Figure 22: Net Present Value Distribution of the HOAX Calls Tool

Table 51: Statistics of the HOAX Call NPV Distribution

Mean	$ 4,990,239
St. Dev.	$ 2,375,643
5th Percentile	$ 1,730,868
25th Percentile	$ 3,259,045
Median	$ 4,645,692
75th Percentile	$ 6,382,809
95th Percentile	$ 9,442,133

8. Assumptions and Limitations

The assumptions about the input variables in Tables 48 and 49 are likely to overestimate cost and underestimate benefit, thus providing "conservative", i.e., low, NPV outputs. The "softest" variable is the deterrence effect of the HOAX call tool in reducing the number of hoax calls per year. The base-case assumption of a 5% decrease is quite modest, and the uncertainty range includes little or no deterrence effect. The other soft variables (increase in the conviction and restitution rates), identified in Section 6 (Benefit Analysis), were found to have little influence on the overall NPV.

Cost estimates for this analysis were fairly straightforward. The benefit estimates do include estimates of soft variables. For these we obtained expert judgements for the base case, and established feasible ranges designed to firmly bound each variable. The sensitivity and uncertainty analyses both indicate that the HOAX call tool has the potential to provide substantial net benefit over the next 10 years. While the exact estimates of the NPV, BCR and ROI are uncertain, the analysis provides strong support for substantial NPV of the HOAX call tool.

9. Recommendations for Additional Research

To further refine the benefit-cost analysis, it would be useful to track and record the following data:

1. Annual number of calls established as hoax calls
2. Annual number of arrests
3. Annual number of prosecutions

4. Annual number of convictions
5. Annual amount of restitutions

Such a database, including years both before and after introduction of the HOAX call tool would allow for a more precise NPV estimate. In addition, as a short-term data collection effort, it would be helpful to conduct interviews with former known hoax callers to learn more about the possible deterrence value of the HOAX call tool.

10. References

1. Coast Guard Compass, http://coastguard.dodlive.mil/2017/07/research-development-test-evaluation-spotlight-search-and-rescue-hoax-calls/. Last accessed on May 7, 2018.
2. United States Coast Guard. Search and Rescue Summary Statistics. Washington DC: USCG, 2015.
3. Interview with Ensign Palomba on June 13, 2018
4. Coast Guard Compass, http://coastguard.dodlive.mil/2017/07/research-development-test-evaluation-spotlight-search-and-rescue-hoax-calls/. Last accessed on May 7, 2018.
5. Ibid.
6. Ibid.
7. United States Coast Guard. Search and Rescue Summary Statistics. Washington DC: USCG, 2015.
8. Interview with Ensign Palomba on June 13, 2018
9. Coast Guard Compass, http://coastguard.dodlive.mil/2017/07/research-development-test-evaluation-spotlight-search-and-rescue-hoax-calls/. Last accessed on May 7, 2018.
10. SimVoi is a commercial Excel add in that is sold by Treeplan (treeplan.com).

Benefit-Cost Analysis of the Bus Operator Awareness Research and Development (BOARD) Training Module

Developer: National Transportation Security Center
Evaluator: Heather Rosoff and Detlof von Winterfeldt, CREATE

1. Summary

Description of BOARD. The Bus Operator Awareness Research and Development (BOARD) TTKP is a training program that was originally developed to improve the situational awareness of public transportation bus operators in the US. This program was never implemented due to the high cost of training. The USCG expressed an interest in adapting and implementing the training program for crews of ferry boats in US harbors. In this study, we analyzed the cost and benefit of the BOARD training program applied to the Staten Island ferries in New York Harbor. There are nine Staten Island ferry boats, accommodating between 1,000 and 6,000 passengers each. Four of these are operating at any given time during the day. Over a year, these ferries move some 21 million people across the harbor. Each boat has a crew of about 10-20, depending on size.

Results. We estimated the total ten-year cost of the BOARD program as $1,017,561. This cost includes the initial cost incurred by the National Transportation Security Center, the oversight cost of the Office of University Programs of DHS, the cost of adapting and pilot testing the training program for USCG use, and the actual training cost. Training costs alone are approximately half of the $1.1 million cost.

Benefits were estimated by calculating the annual probability of an attempted terrorist attack on one of the Staten Island ferries (using worldwide statistics on attacks on ferries, trains, and airplanes), the probability of detecting an attempt with and without training, and the loss of life, if an attempt is not detected and successfully carried out. The benefit was determined for a one-year period by subtracting the expected cost without training from the expected cost with training, which is a positive number, due to the improved detection and interdiction capabilities. The base net present value (NPV) was $1.8 million. An uncertainty analysis showed that the

NPV has a range from \$239 thousand (5th percentile) to \$2.4 million (Median) to 7.9 million (95th percentile).

The main reason for this range are two uncertain variables: the effectiveness of the training program in increasing detection and interdiction; and the probability of an attempted attack. It is important to point out that even at the low end (5th percentile), the expected benefit is close to breaking even with the total cost. Furthermore, the benefit was calculated only for the Staten Island ferries and, if the program can be proven to be successful, the benefit would scale up with a broader application. Therefore, a pilot program for training Staten Island ferry operators and crew members may well be worth the marginal cost, especially if we consider the upfront cost of BOARD and the associated training module as sunk cost.

2. Background (adapted from COE documents)

Problem Context. Public bus transportation is an open form of conveyance serving five and a half billion passengers per year in the US, as compared with six hundred million annual airline passengers. Since 2001 bus systems around the world have been targeted by terrorists 660 times as compared to 77 attacks against airlines. Unfortunately, the open and relatively unprotected operations of the public bus transit system make it a relatively easy "soft target" for terrorist attacks. The counterterrorism measure proven effective in most of the areas that have experienced large-scale terrorist campaigns against their bus systems has been the training and empowerment of frontline employees, integrated with rigorous policing programs. While there are a variety of available "awareness" programs that address the topic of terrorism, there has been a void of materials for bus operators on observing and appropriately reacting to a variety of key behavioral indicators.

The BOARD Training Program. The National Transportation Security Center developed the Bus Operator Awareness Research and Development (BOARD), a training program for bus operators intended to (1) provide capabilities to quickly and effectively evaluate individual behavior before that person has a chance to attack, and (2) train bus driver to take actions to protect passengers when the driver feels they are at risk. Based on research findings, the project identified and developed a set of operational concepts that can provide transit bus operators with tools they can call upon to enhance their capabilities to protect themselves, their passengers, and others in their vicinity, as well as surrounding critical infrastructure.

While training materials were developed and tested, the BOARD program was not implemented due to the cost of training thousands of bus operators. However, USCG staff expressed an interest in evaluating the program to train ferryboat crewmembers in US harbors. In this benefit-cost analysis, we considered an application of the training program to operators and crewmembers of the Staten Island ferries in New York Harbor only.

3. Baseline Performance without BOARD

Table 52 shows the key input parameters of the benefit-cost analysis, both for the baseline and for the improvements over baseline by using BOARD. We apply the baseline calculations to the four Staten Island Ferries only. A key input estimate is the number of attempted terrorist attacks per year. We examined worldwide statistics on terrorist attacks or attempted attacks on planes, trains, and ferries. In the 17 years since 9/11/2001, there were seven attempts worldwide on airplanes (annual probability=0.41) and two on ferries (annual probability=0.12). Three attempted attacks involved US targets (the shoe bomber, the underwear bomber, and the thwarted attempt to use liquid explosives at Heathrow airport targeted for a US-bound airplane), so the annual probability of such an attack will roughly be 3/17 or 0.18. There were no attempts on ferries in the US in that time period. However, using the worldwide statistics, we can determine a ratio of airplane attacks versus ferry attack (3.5) and divide the airplane attack probability by 3.5 to get a rough estimate of a ferry attack in the US of 0.05.

Table 52: Parameters for the Baseline and Benefits Calculations

	Base Case
Number of Ferries (NYH)	4
Number of Crew/Ferry	16
Number of Passengers/Year	23,100,000
Number of Attempts on Ferries/Year	0.05
Probability that the attack is on the SI Ferry	0.20
Probability of detection w/o training	0.1
Increase of detection with training	1.75
Probability of success w/o detection	0.5
Nuber of passengers killed w/ success	100
Value of passenger life	10,000,000
Discount Rate	3%
Expected 2017 cost without training	4,500,000
Expected 2017 cost with training	4,125,000
Expected benefit/year in 2017	375,000
Expected benefit for ten years (discounted)	3,199,636
Net Present Value for Ten Years	2,182,075

The probability of an attempted attack is for an attack on *any* ferry in the US. How likely is it that it would be on the Staten Island ferries, if there is such an attack? This is a fairly soft number, but the Staten Island Ferry is certainly one of the most attractive US targets among all ferries in the US. The Staten Island Ferry is home to huge passenger volume and hosts commutes between iconic sites in New York. In the base case, we estimate that the conditional probability is 0.20; meaning that, given a ferry attack in the US, there is a 20% chance that it is on the Staten Island ferries and an 80% chance that it is on another US ferry.

The other two estimates required for the baseline analysis is the probability of detecting and intercepting an attempted attack without training. Given that there were many undetected attacks on planes, trains, and ferries in the past, we do not think that the detection probability without training is high. In the base case we use 10%, again using a large range for sensitivity and uncertainty analysis.

Without detection, we estimate that the probability of success, given an attack, is 50%. This figure is based on worldwide statistics on successful attempts on airplanes, trains, and ferries. This may be an overestimate, since many failed attempts are not known.

How many people will be killed in a terrorist attack on a Staten Island Ferry? The number of passengers that one of the ferries can accommodate varies from 1,000 to 6,000. A worst-case attack could conceivably kill hundreds of passengers due to an explosion and the sinking of the ferry. Judging by the two major worldwide ferry attacks and their consequences (116 fatalities in one case, 9 fatalities in the other case), this is unlikely. Therefore, we used a fairly modest number of fatalities of 200 in the base case.

Another input is the value of a statistical life (VSL) lost in a terrorist attack. Using the literature of the value of a life, we used $10,000,000 in the base case. The result is an expected annual loss of $4,500,000 (in 2017 dollars) without training.

4. Cost of BOARD

Table 53 shows the cost of developing BOARD at the National Transportation Security Center. The past costs for developing the training program was $367,810. For the current purposes, we also included the cost of transitioning the training material to ferry boat operators and crew, startup costs, and training cost, all borne by OUP and/or USCG.

The cost of training thousands of bus operators was considered prohibitive and, therefore, the program was never implemented in that context. In contrast, the cost of training the crew members of Staten Island ferries is relatively modest ($512,000). This cost estimate is based on providing training for 16 crew members per ferry boat for an 8 hour training course, repeated once a year for 10 years at an hourly cost of $50 per person. There are 4 Staten Island ferry boats operating in two shifts per day, so there will be a need to train 8 crews of 16. The annual repetition of training will take care of the turn-over of crew members. We assume that this can be done by two trainers spending three months of total time each (including preparation, updating materials, and actual training contact), adding another $51,200 in annual trainer costs.

Table 53: Costs for Development and Implementation of BOARD

Cost Category	Start	End	Amount	Amount in 2017 Dollars	
Pre-project costs (COE)					Source
Pre-project costs (other funding)					
Project costs (COE)*	10/1/09	3/31/12 (est.)	$256,508	$279,594	
Project costs (university cost share)					COE/OUP
Oversight cost at the COE			$51,302	$55,919	
Oversight cost at OUP			$60,000	$65,400	COE/OUP
Transition development cost			$100,000	$109,000	OUP
Implementation start up cost			$100,000	$109,000	OUP/USCG
Implemementation cost (User for Training)			$512,000	$398,649	OUP/USCG
Implementation cost (COE)					OUP/USCG
Implementation cost (Other users)					
TOTAL COST			$1,079,810	$1,017,561	

*CTSSR estimated project budget document

5. Benefits of ARMOR

The main benefit of ARMOR is the improved detection rate due to the training. This is the "softest" number of the analysis. The baseline detection rate of an attempted attack was set to 10% (see Table 52). In the base case analysis, we assume that this detection rate increases by 75% to 17.5%. Because this number is hard to determine precisely, we used a large range from 50% to 100% improvement. Note, however, that the actual detection rate, even with training, is fairly low. With the improved detection rate, the 2017 year expected costs are reduced from $4.5 million to $4.125 million, a net reduction of $375,000 per year.

6. Benefit-Cost Analysis – Base Case

In the base case, the net present value of BOARD is $2.2 million over ten years. This includes the investment costs inflated to 2017 and the training costs discounted at 3%. The benefit to cost ratio is approximately 3 and the return on investment is 214%.

7. Sensitivity and Uncertainty Analysis

Break-Even Analysis. A key model parameter for the benefits analysis is the increase in detection probability with training over the detection probability without training. In the base case analysis, we used a detection probability of 10% without training and a 75% increase with training. Considering the cost of $1 million, the break-even point would be at an increase in detection probability of 25%.

Tornado Analysis. There is little uncertainty in the cost calculations, and thus they can be considered as firm. The major uncertainties are about the “soft” input estimates:

1. The probability of an attempted terrorist attack on the Staten Island Ferries
2. The probabilities of detection and interdiction of an attempt with and without training
3. The probability of success, given an attempt

Table 54 shows the base case as well as a low and a high estimate for all variables used in the calculations described above. The resulting range in ten-year net benefits is very large, ranging from a negative net benefit of $1.1 million to a high net benefit of $55.1 million. There is no single variable that is responsible for this large range. Rather, the variation can be attributed to the accumulation of pessimistic (low) estimates that drive the net benefits down and the accumulation of optimistic (high) estimates that drive the net benefits up. To explore this further, we conducted a tornado analysis.

Table 54: Ranges of BOARD Input Estimates for Sensitivity Analysis

Variable	Low	Base Case	High
Number of Ferries (NYH)	4	4	4
Number of Crew/Ferry	10	16	20
Number of Passengers/Year	23,100,000	23,100,000	23,100,000
Number of Attempts on Ferries/Year	0.02	0.05	0.075
Probability that the attack is on the SI Ferry	0.10	0.20	0.3
Probability of detection w/o training	0.05	0.1	0.15
Increase of detection with training	1.5	1.75	2
Probability of success w/o detection	0.25	0.5	0.75
Nuber of passengers killed w/ success	50	100	150
Value of passenger life	6,000,000	8,000,000	10,000,000
Discount Rate	0%	3%	7%

Figure 23 shows a tornado diagram that illustrates how the changes in each uncertain variable (from low to high values) impact the net benefits. The most important variables are the increase of detection capability with training (in % over baseline without training), and the annual probability of an attempt on a US ferry boat. It is interesting to note that each single variable can drive the expected benefit close to zero, but it takes the combination of all lowest values of the variables to create a negative benefit.

Uncertainty Analysis. To explore the effect of uncertainty on the ten-year benefits, we conducted a Monte Carlo simulation, in which we assume triangular probability distributions for all variables. The low value is the minimum of the triangular distribution, the base case is the mode, and the high value is the maximum. The results are displayed in Figure 24. We then ran 10,000 simulations resulting in a distribution of net benefits as shown in Figure 24.

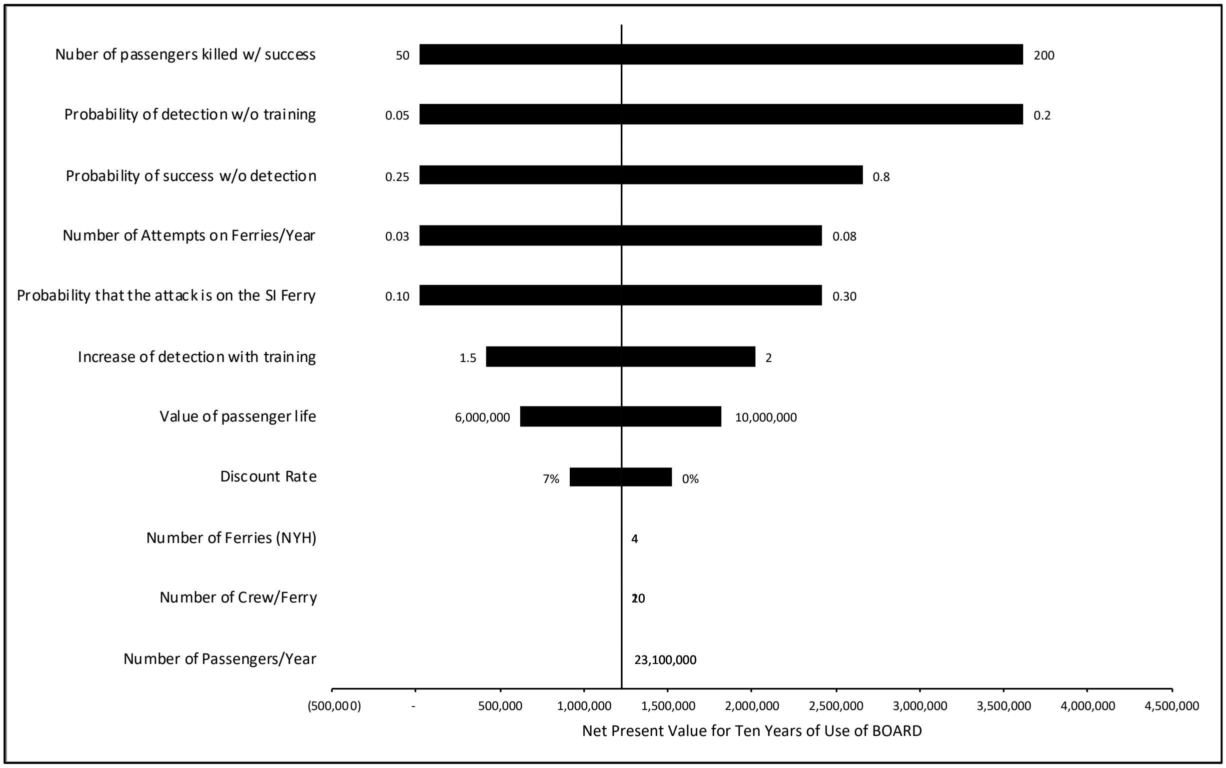


Figure 23: Net Present Value of BOARD - Tornado

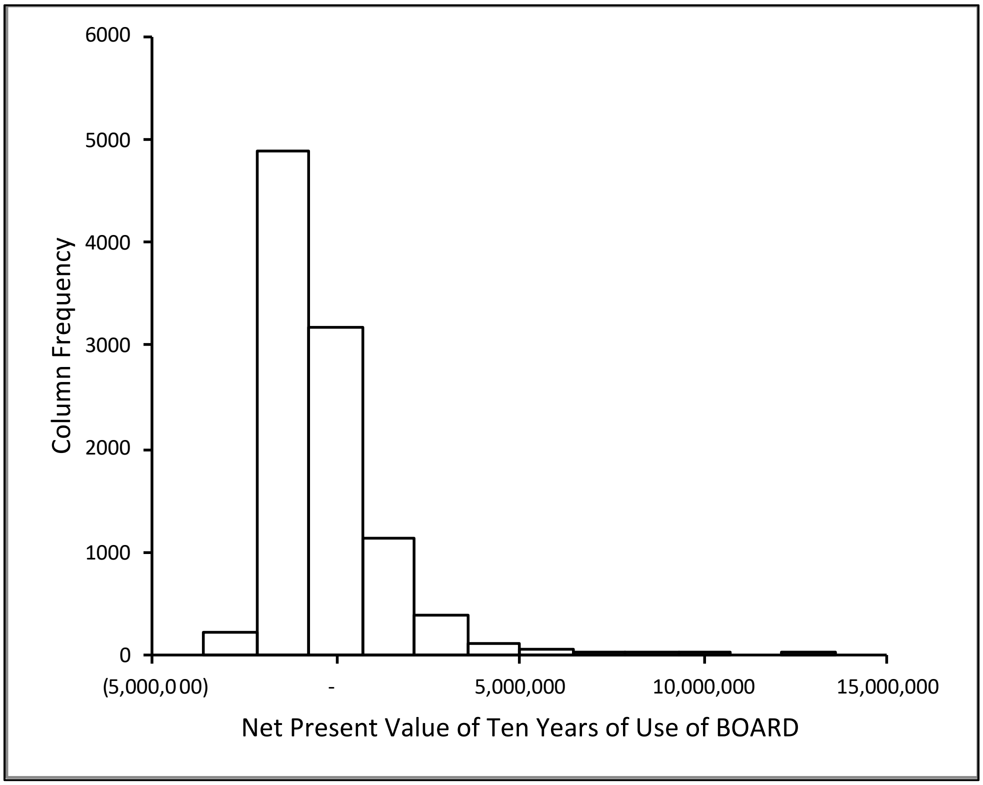


Figure 24: Net Present Value Distribution

Table 55 shows the key statistics of this distribution. In particular, the 5th, 50th, and 95th percentiles are $239 thousand, $2.4 million and $7.9 million, respectively.

Table 55: Statistics of the Net Benefits Distribution

Mean	3,030,064
St. Dev.	2,504,043
5th Percentile	238,740
25th Percentile	1,285,180
Median	2,435,431
75th Percentile	4,083,669
95th Percentile	7,901,884

8. Assumptions and Limitations

The benefits calculations include several parameters that are highly uncertain. The sensitivity analysis also revealed that many of these parameters have an important effect on the benefits, resulting in a large range. In particular, the probability of an attempted attack on a Staten Island ferry, the detection probability without BOARD training, and the increase of the detection probability with training have a large effect on the benefits. The base case, which uses conservative (low) estimates, provides correspondingly low benefits for ten years of use (about twice the cost). The median benefits and resulting net benefits are substantially larger, due to the fact that the input distributions are favoring the upside of benefits.

9. Recommendations for Collecting Additional Information

To improve this analysis, it would be most useful to collect experimental data on detecting attack attempts with and without BOARD training. This could be simulated attacks using red teams and observing separate samples of trained and untrained ferry boat operators.

Benefit-Cost Analysis of E-CAT, the Economics Consequence Analysis Tool

Developer: Center for Risk and Economic Analysis of Terrorism Events (CREATE)
Analyst: Scott Farrow, UMBC/CREATE

May 31, 2018

23. Summary

Description of the Economic Consequence Analysis Tool (E-CAT). The Center for Risk and Economic Analysis of Terrorism Events (CREATE) developed E-CAT as a desktop Excel tool for policymakers and analysts wanting quick estimates of the economic impact of homeland security threats. E-CAT generates value by providing rapid, usably precise estimates, and uncertainty bounds for US gross domestic product and employment caused by threats such as terrorist attacks, natural disasters, and technological accidents. More precise estimates take longer and cost more. CREATE developed nine customized studies using a computable general equilibrium model of the United States, which served as input information for E-CAT.

Results. The total development and implementation costs of E-CAT were $945,009 in present value 2017 dollars. E-CAT generates benefits from cost savings compared to a longer and more expensive analytical approach. The actual benefit depends on the number of studies using E-CAT in forthcoming years. The base case of twenty uses of E-CAT over 10 years would result in a net present value of $0.676 million in 2017 dollars, leading to a 72 percent net rate of return. Twelve studies, over ten years, resulted in the net present value just equaling costs—breaking even. We conducted uncertainty analyses on the number of studies among other variables and found that the mean net present value of the simulation was a saving of $ 0.9 million (median: $0.8 million) but with a 5% chance of $ - 0.4 million and a 95% chance of $2.6 million.

24. Background

*Problem Context***.** CREATE responded to DHS requests for macroeconomic impacts of various threats through an evolving set of models developed or coordinated by Adam Rose of CREATE.

These began with input-output analysis and evolved into Computable General Equilibrium (CGE) models.[1,2] These models represent the macroeconomic economy with hundreds of sectors at a point in time (static).

The E-CAT tool. E-CAT was originally developed at the request of the DHS/Strategic Planning and Risk (SPAR) office for a desktop, rapid assessment tool for macroeconomic consequences. The initial version for three threats was delivered in 2015. Six additional threats for a total of 9 have been developed from DHS funding. The E-CAT tool provides a statistical summary of more complex CGE runs so that rapid estimates are generated, but these estimates are somewhat less precise than customized studies. While the E-CAT estimates are less precise, the results are provided in real time, while allowing the user to interactively explore economic consequences by varying model inputs themselves. E-CAT is described in detail in a book.[3]

Each E-CAT threat module required detailed context development to specify estimated direct impacts from threat scenarios and to translate them into macroeconomic consequences. After estimating numerous scenarios for each threat, regression analysis was used to produce a “reduced-form” summary (meta-analysis) equation of the results that are conditional on a few characteristics, such as magnitude of direct impacts, time of day, urban or rural location, extent of resilience and extent of behavioral effects, etc.

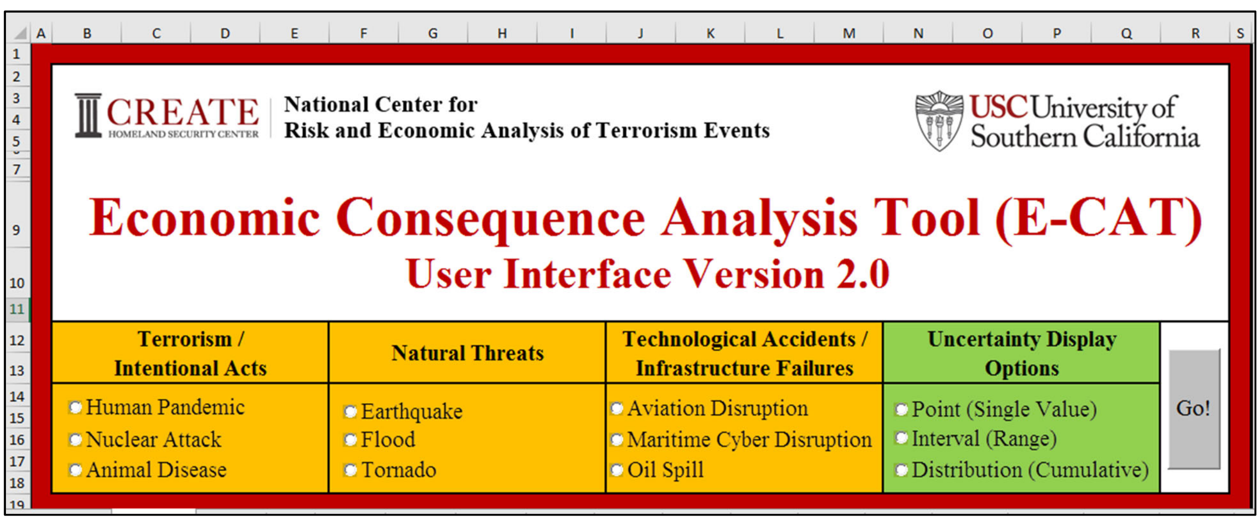


Figure 25: E-CAT Threat and Uncertainty Selection Screen

25. Baseline Performance Without the E-CAT Tool

Numerous agencies seek threat-related information, often including macroeconomic impacts, to inform their management decisions. Similarly, there are a set of agency, university, and consulting analysts who provide studies with varying levels of detail, often using various models. Custom studies are time-consuming and expensive, with prices varying by topic and type of model used, among other factors. Some economic modeling tools, such as input-output analysis, have been in use for decades, and generic, desktop models can be purchased, such as IMPLAN.[4] Using such models still requires significant expertise in order to adapt a particular problem context to the requirements of the model. E-CAT brings to a desktop the statistically based estimates of what a more complex CGE model of the economy would produce in response to specific security and natural hazard threats. In the absence of E-CAT a client could approach a supplier and negotiate a price for a custom study. Such cost information is provided below for the detailed CGE studies that are summarized in E-CAT. The baseline, full-market demand for full-price custom macroeconomic studies is not known, although CREATE researchers have carried out millions of dollars of such work and have generally been engaged in several studies per year.[5]

The assumed baseline in the absence of E-CAT is that the demand for studies of the macroeconomic impacts of the specific homeland security threats at the E-CAT level of precision is 2 studies per year, at a cost consistent with data from CREATE. Some of this baseline demand is observed at CREATE, while other demand is assumed to accrue to other researchers. Consequently, CREATE estimates that the assumed baseline demand is 20 studies in total over the next 10 years at a cost of $ 2.1 million in undiscounted 2017 dollars or a 2017 present value of $1.8 million (discounted at 3 percent). The source of this estimate is discussed in Section 4 below.

26. Cost of the E-CAT Tool

Development and transition costs for the nine threat modules for which custom studies were first done, and then summarized within E-CAT, were obtained from the Center of Excellence (COE), DHS (Office of University Programs-OUP) and other stakeholders. The total cost for nine modules is presented in Table 56 with an average cost of nearly $105,000, and real total cost of $945,009 in present value 2017 dollars.

Table 56: Development and Transition Costs for Nine E-CAT Modules

Cost Category	Start	End	Amount	Source
Pre-project costs (COE)	7/1/2014	6/30/2015	0	
Pre-project costs (other funding)			$197,400	DNDO/NBIC
Project costs (COE)	7/1/2014	6/30/2016	$128,438	CREATE/OUP
Project costs (university cost share)	7/1/2014	6/30/2016	$402,780	CREATE/USC
Oversight cost at the COE (20%)	7/1/2014	6/30/2016	$82,817	CREATE 20%
Oversight cost at OUP	7/1/2014	6/30/2016	$41,100	Oversight OUP
Transition development cost	7/1/2015	6/30/2016	$92,475	CREATE/OUP
Implementation start up cost				
Implementation cost (User)				
Implementation cost (COE)				
Future Implementation cost (Other users)				$10,000 per study
TOTAL PRESENT VALUE COST (2017 $)			$945,009	

The per-study cost of $105,000 is used as the baseline cost for custom studies at an E-CAT level of precision. Custom studies with additional detail (accuracy) than E-CAT have been reported by CREATE to cost on average about $200,000, with a range from $150,000 to $250,000. As the value of such studies should be expected to at least cover their cost, the willingness to pay for the studies is conservatively estimated as the cost; conservatively because some clients may have an expected value greater than the cost of the study.

Once a threat analysis exists within E-CAT, such as for a nuclear attack, then multiple users can be informed by the analysis and thus avoid development costs. However, any organization will incur an implementation cost to learn how to use the application, to organize their analysis, and to integrate the E-CAT results for their purposes. CREATE estimates that any user will incur about $10,000 in implementation costs. This figure is used as the incremental cost for additional analyses, using E-CAT in contrast with the higher cost for a custom study.

Figure 26 below illustrates the baseline assumption of a custom study at the E-CAT level of precision, compared with the implementation cost using E-CAT.

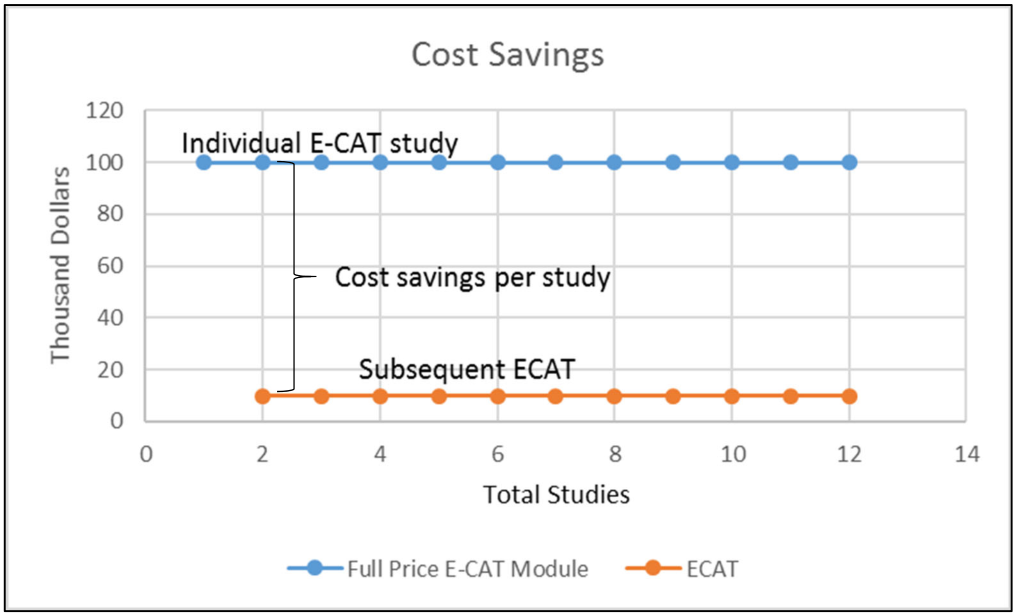


Figure 26: Cost Savings for Additional Studies of a Particular Threat

27. Benefits of the E-CAT Tool

The benefit analysis assumes that the value from a custom analysis in a decision (at an E-CAT level of precision) is the same as using E-CAT. Consequently any difference in a user's net benefit comes from cost differences.[ii,6] The cost difference is that between E-CAT and a custom study[iii]. That value is presented in Table 57 below.

Table 57: Per Use Benefit from E-CAT

Costs	Produce ECAT (PV 2017)	$945,009
	Per module cost, 9 modules	$105,001
	User cost to apply ECAT per use	$10,000
Benefit	Cost saving benefit per ECAT use	$95,001

[ii] There may be other, currently unquantifiable, benefits such as allowing the user more rapid access to information and allowing the user to personally explore the effect of different variables in the model.
[iii] A different assumption is that the forecast number of users would not all pay the full price of a custom study. For instance, an agency might be willing to pay less than the custom price but still more than the cost to implement E-CAT. In short, there may be a downward sloping demand curve for studies. If one assumes a linearly decreasing demand curve from the first to the last study and uses the difference between the willingness to pay for a custom study and the E-CAT cost as the measure of value, then the net benefits are 50 percent of those reported here, an application of Harberger triangles (see endnote 6). To some extent, this alternative is a portion of the uncertainty in the number of studies demanded as analyzed in section 7.

28. Benefit-Cost Analysis – Base Case

The primary estimate of the net present value combines the per-use benefit from Table 56, the base case assumptions of two studies per year for a period of ten years, the development costs of E-CAT, and the base-case project discount rate of 3 percent[iv]. Further evidence for the potential demand for E-CAT is based on demand for the book describing E-CAT which had 943 downloads from the Springer publishing website[7]. The E-CAT software itself is available online without cost[8], but the number of downloads has not been tracked.[9]

Table 58 below shows the sequence of calculation and reports the base case net present value of $0.676 million with a rate of return of 72 percent.

Table 58: Base Case Net Present Value and Rate of Return

Costs	Produce ECAT (PV 2017)	$945,009
	Per module cost, 9 modules	$105,001
	User cost to apply ECAT per use	$10,000
Benefit	Cost saving benefit per ECAT use	$95,001
Parameters	Discount rate (annual %)	3
	Number of years (T)	10
	Demand: number of ECAT studies /year	2
Present Value Benefits as cost savings		$1,620,756
Net Present Value		$675,747
Present Value Rate of Return		72%

29. Sensitivity and Uncertainty Analysis

Break-Even Analysis. Given the cost of development, the investment in the nine E-CAT modules will return a net present value of zero when there are about 12 studies done over 10 years using E-CAT. CREATE estimates that the modules have an analytical life of about 10 years. On

[iv] The PV function of Excel was used to compute the benefit from cost savings with parameters: a) annual discount rate, b) number of years, and c) “payment” as the value of the number of studies times the per study benefit.

average, this break-even rate implies a little over one study per year, using an existing E-CAT. No updating is anticipated for the modules in that time frame.

Tornado Analysis. Contributing elements to the uncertainty of the Net Present Value are presented in Figure 27, using what is called a Tornado diagram. The NPV is dramatically most sensitive to the number of studies per year and the number of years in which the module is used. The sensitivity of each variable is defined by: studies per year ranging from 0 to 5, years of availability from 5 to 15, cost of using E-CAT from $8,000 to $12,000 per study, discount rate from 0 to 7 percent and the cost of development varying by 10 percent.

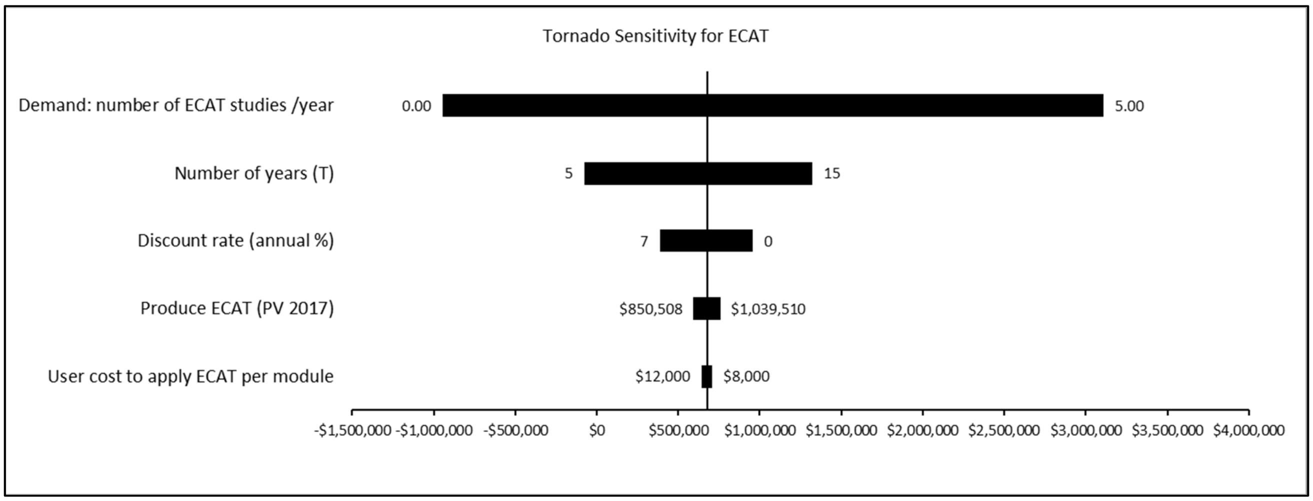


Figure 27: Effect of Variation in E-CAT Cost Parameters on Net Present Value[10]

Table 59 below further illustrates the effect of changes in the number of studies, or the number of years, on the net present value. The number in the top left is the net present value with 2 studies per year over 10 years. This can be seen by the rows (studies per year), and columns (years), and finding 2 studies and 10 years as circled. Numerous other outcomes are possible, increasing with the number of studies and years, but negative returns are shown by the combinations of studies and years with red values (in parentheses).

Table 59: Net Present Value: Varying Studies per Year and Years

		YEARS									
$ 675,747		1	2	3	4	5	6	7	8	9	10
STUDIES	1	$ (852,775)	$ (763,227)	$ (676,288)	$ (591,881)	$ (509,932)	$ (430,370)	$ (353,126)	$ (278,131)	$ (205,321)	$ (134,631)
	2	$ (760,541)	$ (581,446)	$ (407,567)	$ (238,753)	$ (74,855)	$ 84,268	$ 238,757	$ 388,747	$ 534,367	$ 675,747
	3	$ (668,307)	$ (399,664)	$ (138,846)	$ 114,375	$ 360,221	$ 598,907	$ 830,640	$ 1,055,624	$ 1,274,055	$ 1,486,124
	4	$ (576,073)	$ (217,883)	$ 129,875	$ 467,503	$ 795,298	$ 1,113,545	$ 1,422,523	$ 1,722,502	$ 2,013,744	$ 2,296,502
	5	$ (483,839)	$ (36,101)	$ 398,596	$ 820,631	$ 1,230,375	$ 1,628,184	$ 2,014,407	$ 2,389,380	$ 2,753,432	$ 3,106,880

Uncertainty Analysis. To further explore the uncertainties of some of the input variables, we assumed that these uncertainties can be characterized by triangular distributions with a minimum being the low value in Table 60, the mode being the base case value, and the maximum being the high value. We used an Excel add-in[11] to simulate the NPV, using these triangular distributions to characterize uncertainty in the input variables. The analysis assumes that all input variables are independent and thus uncorrelated with each other, and is run for 10,000 iterations.

Table 60: Parameters for Uncertainty Analysis

	Minimum	Mode	Maximum
E-CAT investment	$ 850,508	$ 945,009	$ 1,039,510
E-CAT user cost	$ 8,000	$ 10,000	$ 12,000
Discount rate	0	3	7
Years	5	10	15
Studies per year	0	2	5

Figure 28 presents a histogram of the simulated 10,000 NPV calculations the E-CAT tool future use over 10 years. The NPV is the sum of the NPV of future benefit, and the NPV of past cost (all calculated in 2017 dollars). Table 61 shows the key statistics of this distribution, showing a mean of $916,989; median (50th percentile) of $ 806,360, and ranges from $ - 416,236 (5th percentile) to $ 2,603,125 (95th percentile).

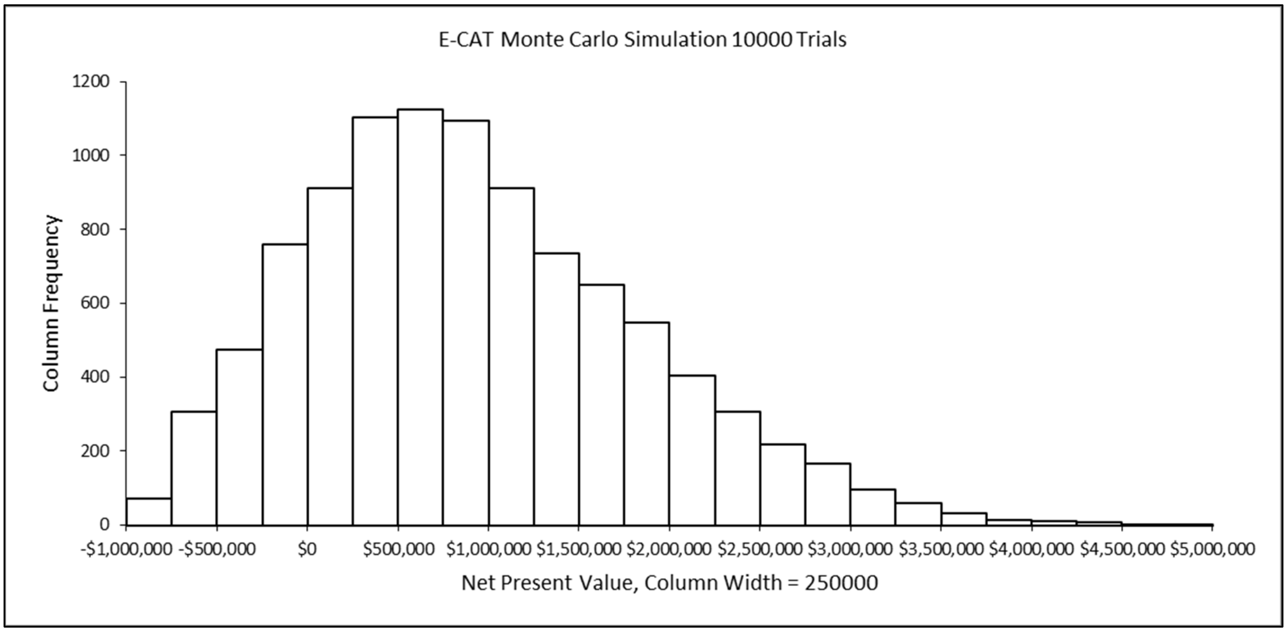


Figure 28: Net Present Value Distribution of E-CAT[12]

Table 61: Statistics of the Distribution of Net Present Value

Mean	$	916,989
St. Dev.		918,690
5th Percentile	$	(416,236)
25th Percentile	$	242,726
Median	$	806,360
75th Percentile	$	1,501,837
95th Percentile	$	2,603,125

Source: CREATE

30. Limitations and Assumptions

Several limitations apply to the analysis, as briefly listed below:

- The analysis omits additional benefits of E-CAT, such as rapid turnaround, user-defined exploration, and a standard methodology with which to compare consequences across multiple threats. These characteristics are especially useful for broad risk management resource allocation decisions, as originally intended by the DHS Policy Office/SPAR.

- There is no explicit valuation of the difference in precision provided by E-CAT and custom studies. Here it is assumed that the level of precision provide by E-CAT is appropriate for the applications where it is used.
- Economic impact studies are heterogeneous, and little is known about their demand in general or for specifics for threats such as those analyzed by E-CAT. The study assumes a subjective forecast of demand based on experience, but direct modeling of the impact of a lower price for a product is not analyzed, although perhaps incorporated in some elements of the uncertainty analysis.

31. Recommendations for Further Research

1. Investigate monitoring of downloads of E-CAT, or appearance of publications or other examples of its use.
2. When applications are found, investigate the cost of implementation within the organization, and ways in which there may have been added value in decision-making, other than cost savings.
3. Attempt to assess if users would have been willing to pay the full price of a custom study.

32. References

1. Rose, A. (2015). "Macroeconomic Consequences of Terrorist Attacks: Estimation for the Analysis of Policies and Rules," in C. Mansfield and V.K. Smith (eds.), *Benefit Transfer for the Analysis of DHS Policies and Rules,* Cheltenham, UK: Edward Elgar.
2. Chen, Z., A. Rose, F. Prager and S. Chatterjee (2016). "Economic Consequences of Aviation System Disruptions: A Reduced-Form Computable General Equilibrium Analysis," *Transportation Research A*, (January): 207–226.
3. Rose, A, F. Prager, Z. Chen, S. Chatterjee, D. Wei, N. Heatwole, and E. Warren (2017). *The Economic Consequence of Disasters: The E-CAT Software Tool*, Singapore, Springer. Available at https://www.springer.com/us/book/9789811025662 .
4. IMPLAN (2017). *IMPLAN Products*. Available at http://www.implan.com/products/
5. Rose, A. (2017). CREATE. Personal Communication, multiple dates, 2016-2017.
6. Harberger, A. (2017). "Triangles and All That", in *Teaching Benefit-Cost Analysis*, ed. S. Farrow. Cheltenham, Edward Elgar.
7. Rose (2017), op. cit., Personal Communication.
8. CREATE (2017). E-CAT Available for Download. http://create.usc.edu/content/e-cat-software-now-available. Accessed February 12, 2018.
9. Rose, (2017), op. cit., Personal Communication.
10. TreePlan (2017). SensIt and SimVOI tools. Available at http://treeplan.com.
11. Ibid.
12. Ibid.