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

Center of Excellence Landscape Study - Phase 2

Submitted to

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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 this 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 U.S. 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 counterterrorism 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

Emeritus Centers

START	National Consortium for the Study of Terrorism and Responses to Terrorism
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

Nine Tools, Technologies, and Knowledge Products (TTKPs) Developed by the Centers of Excellence

(COE Developer)

IRIS	Intelligent Randomization in Scheduling (CREATE)
WTS	Wait Time Study for Customs and Border Protection (CREATE)
EMWS	Enhanced Millimeter-Wave Scanner (ALERT)
3DCT	Computed Tomography Datasets and Automatic Threat Recognition Algorithm (ALERT)
PAS	Passive Acoustic Sensors System for Low Flying Aircraft Detection (MSC)
TRS	Trafficking Risk Score Model (BTI)
RPM	Remote Power Module (ADAC)
GARI	Gang Graffiti Automatic Recognition and Interpretation Tool (CVADA)
SMART	Social Media Analytics and Reporting Toolkit (CVADA)

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EXECUTIVE SUMMARY

For the past 15 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 multi-year effort to assess the costs and benefits of selected TTKPs. This project has two phases: In Phase 1, 10 TTKPs relevant to the United States Coast Guard (USCG) were analyzed. In Phase 2, another set of nine TTKPs relevant to the Transportation Security Agency and to Customs and Border Protection were analyzed. This report summarizes the results of Phase 2.

To begin the process, TSA and CBP staff familiarized themselves with 200 TTKPs, covering a wide range of topics. Based on CBP and TSA staff judgments of the likelihood of a successful transition and the beneficial impacts on their agencies if successfully transitioned, 11 TTKPs were selected for further study.[1] Several of these tools had been applied in the past, including IRIS, a tool to randomize assignments of federal air marshals on international flights. Other TTKPs were seen as having high potential, including a new automatic threat recognition software that uses 3D computed tomography (CT) images. Because the CBP and TSA staff selected TTKPs with high actual or perceived potential, these 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 a 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 and the interception of drug smugglers and sex traffickers. Subsequently, the cost of developing the TTKP was ascertained through the records of the COE that supported its development and interviews or email exchanges with its principal investigator and users. Cost estimates included pre-funding prior to OUP's

[1] Upon further investigation, two of these TTKPs did not reach a stage at which transition to TSA or CBP could be considered, and they were eliminated.

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 $139,000 for a model to detect and intercept sex traffickers to about $4.9 million for an automatic threat detection software program used with 3D CT equipment at TSA checkpoints.

The next step was an assessment of the benefits of the TTKPs. This usually involved building models of the variables that affect 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 10-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, NPVs varied widely, from about $1 million for GARI, a graffiti recognition system, to $539 million for IRIS, a tool to randomize the assignment of federal air marshals on international flights. In total, the median NPV estimates combined to over $1 billion for the nine analyzed 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 ES-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 ES-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. Benefits assessments were highly uncertain, depending on many model parameters.

We recognize that due to these limitations, the actual NPV estimates show a wide range. 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.

Table ES-1: Costs, Medians, and Ranges of Net Present Values for Nine TTKPs

Updated June 13, 2019		Ranges of Net Present Values (in 2017 Dollars)			
Tool, Technolgy, or Knowledge Product (TTKP)	Cost (in 2017 Dollars)	Low NPV (5th Percentile)	Median NPV (50th Percentile)	High NPV (95th Percentile)	Years of Use for Net Benefit Calculations
IRIS	$1,750,443	$241,667,213	$529,831,040	$938,208,625	10 Years, Past Use
Wait Time Study	$408,561	$30,962,073	$282,331,032	$963,227,633	10 Years, Past Use
Enhanced Millimeter Wave	$3,260,599	$48,657,063	$122,194,372	$263,929,961	10 Years, Future Use
3D CT Datasets and ATR	$4,898,926	$62,076,958	$117,741,020	$209,045,620	10 Years , Future Use
Passived Acoustic Sensing	$4,006,100	$8,494,934	$20,893,771	$39,675,882	10 Years, Future Use
Trafficking Risk Score	$139,050	$2,993,538	$8,300,061	$17,970,519	10 Years, Future Use
Remote Power Module	$1,583,640	$1,131,027	$5,541,829	$17,164,044	10 Years, Future Use
SMART	$320,349	$723,670	$2,946,802	$8,894,497	10 Years, Future Use
GARI	$371,869	$47,478	$1,097,247	$5,424,325	10 Years, Future Use
TOTAL	**$16,739,537**	**$396,753,954**	**$1,090,877,174**	**$2,463,541,106**	**ROI = 6,517% at Median NPV**

1. Introduction

Scientific research on homeland security problems can inform security operations and decision-making processes. Security operations can be improved by developing tools and technologies to improve the detection performance of scanning equipment, reduce false alarms, confuse and deter attackers, reduce the cost of defensive actions, or allocate defensive resources more efficiently. Decision-making procedures can be enhanced with access to information that, for example, improves evacuation decisions prior to hurricanes, pre-selects airline passengers for screening, identifies terrorist communications, or spots illegal web traffic for law enforcement.

For the past 15 years, the Office of University Programs (OUP) of the Science and Technology Directorate of the Department of Homeland Security (DHS S&T) has funded university-based research through its Centers of Excellence (COE) program. In the process, the COEs have developed several hundred tools, technologies, and knowledge products[2] for use by DHS offices and components. After spending nearly half a billion dollars on university-based research, OUP staff are increasingly asked by Congress and other agencies to justify the benefits of this research for improving homeland security operations and decisions. In 2016, in response to these questions, the OUP funded a two-year effort to assess the costs and benefits of selected research products. This report describes a methodology for conducting this evaluation and example applications of nine research products, focusing primarily on two end users in the Department of Homeland Security: the Transportation Security Agency and Customs and Border Protection.

The methodology to assess the benefits and costs of these research products used elements of benefit-cost analysis (Campbell & Brown, 2015; Boardman et al., 2018), decision analysis (Raiffa, 1968; von Winterfeldt & Edwards, 1986; Edwards et al., 2004; Howard & Abbas, 2014), and risk analysis (Bedford & Cooke, 2001; Aven, 2003). Benefit-cost analysis was used as the guiding framework of the assessment to compare research impacts with baseline performance and to express the results in terms of net present value (NPV) of the research product. Decision analysis was used when the research products affected a specific choice (decision tree analysis), when they informed decisions (value of information analysis), or when they affected false alarms or detection rates (signal detection theory). Risk analysis was used to

[2] For details of the previous project, see the final technical report submitted to OUP (CREATE, 2018).

express the uncertainties in several input parameters of the benefits calculations and to simulate the resulting uncertainties in the NPV outputs (tornado analysis and probabilistic simulation).

In the following sections, we first describe the overall methodology, starting with the selection of research products and followed by cost and benefits analyses. Special attention is paid to five different benefit models used in this methodology. In Sections 2 and 3, we describe the process of applying this methodology, first in the selection of nine research products by TSA and CBP staff, followed by a detailed benefit-cost analysis of an enhanced automatic threat recognition (ATR) program to enhance the detection of threat objects for 3D computed tomography (CT) scanners. In Section 4, we provide a summary of the benefit-cost analyses of the other eight research products. In Section 5, we summarize the results for all nine research projects, and in Section 6, we discuss lessons, limitations, and future research directions.

2. Methodology

Selection of research products. Over the past 15 years, the Office of University Programs at DHS funded over $400 million in university-based research, resulting in more than 200 research products. Evaluating the benefits and costs of all of these research products was not feasible, so a methodology was developed to select a subset of research products that were used by TSA or CBP or which USCG staff considered to be potentially useful for them. TSA and CBP staff reviewed all 200+ research products and prioritized them based on two criteria:

1. Likelihood of a successful transition to users at DHS
2. Judged beneficial impact, if used

In a previous study (CREATE, 2018) these two criteria were evaluated separately, and a priority index was derived by multiplying them. In this study, we used a simpler approach by asking TSA and CBP staff, in separate meetings, to assign each TTKP into one of three bins:

1. Highly useful – either already in use or a high likelihood of highly beneficial use
2. Potentially useful
3. Not useful

In some cases, two staff members conducted the evaluations independently. In those cases, we averaged the numbers associated with each bin. The results for the highly rated TTKPs are shown in Table 1.

Table 1: Useful or Highly Useful TTKPs

TTKP	CBP	TSA	Analysis for
Satellite Surveillance	1	2	CBP
SMART - Social Media Analysis Tool	1	2	CBP
Remote Power Module	1.5	2.5	CBP
Passive Acoustics Sensors	1.5	3	CBP
Trafficking Risk Score	2	2	Both
3D CT Datasets and Automatic Threat Recognition Program	2	1.5	TSA
CBP Wait Times	2	1.5	Both
Enhanced Millimeter-Wave Scanning Capabilities	2	1.5	Both
GARI - Graffiti Recognition	2.5	2	TSA
PORTSIM	2.5	2	CBP
IRIS - FAMS Scheduling	3	1.5	TSA

This process identified 11 TTKPs that TSA and CPB 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. The purpose was to identify and assess the high-potential research products in order to gauge whether they were jointly creating net benefits that offset the costs of OUP investment. In other words, if the selected 5-10 percent of research products "paid" for the total investment of $500 million, the contributions of the remaining research products may well have been zero, yet the overall investment was worth it.

Baseline performance. The baseline metric varied from research product to research product and, in some cases, there were multiple metrics. For example, the 3D CT Datasets and ATR software were developed to reduce costly false alarms in TSA checkpoint scanners. The baseline false alarm rate was estimated at about 10 percent per passenger. These false alarms lead to additional wait times for passengers and additional work time for TSA officers. Using a simple model that combined false alarm rates, passenger volume, additional wait time, and the associated costs of wait time, we could then calculate the annual costs of the current false alarm rate.

Cost models. Having selected a subset of the 200 research products, the next step in the methodology was to assess their costs. For this purpose, a cost-accounting template was developed that assured that all initial investments were counted, as well as transition, implementation, maintenance, and upgrade costs. The cost assessment template is shown in Table 2.

Table 2: Cost Accounting Template Used for All Benefit-Cost Analyses

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

Costs and benefits occurred in various past years and up to 10 future years for each research product. Future values were discounted at a rate informed by professional practice and government guidance (see, for example, U.S. Office of Management and Budget, 1992; 2003; 2017; Moore et al., 2013; U.S. Council of Economic Advisers, 2017). 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 (U.S. Council of Economic Advisors, 2017). The approach used throughout this project was to adjust nominal past costs or benefits to purchasing power in 2017 using the Consumer Price Index (U.S. Bureau of Labor Statistics, 2017), 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.

Benefit models. Assessing the benefits of research products aimed at improving homeland security decisions and operations is much more difficult than assessing their costs. Part of this difficulty is that many research products have not yet been implemented and used, and as such, only potential benefits can be evaluated rather than actual ones. Another difficulty is that there are several different types of benefits which require different assessment models. We identified five categories of benefits from the literature and from selected applications of benefit-cost analyses (CREATE, 2018):

1. Reduced cost at the same security
2. Increased security at same cost level
3. Reduction of false alarms and/or increase in detection capabilities
4. Reduction of threats by deterrence
5. Value of information for improved decision-making

In the following we will discuss each of these benefit categories and associated models.

Reduced cost at same security level. The easiest way to demonstrate benefits of research products is to show they contributed to reducing operational costs while maintaining the same level of security or effectiveness. An example is research that resulted in a randomization of patrols and checkpoints at Los Angeles International Airport (LAX), taking into account the relative value of protecting specific terminals and targets. Purely random assignments can be shown to be inferior to those that give more weight to high-value targets and lower weight to low-value targets. Thus, when taking the value of the targets into account, one can show an increase in expected protection levels over purely random assignments or over human assignments mimicking randomness.

Recognizing the potential increase in security when using such "smart" allocation procedures, the decision-maker can either hold expenditure constant and experience greater safety or reduce the staffing and related costs to maintain the current level of security. In the latter case, the cost savings represent the benefits of the research product. The main assumption is that the reduction in costs does not adversely affect security levels.

Another version of cost savings occurs when some infrastructure investments can be delayed without reducing the level of security. An example is research that resulted in a reallocation of resources of the U.S. Coast Guard to rebuild and re-open facilities after a major disaster. Similar to "smart" randomization, this procedure created allocation schemes that used early expenses for improving high-value assets and delayed expenses for low-value assets. The benefit in this case is the result of delaying costs, which leads to a lower net present cost at the same security level.

Increased security at the same cost level. If a research product results in higher security or protection levels at the same cost, the benefits can be gauged by the improved security. Pricing out increased security can be difficult, but in some cases a relative increase in security level can be established. For example, a system of smart randomization of checkpoints and patrols may lead to a 50 percent increase in the expected protection level (calculated as $S=p_i * v_i$, where S is the security level, p_i is the percent of time a target is protected, and v_i is the value of the target). Even without determining the expected risk reduction, one can draw some conclusions about the value of the increased protection.

The simplest assumption to make in this calculation is that the security level increases linearly with the effort or cost of protection. In this case, one can use the avoided cost for getting to the new, higher security level (using the current system) as an indicator of the added value. More complex assumptions can be made using non-linear cost-security relationships, which typically lead to a reduction in the benefit estimates as compared to the linear assumption.

Reduction of false alarms and/or increase in detection capabilities. Many homeland security research products improve detection capabilities; for example, detecting guns and explosives at TSA checkpoints in airports or detection of radiological materials at ports of entry. Determining the benefits of reductions in false alarms is relatively easy. The key idea is to price out the costs of a false alarm (e.g., additional time and staff effort to do a more detailed check and analysis) and then determine the cost reduction that can be achieved by reducing false alarms.

The benefits of improving detection are more difficult to model. One way to do this is to price out the cost involved to achieve the same level of detection with current (baseline) methods. Another way is to track the risk reduction and determine the equivalent expected cost reduction. This involves assessing the threat probability and reduction over baseline, the detection probability and reduction over baseline, and the expected cost reduction.

Ideally, a research product leads to implementations that reduce false alarms and increase detection. This is, however, rarely the case. For example, a new algorithm to process energy signatures from radiological detection equipment can be shown to reduce false alarms, but it may come at the cost of a slight decrease in detection rates. In another example described below, a new method for swabbing skin, clothing, and other surfaces to detect explosive residue demonstrably leads to increases in false alarms but also to improvements in detection. It is therefore important to analyze both false alarms and detection rates to determine the value of these research products.

Reduction of threats by deterrence. Research products can reduce the threat of terrorism by deterring terrorist attacks. This can be done in several ways. If a research product creates mechanisms to improve the detection and interdiction of specific types of terrorist attacks, and if this is made known to terrorists, they will likely avoid situations in which they are more likely to get caught and change their tactics accordingly. In addition, if research products create improvements to identify terrorists after the fact, e.g., though better analytics and data processing, terrorists may be dissuaded from using types of attacks that are likely to lead to identification and conviction.

A non-terrorist example is the deterrence of hoax calls made to the U.S. Coast Guard. There are numerous hoax callers to the U.S. Coast Guard every year who provide false statements about emergencies, leading to expensive search and rescue missions. A research product using sophisticated voice pattern recognition and analysis methods was developed that allows the U.S. Coast Guard operator to identify hoax callers and assists in their subsequent prosecution and conviction. This should eventually lead to a reduction of hoax calls.

Value of information for improved decision-making. The value of information (VOI) paradigm is well known in decision analysis. It is usually applied to contemplating the net expected value or utility gained when using a potential source of information. Thus, at the time the VOI is calculated, the information has not yet been obtained. Depending on the possible outcomes of the information collection effort, the decision alternatives are reconsidered with updated probabilities of the states of nature, which made the decision complicated to start with. The expected value of sample information, or EVSI, is the difference between the expected value of acting with the information and the expected value of acting without it. The cost of information gathering must then be subtracted to determine the net expected value of information.

In the context of evaluating the benefits of homeland security research products, this paradigm can be used in a slightly modified way. Some research products can be accessed at a fairly low cost to provide information that can be useful for making decisions. The investment in this research product has often been large (i.e., in the millions of dollars) and while this is a sunk cost for the decision-maker at hand, these costs have to be considered when evaluating the net expected value of information that the research product provides. Therefore, the question often is: should I access or use the information provided by the research product or act without it?

An example is a new hurricane prediction model that provides more precise information about maximum wind speeds and flood levels than existing prediction models. The U.S. Coast Guard has used this new model to make decisions about relocating assets prior to a storm (Brown, 2018). In one case, the decision was made to keep the Coast Guard helicopters in an old hangar prior to Hurricane Maria in 2017, rather than relocating them – at substantial costs – to avoid possible damage. Had the Coast Guard relied on existing models, they would likely have relocated the helicopters. As it turned out, the hangar withheld the storm, thus saving substantial relocation costs and providing the additional benefit of having the helicopters available immediately after the storm subsided.

Net present value calculations, benefit-to-cost ratio, and return on investment. The cost and benefit information can be summarized in several ways: the net benefits, the benefit-to-cost ratio (BCR), or the return on investment (ROI). Since costs and benefits are often distributed over time, often with upfront costs and delayed benefits, a proper calculation has to consider the time value of money. In our methodology, we inflate costs incurred prior to 2017 by the consumer price index, and we discount future costs and benefits by the social discount rate (3 percent in the base case, and 0 and 7 percent in the sensitivity analysis). The BCR is defined as the ratio of the net present value of the costs, divided by the net present value of the benefits:

$$BCR = NPV(Cost)/NPV(Benefits)$$

The ROI is the ratio (as a percentage) of the present value of the net benefits, divided by the net present value of the cost:

$$ROI=\{NPV(Benefits)-NPV(Costs)\}/NPV(Costs)$$

Sensitivity and Uncertainty Analysis. While the cost estimates are usually fairly well established with little or no uncertainty, many of the inputs to the benefits models are highly uncertain, especially if the research product has not been implemented or used yet. For example, the decrease in detection rates of a new gun or explosives detection device remains uncertain, even after extensive testing.

Our methodology includes two sensitivity analyses and one uncertainty analysis. In the first sensitivity analysis, we calculated the break-even point at which benefits just equal the costs. For example, we determined how much the detection rate would have to be increased in order to make up the cost of a new detection device. The second sensitivity analysis uses a software package called Sensit to create a so-called "tornado diagram" (Treeplan, 2017). First, we defined a base case and reasonable ranges (lower and upper estimates) for each uncertain parameter of the benefits model. Then we calculated the net benefits for each parameter at its high and low levels. The tornado diagram shows the ranges of the net benefits as horizontal bars, with the largest bar at the top and with successively shorter bars below (thus the name "tornado"). This diagram provides us with information about which parameters matter most to the net benefit calculations and which matter the least.

Following the tornado analysis, we conducted a complete uncertainty analysis for the parameters that matter most. Since we are dealing with multiple research products and hundreds of uncertain parameters, a complete assessment of the uncertainties using expert judgment was not feasible. Instead, we used triangular distributions throughout, with the low, base case, and high estimates defining the triangular distribution for each parameter. Using these triangular distributions, we utilized a probabilistic simulation software called SimVoi (Treeplan, 2017) to create the distribution over the net present value for each research product. As summary measures, we used the 5th percentile, the median, and the 95th percentile of this distribution over net benefits.

3. Application: Benefit-Cost Analysis of the 3D Computed Tomography Datasets and Automatic Threat Recognition Software

3.1. Summary

Description. The Center of Excellence for Awareness and Localization of Explosives-Related Threats (ALERT) created datasets and advanced threat recognition (ATR) algorithms for use in three-dimensional (3D) computed tomography (CT) detection equipment that is scheduled to be deployed at 2,500 TSA checkpoints for carry-on luggage. The datasets have been developed to optimize threat recognition algorithms without using sensitive or classified information. The ATR was developed by a subcontractor of ALERT using the ALERT datasets. The ATR algorithm is licensed to a vendor of the 3D CT scanners for a one-time fee. ALERT staff estimates that the vendor will capture 25 percent of the market of checkpoint scanners (Silevitch, 2017; 2019a; 2019b). The main benefit from using the datasets and the optimized ATR algorithm is a reduction of false alarms due to the new scanners. While it also may have benefits from increasing detection rates (or reducing misses), the benefit-cost analysis (BCA) in this report focuses on reduction of false alarms.

Results. The costs of the development of the datasets and the ATR is estimated at $4,898,926 (in 2017 dollars). This includes $740,000 in funding by the Office of University Programs (OUP), COE and OUP overhead, and $3,555,000 in transition-development funding by the Science and Technology Directorate (S&T) and the Transportation Security Agency (TSA).

The benefits are primarily due to a reduction of false alarm rates (FARs), which result in time savings of TSA staff and travelers. The baseline FAR of current 2D X-ray scanners is around 10 percent, which includes both real false-positives (i.e., nothing is found during secondary inspection) and nuisance alarms (i.e., a prohibited but non-threat item is found during secondary inspection, e.g., a large water bottle or a computer). A report by the National Research Council (NRC, 2013) mentions that the benefits of a 1 percent reduction of false alarms throughout the TSA system would result in a savings of $20 million per year.

In this BCA, we take a different approach to estimating benefits by first estimating the reduction in false alarms due to the optimized ATR and then calculating the time savings due to this reduction. We estimate a reduction in false alarms of 25 percent, ranging between 20 and 30 percent. We estimate that the time spent in secondary search is about 7.5 minutes (ranging from 5 to 10 minutes) due to the process of waiting for the carry-on luggage and for searching and repacking the luggage. We use Department of Transportation (DOT) guidance on valuing travelers' time savings and the approximate cost of a TSA staff member to estimate the value of officers' time savings.

TSA is planning replace about 2,500 scanners with 3D CT scanners (Washington Examiner, 2018). The 3D CT vendor that uses the ALERT-funded ATR is expected to capture 25 percent of this market, or about 625 scanners (Silevitch, 2019). TSA estimates the cost of each scanner at about $330,000 (FCW, 2019). Since the TSA will purchase new scanners in any case, we do not include the scanner costs. We only take a portion of the credit of reducing false alarms as the marginal benefit of reducing the false alarms (30 percent in the base case, with a range from 20 to 40 percent).

In the base case, the net benefits are $10,717,594 per year or $107,175,938 for 10 years. Due to the substantial uncertainty about several of the input variables of the benefit model, we conducted sensitivity and uncertainty analyses, which resulted in a median net benefit of $117,741,020 for 10 years of use, with a range from $62,076,958 (5th percentile) to $209,045,620 (95th percentile).

3.2. Background

The current technology to scan checked and carry-on baggage at airports is a 2D X-ray scanner. The TSA is planning to replace these 2D scanners with 3D CT scanners at all 2,500 checkpoints at U.S. airports. In 2019 alone, the agency signed a contract with a 3D CT vendor for $98.6 million to purchase 300 scanners (FCW, 2019). Over the coming five years, TSA is planning to deploy the 3D CT systems at all passenger checkpoints at U.S. airports.

The advantages of these new scanners have been described by many sources, most notably the National Academy of Sciences (NRC, 2013). Among the features of the new equipment are the ease of use, the 3D view, and, most importantly, the reduction of false alarm rates and the increase in detection rates. Of course, with the increase in detection comes the decrease in misses, i.e. missed cases of true threat objects, thereby reducing risks to the airline industry, the airline passengers, and the national economy. The NRC report includes a reference to the "often-cited approximate number of annual savings of $25 million per percentage drop in the false alarm rate" (NRC, 2013, page 82).

3D CT scanners consist of the scanning equipment, which is not unlike a medical CT scanner, and an automatic threat recognition (ATR) software that assists the TSA officer in determining whether an object viewed on the 3D screen poses an actual threat (e.g., explosive materials, guns, knives, etc.). One issue with developing an ATR is the lack of available data on threat objects, because most of this data is classified or deemed law enforcement sensitive. It is therefore important to optimize an ATR without access to classified or sensitive information though datasets that mimic the types of threat materials and shapes that can be found in carry-on or checked baggage.

Since about 2010, ALERT conducted research that contributed to the creation of an unclassified dataset for testing and developing ATRs and funded the development of a new ATR through a subcontract to an ATR vendor. The ATR developer has, in turn, teamed up with a CT equipment vendor and established a licensing agreement with this vendor. In this BCA, we are restricting the analysis to:

1. the benefits and costs due to the development of the datasets and the ATR;
2. the benefits due to reducing false alarms and subsequent savings in wait time for passengers and secondary investigation time for TSA agents; and
3. the benefits applied to the equipment vendor that has a relationship with the ALERT-funded ATR developer, with only a partial market of the 2,500 scanners that will eventually be purchased.

We are thus not taking credit for:

1. other wait time benefits, like improved flows of passengers through the checkpoint system due to the fact that the new system will no longer require removal of computers and liquids; or
2. improved detection rates due to the CT scanner and associated ATR.

Due to these parameters, we expect the benefits in this BCA to be on the low side.

3.3. Baseline

As stated above, this BCA considers the main benefit of 3D CT scanners to be the reduction of false alarms and the resulting decrease in wait time for passengers and time spent by TSA officers on secondary inspections of baggage. Information about FARs is sensitive, but informal interviews with passengers and airport officials suggest that the current base rate using 2D X-rays is between 5 and 15 percent. In the base case, we used a FAR of 10 percent. Alarms trigger a manual inspection of the carry-on baggage, which involves wait time for the passenger and inspection time for the TSA officer. The actual time is also a sensitive number, but experience with air travel suggests that this time varies between 5 and 10 minutes. The longer times usually occur when there are several alarms close to each other. In the base case, we used 7.5 minutes.

The cost of unproductive wait time for travelers has been determined by the U.S. Department of Transportation to be \$0.79 per minute (U.S. DOT, 2017). The cost of an additional minute of secondary inspection time was derived from the annual burdened salary of a TSA officer, estimated at \$100,000 per year. This cost results in \$0.27 per minute of effort.

Using 719 million passengers in 2017 and the above estimates for percentages of false alarms and the cost of wait time per false alarm, we arrived at a base case estimate of the cost of false alarms to be \$571,605,000. Note that this corresponds to \$57,160,500 for each percentage of false alarms, about twice the cost that the NRC referred to. When using low-end estimates, we calculate a cost of \$122,230,000 or \$12,223,000 per percentage of false alarms, about one-half the NRC estimate.

3.4. Cost Analysis

The costs of the ALERT-funded development of the datasets and the ATR were provided by the Director of the ALERT Center of Excellence, Michael Silevitch. They are shown in Table 3.

Table 3. Cost of Development of the Datasets and ATR

Cost Category	Start	End	Amount in Real Dollars	Amount in 2017 Dollars	Source
Pre-project costs (COE)					
Pre-project costs (other funding)					
Project costs (COE)	9/1/13	6/30/18	$ 740,000	$ 748,315	COE/OUP
Project costs (university cost share)					
Oversight cost at the COE	9/21/10	6/30/18	$ 210,000	$ 216,987	COE/OUP
Oversight cost at OUP	9/21/10	6/30/18	$ 160,000	$ 165,324	OUP Overhead
Transition development cost	9/21/10	2/27/15	$ 3,555,000	$ 3,768,300	S&T, TSA
Implementation start up cost					
Implementation cost (User)					
Implementation cost (COE)					
Implementation cost (Other users)					
TOTAL COST			**$ 4,665,000**	**$ 4,898,926**	

Note that these cost estimates stop with the transition development costs, up to the deployment in the equipment marketed by the CT vendor. We do not include the cost of the CT scanning equipment, which the TSA would have to buy anyway, regardless of the ATR used. Thus, we only consider the marginal cost of the dataset development and the ATR, and we are also careful to only consider the marginal benefits of these developments, expressed as a percentage of the benefits of the combined equipment, ATR, and dataset development (see next section for explanation of the marginal benefits).

The cost estimates were converted to 2017 dollars by assuming that the costs were equally distributed in the time period referred to by the ALERT COE staff and then either inflated to 2017 dollars using the Consumer Price Index or deflated at 3 percent for costs incurred in 2018.

3.5. Benefit Analysis

Table 4 shows the inputs and outputs of the benefits analysis. In addition to the inputs for the baseline analysis discussed in Section 3.3, the analysis required three inputs:

1. the percentage reduction of false alarm rates relative to baseline false alarms
2. the percentage of market share captured by the CT vendor
3. the percentage of the false alarm reduction attributable to the CT equipment vs. attributable to the datasets and the ATR

These estimates and ranges were elicited in an interview with Michael Silevitch and Carl Crawford on April 3, 2019.

Note that this table also shows estimates that can be used to determine additional benefits from increasing the detection rate (i.e., the baseline detection rate, the increase in the baseline detection rate, and the cost of a successful attack in case of a missed threat object). Because the data required for firming up these estimates are sparse or classified, we did not use them in our benefits calculations.

All benefit estimates were first calculated for the first year of use in 2017, and then we calculated the discounted benefits for 10 years of use and subtracted the costs in 2017 dollars to arrive at the net 10-year benefits.

Table 4. Benefit Analysis

Input Variable	Base
Number of Travelers/Year	719,000,000
Current False Positive Rate	10.0%
Decrease in False Positives	25%
Time in Secondary (Min)	7.5
Cost of One Minute of Wait Time	$0.79
Cost of One Minute of TSA Time	$0.27
Percent attributable to CT Vendor	25%
Percent attributable to ATR	30%
Current Cost of False Positives/Year	$ 571,605,000
3D Cost of False Positives/Year	$ 428,703,750
Attributabe Benefits/Year	$ 10,717,594
Discount Factor	0.030
Total Value of 3D CT Scanners for 10 Years	**$ 107,175,938**
Total Net Benefits for Ten Years	**$ 102,277,012**

3.6. Benefit-Cost Analysis – Base Case

Table 5 shows the results of this analysis in terms of benefits and costs in 2017 dollars, net present value (NPV) benefits, and the return on investment.

Table 5. Estimated Base Case Benefits and NPV for ALERT's Datasets and ATR

PV Benefits (2017 dollars)	$ 107,175,940
PV Costs (2017 dollars)	$ 4,898,926
NPV (2017 dollars)	$ 102,277,014
Return on Investment	2088%

3.7. Sensitivity and Uncertainty Analysis

Break-even analysis. There are several ways to conduct break-even analyses for the ALERT datasets and ATR tool. For example, the benefits just equal the costs when the reduction of the FAR is 1.1425 percent, a very small reduction that will certainly be exceeded by the CT equipment and ATR. Another example is the share of attributable benefits of the datasets and ATR versus the CT equipment. The break-even point here is 1.37 percent.

Tornado analysis. To conduct a tornado sensitivity analysis, we elicited ranges of input values around the base case displayed in Table 4. Data regarding the low and high values of the percentage of false alarm reduction attributable to the ATR, the percentage reduction in false alarms, and the percentage of market share of the CT equipment vendor came from interviews with the COE Director and the Principal Investigator of the projects. The low and high values for the current false alarm rate, the time in secondary search, the cost of passenger wait time, and the cost of TSA officers' time were not elicited from experts but assigned to cover a wide reasonable range. Using these ranges results in a wide range of net benefits, from $7,324,074 to $693,969,074.

Table 6. Base Case and Ranges of Input Parameters Values

Input Variable	Low	Base	High
Number of Travelers/Year	719,000,000	719,000,000	719000000
Number of Attack Attempts Per Year	0.1	0.2	0.4
Detection probability with current system	0	0	0
Current False Positive Rate	5.0%	10.0%	20%
Decrease in False Positives	20%	25%	30%
Time in Secondary (Min)	5	7.5	10
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
Percent attributable to CT Vendor	20%	25%	30%
Percent attributable to ATR	25%	30%	40%
Current Cost of False Positives/Year	$ 122,230,000	$ 571,605,000	$1,941,300,000
Current Cost of False Negatives	$ -	$ -	$ -
3D Cost of False Positives/Year	$ 97,784,000	$ 428,703,750	$1,358,910,000
Attributabe Benefits/Year	$ 1,222,300	$ 10,717,594	$ 69,886,800
3D Cost of False Negatives	$ -	$ -	$ -
Discount Factor	0.000	0.030	0.070
Total Value of 3D CT Scanners for 10 Years	**$ 12,223,000**	**$ 107,175,938**	**$ 698,868,000**
Total Net Benefits for Ten Years	**$ 7,324,074**	**$ 102,277,012**	**$ 693,969,074**

Figure 1 shows the resulting tornado diagram. It illustrates that the current FAR is the most important input parameter, followed by four other parameters. The cost of TSA officers' time is the least important one considered in this analysis. The other parameters were either fixed (number of travelers per year) or not considered in this BCA, which solely focused on false alarms (parameters related to detection).

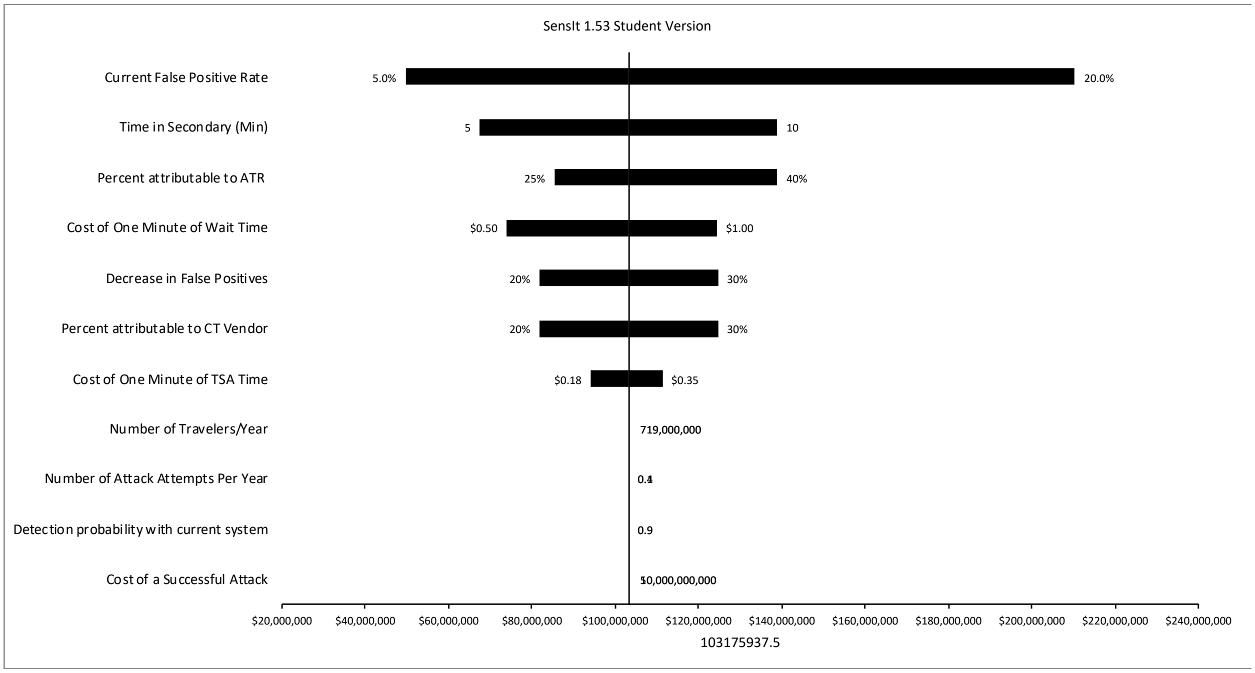


Figure 1. Tornado Analysis of the Input Parameters for the ALERT Datasets and ATR Project

Uncertainty Analysis. To conduct an uncertainty analysis, we used triangular distributions, with the minimum set at the low value of Table 6, the mode at the base case, and the maximum at the high end of Table 6. The results are shown in Figure 2. Table 7 shows the statistics of this distribution, with a 5th percentile of $62,076,958, a median of $117,741,020, and a 95th percentile of $209,045,620.

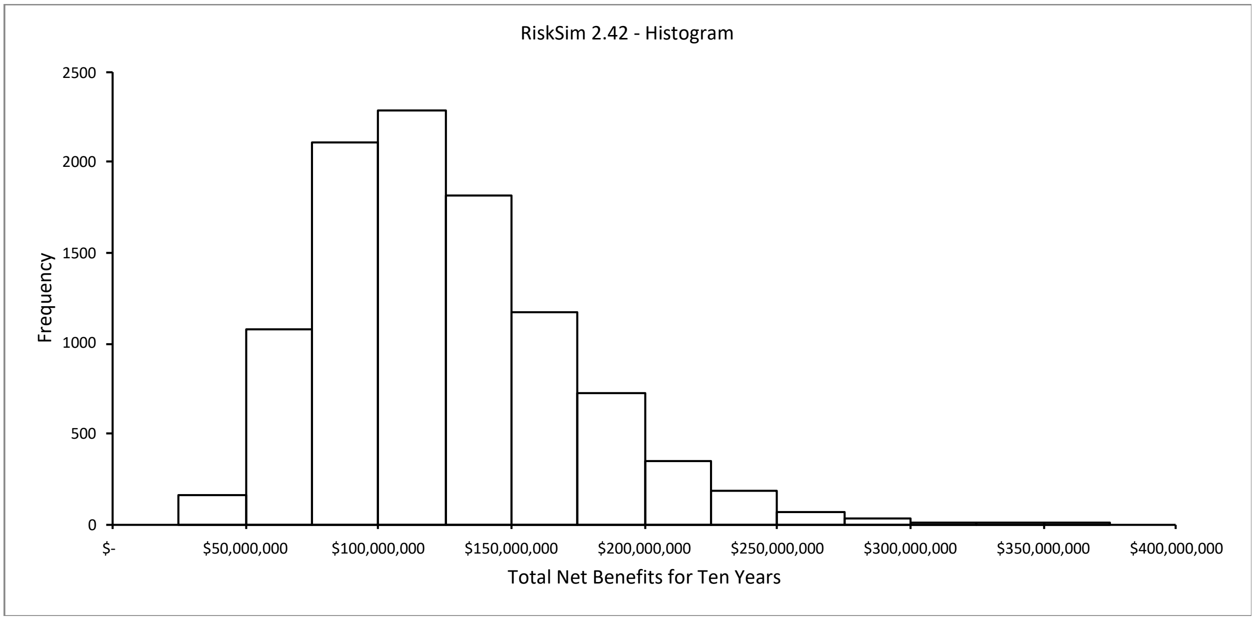


Figure 2. Results of the Uncertainty Analysis

Table 7. Statistics of the NPV Simulation

Mean	$124,454,313
St. Dev.	$ 45,828,173
5th Percentile	$ 62,076,958
Median	$117,741,020
95th Percentile	$209,045,620

3.8. Assumptions and Limitations

The main assumption in this BCA is that all costs and benefits are marginal, i.e., we don't count the total lifecycle costs and benefits of converting the current 2D scanners to 3D scanners, but only the costs and benefits of the ALERT datasets and ATR project. A key assumption in this analysis is the percentage of false alarm reduction attributable to this project by ALERT.

We received communication from the ALERT team (Crawford, 2019) that the ATR developer is receiving $5,000 per scanner as a license fee from the CT vendor, with a market of 25 percent of the CT scanners, or 625 scanners. This is a one-time fee only. If we were to apply this license fee as the only benefit of the ATR software, this would result in a benefit of only

$3,125,000, less than the cost of development. If applied to all 2,500 scanners, the benefits as measured by the license fee would be $12.5 million, exceeding the cost of development. These numbers establish a lower bound of benefits. Most of the other input parameters can be ascertained by collecting additional information.

3.9. Recommendations for Collecting Additional Information and Analysis

It should be easy to collect additional information on the most important parameter value: the baseline false alarm rate. This is available from TSA but considered law enforcement-sensitive. Similarly, the reduction of the false alarm rate can be ascertained after tests with the CT scanners are completed. Wait time for passengers in secondary screening and time for secondary inspections by TSA officers can also be determined more precisely using TSA data. The percentage of market share captured by the CT vendor won't be known for some time but will be known in a few years to refine this BCA.

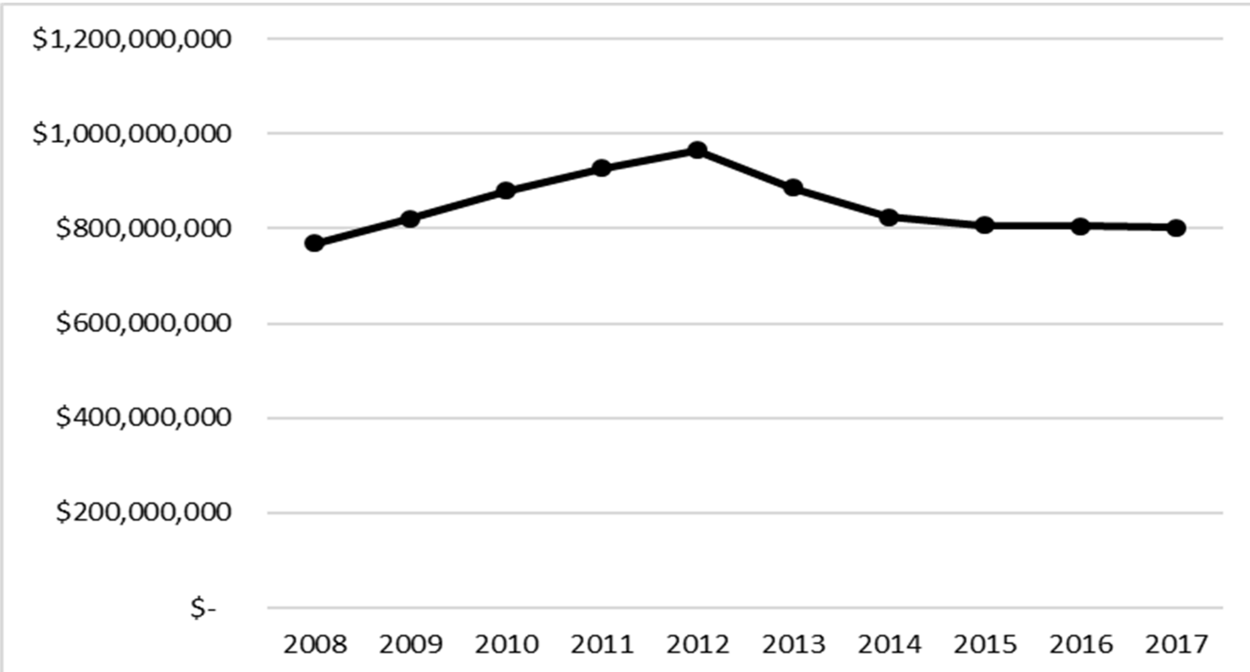
4. Summaries of Applications of Eight Other TTKPs

In the previous section, the ALERT tool for datasets and ATR development provided an example of an application of the benefit- cost analysis methodology employed in this study. In this section, we summarize the results of the other TTKPs evaluated in this study. These summaries are, by necessity, brief. In the appendix, we provide additional detail for all benefit-cost analyses in the format used in Section 3.

While we began with 11 TTKPs selected by CBP and TSA staff, we eliminated two TTKPs for different reasons. We eliminated PORTSIM because we could not identify any users or uses for CBP or TSA. We also eliminated the Satellite Surveillance TTKP as the principal investigator stated that there had not been sufficient funding to develop this TTKP to a point of transition to any user at DHS. This left us with nine analyses, summarized below.

4.1. Benefit-Cost Analysis of Intelligent Randomization in Scheduling (IRIS)

Description. The Center for Risk and Economic Analysis of Terrorism Events (CREATE) developed a computerized support tool to randomize almost all international flight scheduling for the Federal Air Marshal Service (FAMS), an aviation-focused portion of the Transportation Security Administration. FAMS personnel fly semi-covertly on domestic and international flights and are armed and trained to respond to in-flight terrorist attacks (Biles, 2013; GAO, 2016; Stewart & Mueller, 2018). Figure 3 shows the scale of operations based on the FAMS budget, which has been somewhat less than a billion dollars per year.



Data: FAMS (2018)

Figure 3. Budget Authorization for the Federal Air Marshal Service (in Fiscal Years)

The Intelligent Randomization in Scheduling (IRIS) tool automates the flight assignment process for federal air marshals (FAMs) on almost all international flights while incorporating advanced randomization methods into the allocation process (Tsai et al., 2009). The tool has been in use by FAMS since late 2009 and remains in use today (An & Tambe, 2018; FAMS, personal communication).

Results. IRIS generates ongoing benefits and costs. This analysis focuses on the 10-year period from November 2009 to November 2019, most of which is retrospective. Two different analyses are presented. The first is a stand-alone cost savings and security analysis of the use of IRIS by FAMS; the second is a layered analysis that embeds FAMS within multiple general and airline security-focused programs. The baseline costs and benefits are the procedures that were in place at FAMS for 2008-2009, before IRIS was deployed. Costs to develop and deploy IRIS are estimated at $1.8 million (in 2017 dollars), which includes the cost of research and transition efforts at CREATE, university overhead and oversight cost at the Department of Homeland Security (DHS) Office of University Programs (OUP), and associated development and management costs at FAMS. The potential benefits of using IRIS each year involve three components: 1) personnel cost savings at the baseline level of activity, 2) personnel cost savings as the level of activity increases, and 3) improved security due to better randomization. The estimated security improvement, while relatively imprecise, dominates the personnel cost savings. The estimated benefits in the base case stand-alone analysis are $554.9 million (in present value 2017 dollars), yielding net present value (NPV) returns of $553.1 million (in 2017 dollars) for a 31,599 percent rate of return (the net benefits are about 316 times the cost). Numerous break-even, sensitivity, and uncertainty analyses results are presented. In the simulation analysis, no trial among the 10,000 iterations resulted in a negative NPV; the 5th and 95th percentiles for NPV were $241.1 and $940.4 million, respectively (in present value 2017 dollars), with a mean of $555.5 million.

The second, layered security approach that is often thought to reduce the benefits of FAMS (Stewart & Mueller, 2012; 2018) is used to check the stand-alone results. Replicating the results of Stewart and Mueller, with adaptations to the international context in which IRIS is used, results in an NPV of $2,682 million (in 2017 dollars), substantially more than the estimate using the stand-alone analysis. As the layered analysis contains many more assumptions than described below, the stand-alone analysis is used as the default analysis in summaries of this case.

4.2. Benefit-Cost Analysis of the Wait Time Study for Customs and Border Protection

Description. The Center for Risk and Economic Analysis of Terrorism Events (CREATE) carried out a quantitative study of the economic benefits attained by increasing the number of Customs and Border Protection Officers (CBPOs) at U.S. ports of entry. CBPOs are the front-line inspectors who are critical to the normal flow of people and trade across the U.S. border by enforcing customs, immigration. and agricultural laws.[3] To the extent that inspection times become long, costs are incurred; too short, and inspection time may compromise enforcement. The Wait Time study was commissioned by U.S. Customs and Border Protection

[3] Enforcement between ports of entry is carried out by a different organization, the U.S. Border Patrol.

(CBP) (Roberts et al., 2013) and was followed by peer-reviewed publications (Roberts et al., 2014a; Avetisyan et al., 2015). The study combined micro- and macroeconomic information and models to estimate the change in Gross Domestic Product (GDP), the cost of wait time at the borders, and changes in jobs as a result of an increase or decrease in the number of CBPOs. The Wait Time study (Roberts et al., 2014a; 2014b) was used in congressional budget testimony, which was followed by an increase in the authorized number of CBPOs.

Results. The Wait Time study is credited with a portion of the increased economic benefits from the congressionally approved expansion of CBPOs, which also comes with increased personnel costs. This analysis focuses on the 10-year period from Fiscal Year (FY) 2014 to FY 2023. Five of these years are retrospective, in that data were made available on the hiring that actually occurred. Five years are prospective and assumed to be the same in nominal value as 2018, the last year for which actual data are available.

Study costs are estimated at $0.4 million (in 2017 dollars), which includes the cost of research and transition efforts at CREATE, university overhead and oversight cost by the Department of Homeland Security (DHS) Office of University Programs (OUP), and associated development and use costs at CBP. The estimated base case benefits are $173.5 million in present value 2017 dollars. The change in net benefits in the base case are based on valuing the changes in wait times for U.S. residents at ports of entry and deducting the full costs of the increase in number of CBPOs. Note that costs are incurred by the government, but benefits are received by a wide range of citizens and businesses. That change in benefits yields net present value (NPV) returns of $173.1 million (in 2017 dollars), for a rate of return of 42,361 percent (the net benefits are about 424 times the cost). Break-even and uncertainty analyses are carried out. The break-even share of benefits for the Wait Time study that results in NPV just equaling zero is 0.02 percent. Benefits are substantially higher when macroeconomic impacts are included, a sometimes controversial analysis but frequently used in the economics literature (U.S. OMB, 1992; 2003; Rose et al., 2017; Farrow & Rose, 2018). Median NPV, taking into account all quantified sources of uncertainty, is $282.3 million.

4.3. Benefit-Cost Analysis of Enhanced Millimeter-Wave Scanner (EMWS)

Description. The Enhanced Millimeter-Wave Scanner (EMWS) tool is a product developed by the Awareness and Localization of Explosives-Related Threats (ALERT) Center of Excellence (COE). The EMWS tool is a result of two projects that improve detection capabilities of the existing millimeter-wave imaging technology. Millimeter-wave scanners are used in U.S. airports by the Transportation Security Administration (TSA) to detect objects, such as weapons or explosives, that are concealed underneath clothing. Existing millimeter-wave scanners are unable to distinguish the type of object that is concealed and often mistakenly identify innocuous material as aberrations. The EMWS provides a method to differentiate between innocuous material and contraband.

The valuation of the EMWS tool is driven by the cost savings associated with reducing the amount of time that is spent investigating false alarms. A false alarm results in delays to passengers who are directed to secondary screening (pat-downs) as well as TSA agent time to perform the screening.

Results. The development of the EMWS tool resulted in costs of $3,260,599 (in 2017 dollars). These costs were primarily from direct project costs and associated oversight costs at OUP. The cost of the EMWS devices are comparable to the cost of existing alternatives, so additional deployment costs will be minor if the deployment of the EMWS follows the existing deployment and replacement schedule.

The benefits of the EMWS tool are derived from a reduction in false alarms relative to the existing scanning technology, which can incorrectly flag skin folds, colostomy bags, and other innocuous aberrations as potential threats. This results in secondary screening for passengers which increases passenger wait time. It also requires a TSA agent to provide the secondary screening. The value of the EMWS is derived from the reduced passenger wait time and the reduced TSA staffing time associated with reducing the likelihood that a false alarm is triggered. Benefits are evaluated under a 10-year time horizon of future product usage.

The EMWS tool results in base case total benefits of approximately $99 million (in 2017 dollars). Sensitivity analysis was conducted to identify the parameters that are most important in driving the value of the EMWS tool. The duration of the secondary pat-down and the value placed on traveler time under Department of Transportation guidelines are key drivers of total value. The value of the EMWS is also sensitive to the false alarm rate of existing technology and the reduction in false alarms from the EMWS tool relative to existing alternatives, but these parameters are highly uncertain. A break-even analysis was also conducted which indicated that the EMWS benefits would exceed the development costs if the baseline false alarm rate is above 0.6 percent or if the EMWS tool reduces false alarms by more than 1 percent. A simulation analysis of all of the uncertainty in the model finds a range of net benefits, with a 5th percentile value of $51 million, a 95th percentile value of $264.7 million, and a median value of $123.2 million.

4.4. Benefit-Cost Analysis of the Passive Acoustic Sensors (PAS) System for Low Flying Aircraft Detection

Description. As an alternative technology to the widely used radar systems to monitor and detect illicit low-flying aircraft, the passive acoustic detection and tracking system provides several appealing features, including its simplicity and relatively low cost. The Passive Acoustic Sensors (PAS) system was developed by the Maritime Security Institute at Stevens Institute of Technology. The system was designed to automatically detect, track, and classify low-flying aircraft by using a network of passive acoustic sensors. The system captures signals and images of the passing aircraft by its sensors, microphones, cameras, and other electronics, and sends the pre-processed signals wirelessly to the central processing station to determine the location of the aircraft. Although the PAS system has not been deployed by U.S. Customs and Border Protection (CBP), it has been tested for an extended period in mountainous areas.

Results. The estimated total development cost of the PAS system is about $4.0 million. This estimate only includes the development and implementation costs of the technology. In addition, the system cost of each field station is about $125,000, which is projected to be able to adequately function for at least 10 years. The annual operation and maintenance costs for each station are estimated at $2,000.

To estimate the benefits of the PAS system, we assume that it will be utilized as a supplemental detection and tracking technology to the current Tethered Aerostat Radar System (TARS) operated by CBP in Rio Grande City, Texas, the location where the most active detection and seizure activities by TARS are recorded. The main benefits of the PAS system are estimated as the market value of intercepted illegal drugs from additional seizures that the PAS system can help achieve. In the base case, it is estimated that the total net benefits for 10 years of deployment of the system are about $18.1 million.

There is substantial uncertainty in terms of additional number of seizures that result from the deployment of the PAS system, the quantity of narcotics intercepted per seizure, and the market values of the narcotics. We conducted sensitivity analyses on these variables and found that the net benefit could range from $8.5 million (5th percentile) to $39.7 million (95th percentile), with a median of $20.9 million.

4.5. Benefit-Cost Analysis of the Trafficking Risk Modeling Tool

Description. Giant Oak Inc., through funding support from the National Center for Border Security and Immigration, developed a Bayesian model to predict the likelihood of an individual being trafficked based on specific information such as age, gender, race, country of origin, etc., that is available when the individual enters the U.S. at border crossings. The tool was developed based on two major databases of trafficking victims, the Human Trafficking Reporting System and the Trafficking Information Management System, which contain more than 2,200 individual trafficking cases. The objective of this predictive model is to identify more potential trafficking victims with a given number of screens. Currently, the tool has not been deployed by CBP or any other government agencies. Therefore, its performance in real-world applications still needs to be determined.

Results. The total development cost of the Trafficking Risk Modeling tool is $139,050 in 2017 dollars. Since the tool has not been deployed, there are no transition development or implementation costs. In addition, we assume that there will be costs for using the tool on an annual basis if it is deployed in the future, which is assumed at $100,000 in the base case analysis. Both of these costs are counted in the analysis of the net benefits of the tool.

The benefits of using the Trafficking Risk Modeling tool include the values of saving additional trafficking victims and convicting additional traffickers above the baseline levels. In the base case, we estimate that the discounted net benefits from using the tool for 10 years is $7.2 million.

There is considerable uncertainty in terms of the baseline number of trafficking victims identified by CBP at border crossings, the percentage of additional victims who can be identified above the current baseline levels if the Trafficking Risk Modeling tool is deployed, as well as the values of saving one trafficking victim and convicting one trafficker. We conducted sensitivity analyses on these and other key variables and found that the net benefit could range from $3.0 million (5th percentile) to $18.0 million (95th percentile), with a median of $8.3 million.

4.6. Benefit-Cost Analysis of the Remote Power Module (RPM)

Description. The Remote Power Module (RPM) is a fully automated, renewable hybrid power station that uses wind, solar, and diesel power. The RPM is equipped with a comprehensive power monitoring system that helps protect against spurious failures, optimize its three power sources, and allows for remote control and access to its operation. This TTKP allows high frequency radar (HFR) to be deployed in areas off the main power grid. These HFRs collect important information about ocean circulation, wave height, U.S. Coast Guard search and rescue conditions, vessel tracking, contaminant spills, marine navigation, and the marine ecosystem/fisheries. The capability to collect this information in remote areas may be increasingly beneficial moving forward, especially in light of the fact that this technology can be deployed rapidly.

Results. The total estimated funding for the RPM was $1.7 million (in 2017 dollars) and includes all OUP funding from 2008 to 2014. The primary benefit of the RPM is the cost savings as compared to the initial cost, delivery, maintenance, fuel, and fuel delivery for a conventional diesel power source. Benefits, defined as RPM cost savings, are largely dependent on the number of past and projected RPM deployments through 2027; the base case analysis indicates a benefit of $6.4 million (in 2017 dollars). The total net benefit was estimated to be $4.6 million (in 2017 dollars), resulting in a 269 percent return on investment (ROI) and a benefit-cost ratio of 3.69. A sensitivity analysis indicated a great deal of uncertainty in net benefits, with a median of $5.5 million and a range from $1.9 million (5th percentile) to $15.1 million (95th percentile).

4.7. Benefit-Cost Analysis of the Gang Graffiti Automatic Recognition and Interpretation Tool (GARI)

Description. The Center for Visualization and Data Analytics (CVADA) developed a computerized support tool, the Gang Graffiti Automatic Recognition and Interpretation (GARI), for law enforcement officers and first responders to identify, monitor, and track gangs. Users simply take a photo of graffiti (or gang tattoos) on their phone or tablet, wirelessly upload the image to the comparison database, and receive expert-level intelligence in the field instantaneously. (There is also a community version of the app that works similarly, but only allows for the reporting of graffiti.) The resulting information identifies the specific gang(s) affiliated with the graffiti symbol(s) captured in the image and provides the user with the gang's geolocation and historical data.

This information can then be used to track gang movements, activity, affiliation, growth, and to create an easily accessible record of different graffiti markings and their significance (e.g. challenges, warnings, or intimidation/threats) for further analysis and reference. This helps law enforcement officers identify and target youth who are at risk of gang recruitment and prepare for potential outbreaks of gang violence, creating unique prevention opportunities.

Results. The total estimated funding for GARI—$372,000 (in 2017 dollars)—includes all OUP funding from August 2010 through December 2016. The primary benefits of GARI are the worker cost-savings, as compared to manual database management, and the expert interpretation of gang-related images. The cost savings attributed to GARI are related to projected GARI deployments through 2027; the base case estimate of total benefits is $1.8 million (in 2017 dollars). The total net benefit was estimated to be $1.4 million (in 2017 dollars), resulting in a return on investment (ROI) of 378 percent and a benefit-cost ratio of 4.78. A sensitivity analysis indicated a great deal of uncertainty in GARI net benefits, with a median of $1.1 million and a range from $94,000 (5th percentile) to $5.5 million (95th percentile).

4.8. Benefit-Cost Analysis of the Social Media Analytics and Reporting Toolkit (SMART)

Description. The Social Media Analytics and Reporting Toolkit (SMART) is a product developed by the CVADA COE. SMART allows users to map geocoded data from social media communications like Twitter and Instagram, based on key words or phrases. The primary purpose of the technology is to increase situational awareness during and after large events so that security and law enforcement personnel can optimally allocate resources, either reducing response times or reducing the staffing costs needed to identify problems.

The valuation is primarily based on the cost savings associated with reduced or optimized staffing that SMART makes possible. There is also a second component of the SMART benefits that relates to the likelihood that SMART changes the overall likelihood of a threat causing damage.

Results. The SMART tool resulted in costs of $320,349 (in 2017 dollars). These costs were related to direct project costs and university cost share. One of the primary benefits of SMART is that it has an intuitive interface which requires little training, so it is unlikely that there will be substantial additional costs associated with deployment of the tool.

The benefits of SMART are associated with reductions in the staffing needed to maintain security at large events. By leveraging user-generated social content to more quickly identify concerns, security and medical personnel can be more efficiently dispatched to address issues in crowds. The benefits of SMART are evaluated under the assumption that identification and response times change linearly with the number of security personnel who are deployed to an event. SMART results in an overall reduction in response times, so its value can be assessed by identifying the costs needed to provide security personnel to reduce the response time by the same amount. Benefits are evaluated under a 10-year time frame, with the assumption that there are 50 events each year at which SMART can be used.

5. Summary Results of Nine TTKPs

Table 8 shows the net 5th, 50th, and 95th percentiles of the net present value (NPV) of the benefits for all nine research products. The sum of the median net benefits (NPV as defined above) is about $385 million, which is close to the OUP budget for the past 13 years, since 2004. Even at the low end (5th percentile), the sum of the NPVs exceeds the cost of the research products. At the high end, the sum of the median NPVs is about 20 times larger than the costs.

Table 8: Costs, Medians and Ranges of Net Present Values for Nine Research Products

Updated June 13, 2019		Ranges of Net Present Values (in 2017 Dollars)			
Tool, Technolgy, or Knowledge Product (TTKP)	Cost (in 2017 Dollars)	Low NPV (5th Percentile)	Median NPV (50th Percentile)	High NPV (95th Percentile)	Years of Use for Net Benefit Calculations
IRIS	$1,750,443	$241,667,213	$529,831,040	$938,208,625	10 Years, Past Use
Wait Time Study	$408,561	$30,962,073	$282,331,032	$963,227,633	10 Years, Past Use
Enhanced Millimeter Wave	$3,260,599	$48,657,063	$122,194,372	$263,929,961	10 Years, Future Use
3D CT Datasets and ATR	$4,898,926	$62,076,958	$117,741,020	$209,045,620	10 Years , Future Use
Passived Acoustic Sensing	$4,006,100	$8,494,934	$20,893,771	$39,675,882	10 Years, Future Use
Trafficking Risk Score	$139,050	$2,993,538	$8,300,061	$17,970,519	10 Years, Future Use
Remote Power Module	$1,583,640	$1,131,027	$5,541,829	$17,164,044	10 Years, Future Use
SMART	$320,349	$723,670	$2,946,802	$8,894,497	10 Years, Future Use
GARI	$371,869	$47,478	$1,097,247	$5,424,325	10 Years, Future Use
TOTAL	**$16,739,537**	**$396,753,954**	**$1,090,877,174**	**$2,463,541,106**	**ROI = 6,517% at Median NPV**

For most analyses, we used the 10-year NPV of future use, calculated in 2017 dollars. There were two exceptions that had past applications. For IRIS, we used 10 years of past benefits; for the Wait Time Study, we used a mix of six past and four future years.

IRIS has by far the highest NPV, which was primarily due to the increase in security provided by the randomization of federal air marshals. The Wait Time Study also had high net benefits because it allowed the hiring of a large number of CBP officers that resulted in the reduction of wait time and associated regional and economic impacts at U.S. ports of entry. The Enhanced Millimeter Wave and the 3D Datasets and ATR TTKPs each had net benefits exceeding $100 million, due to the reduction of false alarms at TSA checkpoints.

At the lower end of the net benefits are five TTKPs with net benefits of less than $21 million. Of these, GARI and SMART have the lowest net benefits.

6. Lessons, Limitations, and Future Directions

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 research products. While the cost estimates had 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 research product would be, once applied.

The best benefit estimates (and therefore the lowest uncertainty band) were for research products that were applied in the past, like IRIS and the Wait Time Study. Both tools were developed by the National Center for Risk and Economic Analysis of Terrorism Events (CREATE), the first COE founded in 2004. Because of the early development of these TTKPs, they had been applied for several years, with a total median net benefit of about $800 million. This compares to $60 million of total OUP funding received by CREATE over a 10-year time period.

For the research products 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, within the results of the BCA of the 3D CT Datasets and ATR and the Advanced Millimeter Wave TTKPs, the benefits largely depend on the adoption of the technologies and software tools developed by ALERT.

In the process of conducting the BCAs for the nine TTKPs described in this report, as well as for the 10 TTKPs studied previously, we learned that the benefits of research resulting in research products can come from a variety of sources:

1. reduced cost at the same security level
2. increased security at the same cost level
3. reduction of false alarms and/or increase in detection
4. reduction of threats by deterrence
5. value of information for improved decision-making

The results presented in this paper represent a lower bound of the net benefits of OUP research. These benefits are rather narrowly construed, in that they do not include spinoff products or the fact that several of the projects involve basic research that would lead to still further basic research, as well as additional applications. They also cover only nine (of about 200) research products that were considered of high value to TSA and CBP staff. While many of the research products funded by OUP will never be implemented, these nine alone generated a net benefit exceeding 10 years of OUP funding. This is an example of the typical finding that 10 percent of R&D investments typically pay for the total investment, while 90 percent produce little or no benefit. Our analysis, therefore, provides some support of the value of conducting OUP-funded research.

Each of the nine BCAs has its specific limitations. They are discussed at the end of each description of the nine BCAs in CREATE (2018). As an overall note, the most important limitation of these analyses is the uncertainty in the benefits of several of the research products that are in transition to application.

We recognize that, due to these limitations, the actual BCA estimates are very uncertain in several cases. One of the major benefits of conducting the benefit-cost and uncertainty analyses described in this paper is the identification of five distinct benefit models that are used by OUP as templates for future benefit-cost analyses. These models also define success metrics (e.g., reduction of false alarms) 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 research product developers included an evaluation component to their projects, in which benefits metrics are well-defined a priori and relevant data collected in collaboration with research product users.

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Center of Excellence Landscape Study- Phase 2

APPENDIX

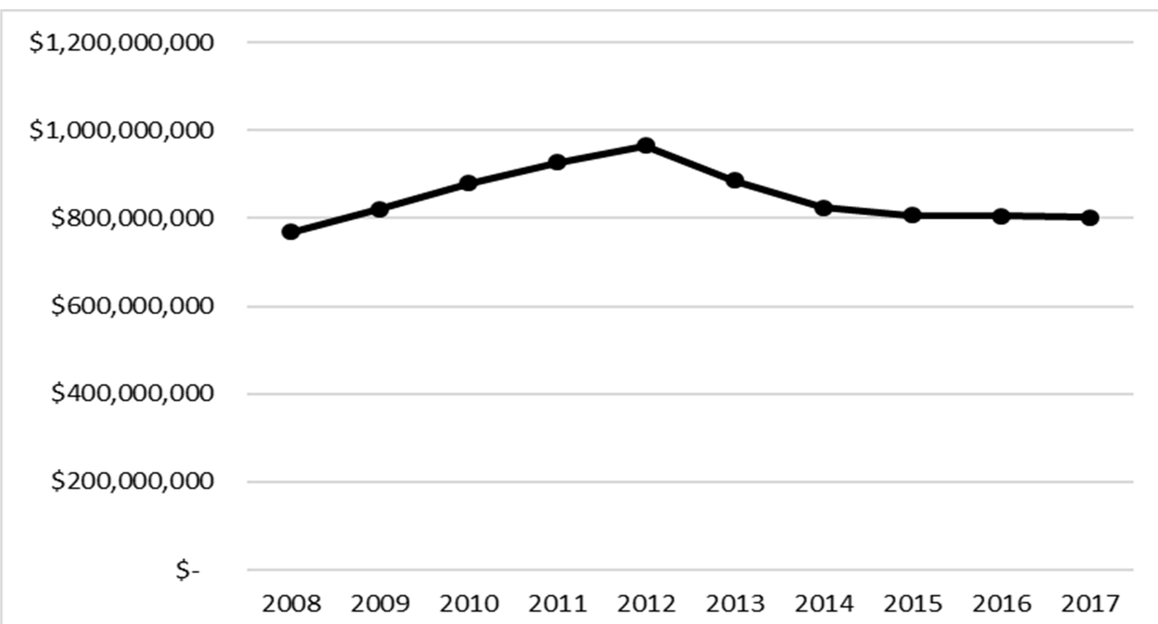
Description of Nine Benefit-Cost Analyses

Benefit-Cost Analysis of Intelligent Randomization in Scheduling (IRIS)

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

1. Summary

Description. The Center for Risk and Economic Analysis of Terrorism Events (CREATE) developed a computerized support tool to randomize almost all international flight scheduling for the Federal Air Marshal Service (FAMS), an aviation-focused portion of the Transportation Security Administration. FAMS personnel fly semi-covertly on domestic and international flights and are armed and trained to respond to in-flight terrorist attacks (Biles, 2013; GAO, 2016; Stewart & Mueller, 2018). Figure A-1 shows the scale of operations based on the FAMS budget, which has been somewhat less than a billion dollars per year.



Data: FAMS (2018)

Figure A-1. Budget Authorization for the Federal Air Marshal Service (in Fiscal Years)

The Intelligent Randomization in Scheduling (IRIS) tool automates the flight assignment process for federal air marshals (FAMs) on almost all international flights while incorporating advanced randomization methods into the allocation process (Tsai et al., 2009). The tool has been in use by FAMS since late 2009 and remains in use today (An & Tambe, 2018; FAMS, personal communication).

Results. IRIS generates ongoing benefits and costs. This analysis focuses on the 10-year period from November 2009 to November 2019, most of which is retrospective. Two different analyses are presented. The first is a stand-alone cost savings and security analysis of the use of IRIS by FAMS; the second is a layered analysis that embeds FAMS within multiple general and airline security-focused programs. The baseline costs and benefits are the procedures that were in place at FAMS for 2008-2009, before IRIS was deployed. Costs to develop and deploy IRIS are estimated at $1.8 million (in 2017 dollars), which includes the cost of research and transition efforts at CREATE, university overhead and oversight cost at the Department of Homeland Security (DHS) Office of University Programs (OUP), and associated development and management costs at FAMS. The potential benefits of using IRIS each year involve three components: 1) personnel cost savings at the baseline level of activity, 2) personnel cost savings as the level of activity increases, and 3) improved security due to better randomization. The estimated security improvement, while relatively imprecise, dominates the personnel cost savings. The estimated benefits in the base case stand-alone analysis are $554.9 million (in present value 2017 dollars), yielding net present value (NPV) returns of $553.1 million (in 2017 dollars) for a 31,599 percent rate of return (the net benefits are about 316 times the cost). Numerous break-even, sensitivity, and uncertainty analyses results are presented. In the simulation analysis, no trial among the 10,000 iterations resulted in a negative NPV; the 5th and 95th percentiles for NPV were $241.1 and $940.4 million, respectively (in present value 2017 dollars), with a mean of $555.5 million.

A second, layered security approach that is often thought to reduce the benefits of FAMS (Stewart & Mueller, 2012; 2018) is used to check the stand-alone results. Replicating the results of Stewart and Mueller, with adaptations to the international context in which IRIS is used, results in an NPV of $2,682 million (in 2017 dollars), substantially more than the estimate using the stand-alone analysis. As the layered analysis contains many more assumptions than described below, the stand-alone analysis is used as the default analysis in summaries of this case.

2. Background

Armed FAMs have been flying domestic and international flights for decades, although from different organizational settings within the government (Biles, 2013; Elias, 2009). Funding for FAMS increased significantly following the aviation-mode attacks on 9/11, the subsequent bombing attempts made on U.S. flights by “shoe bomber” Richard Reid and “underwear bomber” Umar Farouk Abdulmutallab (DHS Budget, Annual; Biles, 2013), and other attacks worldwide.

While it is intended that FAMs remain unobserved, a report in 2006 (U.S. GAO, 2009) recommended improving the randomization of flight assignments so as to improve security. The baseline process prior to IRIS primarily involved a human scheduler assigning FAMs to flights based on risks identified by management and various operational considerations (Tsai et al., 2009). As human schedulers are known to be relatively poor randomizers, the IRIS tool was developed not only to carry out improved randomization but to potentially include weighting based on value attributes and the likely responses of terrorist groups using a game-theoretic framework (Tsai et al., 2009). More recently, FAMS has been criticized for the lack of an explicit risk-based approach in the deployment of FAMs (U.S. GAO, 2016). Many data items related to FAMS are classified or otherwise unavailable (e.g., U.S. GAO, 2016; Taylor et al., 2017) and so various approximations and expert-informed data are utilized in public evaluations, including this one.

IRIS is one of a suite of game-theoretic security optimization models developed at CREATE. Common among these models is the allocation of a security asset—for example, an individual, a patrol boat, or an inspection team—in a way that meets the operational criteria of the defending organization, improves the randomization of the allocations, and potentially takes into account differing values of defended targets and the variably rational and irrational responses of attackers. IRIS was developed to assign FAMs to flights, balancing the large and complex scheduling constraints of airlines and personnel while including the common elements identified above.[4] Development of IRIS occurred with the close cooperation of FAMS. The existing application of IRIS focuses on international scheduling (An & Tambe, 2017; Jain,

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[4] Ongoing evolution of IRIS is carried out by Avata Intelligence (Jain, 2018). Related computer programs have been developed (An & Tambe, 2017) for the U.S. Coast Guard to design patrol boat schedules (PROTECT) and for use at Los Angeles International Airport to assign inspection points and schedule personnel (ARMOR).

2018). The actual implementation, elements of further development, and advanced testing of the program have been under the control of FAMS and subject to security control (Taylor et al., 2017), although FAMS personnel have been of substantial help in providing unclassified information for this evaluation.

3. Baseline

Prior to IRIS, international scheduling was conducted by personnel who attempted to randomize flight assignments. Psychologists and statisticians have documented that people acting alone are relatively poor randomizers and tend to fall into patterns. Such patterns are understood to be detrimental to security, as an intelligent adversary can observe the patterns and choose the timing of the attack to avoid security measures (Tsai et al., 2009). The IRIS program facilitated the scheduling issue so that less personnel time was required for scheduling while randomization was improved.

While discussed in more detail in the benefits section below, the baseline involves components of both scheduling personnel and security. Although the level of baseline activity was not revealed by FAMS, they provided information in response to written queries about changes from the baseline for full-time equivalent personnel (FTEs) and the expenditures that would have been necessary to achieve an IRIS-level of security had the weaker randomization methods remained in use. Further, as discussed in the benefit analysis in Section 5 below, evaluation studies carried out for IRIS and similar programs provide estimates of the upper bound of the proportional increase in security from different uses of the program (Tsai et al., 2009; Taylor et al., 2011).

4. Cost Analysis

The development and transition costs for IRIS are relatively well-known. Costs were recorded and reported for CREATE for three different phases of development of IRIS, between 2008 to the current time. Additional oversight and overhead costs applied consistently across a set of cases were allocated to DHS. FAMS also reported an estimate of personnel time and FTE costs for contracting and providing contextual information during the development process. The available cost information is reported in Table A-1, where nominal (as-spent) dollars are reported along with present value 2017 dollars, which were adjusted using the CPI index and assuming a zero real discount rate. As referenced in Table A-1 below, COE stands for the Center of Excellence that carried out the work, and OUP stands for Office of University Programs, who funded the project.

Table A-1. Development Costs for IRIS

Cost Category	Start	End	Amount	2017 Dollars
Pre-project costs (COE)				0
Pre-project costs (other funding)				0
Project costs (COE)				0
IRIS A	2007	2012	$425,125	$ 475,240
IRIS IV	2012	2013	$152,989	$ 161,897
IRIS	2016	2018	$448,900	$ 447,174
Project costs (university cost share)				$ -
Oversight cost at the COE				$ -
IRIS A	2007	2012	$85,025	$ 95,048
IRIS IV	2012	2013	$30,598	$ 32,379
IRIS	2016	2018	$89,780	$ 89,435
Oversight cost at OUP				$ -
IRIS A	2007	2012	120000	$ 134,146
IRIS IV	2012	2013	40000	$ 42,329
IRIS	2016	2018	60000	$ 59,769
Transition development cost				
Implementation start up cost	2008	2017	200,000	$ 213,025
Implemementation cost (User)				$ -
Implementation cost (COE)				0
Implementation cost (Other users)				0
TOTAL COST			$1,652,417	$1,750,443

Source: CREATE, FAMS

5. Benefit Analysis

There are several categories of benefits of the IRIS tool: 1) personnel cost savings at the baseline level of activity, 2) personnel cost savings as the level of activity has changed, and 3) cost savings and improved security due to improved randomization. The first two cost savings benefits occur whether or not IRIS is evaluated as a stand-alone tool or as part of a layered system; costs are saved in either case. However, the value of improved security differs in a stand-alone analysis as compared to a layered analysis and is difficult to determine in either case. The personnel cost savings benefits will be discussed first, followed by methods and estimates of improved security for the two cases.

Personnel Cost Savings Benefits. IRIS changed the technology of assigning FAMs to flights by partially automating a labor-intensive process. From the baseline level of assignments in 2009, FAMS estimates that IRIS saved 25 percent of the wage and benefits cost of an FTE (FAMS, personal communication 2018). For this and later personnel-related analyses, FAMS provided an estimate of the full cost of an FTE at $150,000 (in 2017 dollars), resulting in a cost savings of $37,500 per year. In addition, the assignment workload has generally been larger since 2009 but is also variable. FAMS reported that a 50 percent increase in assignments would lead to additional cost savings over the baseline of 50 percent of an FTE: a 1 percent increase in cost savings for each percentage increase in assignments. While the number of personnel and assignments are unknown, FAMS provided information on expenditures related to assignments for each year. Consequently, additional cost savings as a fraction of an FTE were recorded for each year based on the change in assignment expenditures as compared to the base year. While incorporated in a later table, these two cost savings benefits total $0.7 million in present value 2017 dollars.

Value of Improved Security from Improved Randomization. The value of improving security varies by context and is almost always difficult to estimate (Farrow & Shapiro, 2009; Mansfield & Smith, 2015). Relatively extensive evaluation testing has been performed on IRIS specifically, along with a family of similar models (Taylor et al., 2011; 2017). The source of improved security is the improved randomization compared to the original practice. Some tests identify relative improvements of different defensive strategies given the assumptions of the models. Other approaches include expert testimony, Red Team testing, and so on. Taylor et al. (2011; 2017) indicate that further testing was done within FAMS in a classified manner to which they were not privileged.

The security benefits of IRIS are based on lower costs to achieve a given level of security and the reinvestment or increased funds to improve security. The analysis is driven by an estimate from FAMS of the expenditures that would have been necessary using the baseline randomization system in order to achieve the level of security provided by IRIS' improved randomization. While it would have been possible to achieve the original level of security at a lower cost due to improved randomization, it appears that those realized cost savings have been reinvested into security improvements.

Figure A-2 below illustrates the randomization and security benefits. FAMS provided an estimate of the proportional decrease, with uncertainty ranges, in international expenditures between the two cases for the total amount shown in the typical benefit-cost areas B+C+F (Boardman et al., 2017), the difference between the two incremental cost lines. The estimated benefit is smaller, however, as a portion of the cost savings from increased security (area F), which would not have rationally been spent using the baseline system.[5] Consequently, cost savings from improved randomization equal the cost savings at the original level of security (area B) plus a portion of the cost savings from increased security (area C).

Area F in Figure A-2 should be deducted from the gross savings estimate obtained by the product of the international expenditures and the security cost savings proportion from IRIS. Using additional information on the proportional improvement in security from modeling tests (Taylor et al., 2011; 2017; Jain, 2018), CREATE estimates that IRIS provides an increase in security of 32 percent compared to the baseline process. This estimate is somewhat more than the approximate 20 percent increase in security reported as the gain from IRIS compared to a well-implemented uniform statistical randomization (Tsai et al., 2009). This information can be shown to be sufficient to estimate the cost savings of improved randomization and security (areas B+C) as gross cost savings (areas B+C+F) less the cost savings that would not have been realized (area F). As there is large uncertainty about the estimated increase in security, the uncertainty analysis to follow uses an upper bound of a 64 percent increase in security in the absence of operational constraints and a lower bound of zero, assuming that operational constraints totally offset the security benefits in conjunction with the modal estimate of 32 percent.

The benefits must be further adjusted for the use of IRIS on international flights. No official estimates of the international expenditures as a proportion of total FAMS expenditures exist, although international flights are frequently mentioned in the literature as an important component. It is assumed here that the international expenditures represent 50 percent of FAMS expenditures, with an uncertainty range from 25 to 75 percent.

[5] In Figure A-2, MC is marginal cost and (1-P) is the probability of no attack or a failed attack defined as security. The model assumes rationality and a quadratic cost function. Additional detail on this expected value model is available from the author (and in process for a published article).

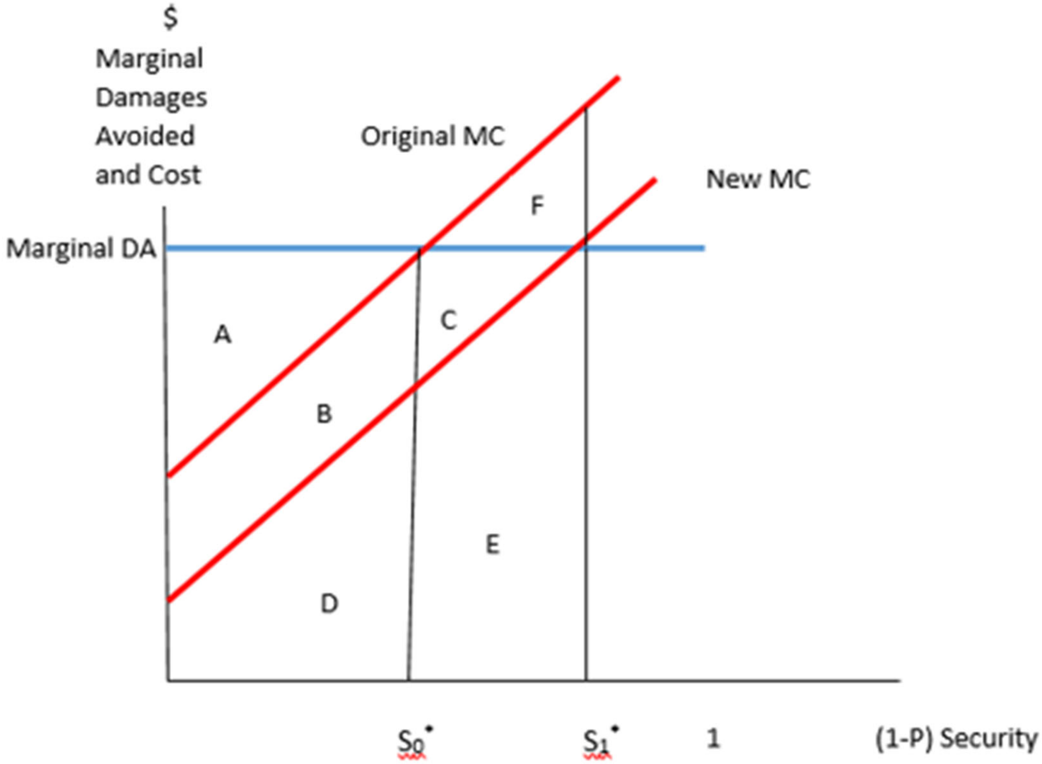


Figure A-2. Security Benefits and Costs

FAMS estimated it would have taken 15 percent more of their baseline international program expenditures to achieve the new level of security (with a minimum and maximum of plus or minus 75 percent of that figure). Deducting the base case mean proportion of area F reduces this datum to about 12.6 percent. The resulting security benefits were generated on a year-by-year basis and converted to present value 2017 dollars. The annual benefits averaged about $56.3 million per year for total net present value security benefits of $554.9 million (in 2017 dollars) over the 10-year period. Almost all the benefits—$554.1 million— resulted from improved randomization, although there are $0.7 million in benefits realized from personnel cost savings (details may not add to total due to rounding).

Table A-2 below presents the sources of the base case NPV for the stand-alone analysis, including the break-down between cost savings from scheduling personnel and those from improved randomization.

Table A-2. Estimated Base Case Benefits and NPV for IRIS

Results (2017 dollars)	
NPV benefits Total	**$ 554,877,453**
NPV Costs	**$ 1,750,443**
NPV	**$ 553,127,011**
Return on Investment	**31599%**
Personnel cost saving benefit	$ 727,875
Security cost-savings benefit	$ 554,149,578

Source: CREATE

Layered Analysis. An alternative, layered analysis is used as a check on the net present value results of the stand-alone model. The benefits in a layered security analysis involve substantially more elements than in the stand-alone analysis and as such, a layered analysis is often expected to reduce the benefits resulting from any one security practice. As the stand-alone analysis above suggests very large returns, it is useful to investigate whether an alternative layered analysis of IRIS substantially reduces the benefits in the base case.

As investigated in a number of articles and books by Stewart and Mueller (2009; 2010; 2013; 2018) and Mueller and Stewart (2010), there are numerous layers of security to prevent aviation hijackings, bombings, and other destructive events related to airplanes and airports. Following Stewart and Mueller, there are a series of pre-boarding security measures which can prevent attacks. There are also a series of in-flight security measures which can help prevent attacks or hijackings, such as passenger resistance, the real or perceived presence of FAMs, hardened cockpit doors, and federal flight deck officers (FFDOs), who are armed following training. Using a probability tree analysis, which has evolved somewhat over time, and values informed by the literature for all FAMS activities, Steward and Mueller (2009) conclude that FAMS, in the absence of FFDOs or additional barriers to cockpit entry, reduces the risk of a successful attack by between 0 and 2 percent. At their mean estimate for that value of 1 percent and making assumptions about the mean cost of a successful attack ($50 billion) and the budget of FAMS (overstated as $1,200 million). They conclude that the benefit-cost ratio of all FAMS at their mid-point values is 0.42, implying that costs exceed the benefits. In their other analyses, they reach similar results.

The results to follow are not a thorough critique of the Stewart and Mueller results. Instead, the layered analysis of Stewart and Mueller is investigated for its sensitivity to the actual context in which IRIS is currently implemented and for the estimated security enhancing effect of IRIS. First, the probability tree analysis using the assumptions of Stewart and Mueller (2009) was successfully replicated. Then, three of 11 quantitative assumptions are changed in their framework due to the international application of IRIS. The changed assumptions result from the changed conditions of international flights. Stewart and Mueller assume that a hardened cockpit door is 75 percent effective in foiling attacks in their "all flights" analysis, but they also investigate a case where the cockpit door is half as effective (37.5 percent). Some argue that the current security practice regarding cockpit doors can be overcome with planning when the doors are opened and closed. On average, an international flight segment on U.S. carriers are over twice as long as the average domestic segment—1,971 miles compared to 735 miles—and with a larger proportion greater than 1,000 miles: 68 percent compared to 25 percent (U.S. Bureau of Transportation Statistics, 2017). The longer international flights suggest an expectation that the cockpit door is opened more frequently than on domestic flights. Consequently, the lower effectiveness value of Stewart and Mueller is used for the specific context in which IRIS is applied. Steward and Mueller also include armed onboard law enforcement personnel and FFDOs as two layers of security. There are, however, few international destinations where law enforcement and FFDOs can carry weapons onboard (ALPA, 2012).

These armed layers of defense on domestic flights are thus removed from the IRIS context. The baseline international result for all FAMs is that the benefit-cost ratio becomes approximately 2, or that benefits exceed costs. The incremental security benefit of IRIS then changes the Stewart and Mueller risk reduction of FAMS activities. As in the stand-alone analysis, the risk reduction due to IRIS is estimated as 32 percent. When this improvement is used in the layered analysis, the estimated present value of benefits from IRIS is $268.3 million per year, almost five times the stand-alone average annual estimate of $56.3 million.[6] The primary cause of this larger estimate is that the increase in security is fully, instead of partially, incorporated into the change in risk. As Steward and Mueller have demonstrated, their results are sensitive to a variety of assumptions, including the degree of risk aversion of managers. The same issues would also occur in this modified, layered analysis of IRIS. Consequently, the

[6] The conditional damage used by Stewart and Mueller in the layered analysis of $50 billion is clearly an approximation, so no adjustments are made in the 10-year period for inflation or discounting. In other words, each year is assumed to be estimated in present value 2017 dollars comparable to the costs.

layered analysis is consistent with large benefits resulting from IRIS in its actual domain of application. However, the stand-alone analysis, even though smaller, will be used as the base case for its: 1) greater transparency, 2) fewer quantitative assumptions about the security from each layer, and 3) not needing to estimate the value for the consequence of a successful terrorist aviation attack, which is itself highly uncertain.

6. Benefit-Cost Analysis — Base Case

Given the base-case inputs and the present value (in 2017 dollars) of the costs and the benefits of the stand-alone analysis from Tables A-1 and A-2, the estimated net present value (NPV) of using IRIS is $553.1 million based on the stand-alone analysis. This results in a base case return on investment (ROI) of 31,599 percent, meaning that IRIS is estimated to have returned on net about 316 times its cost in present value terms. These results can also be seen in Table A-2, above.

7. Sensitivity and Uncertainty Analysis

Break-even Analysis. Several different break-even analyses are carried out. A key driver of benefits is the percentage cost increase to achieve the same level of security as with IRIS. Allowing that percentage to change while holding costs and other cost savings constant results in a break-even estimate of 0.02 percent. In other words, if FAMS estimated they could have achieved the same new level of security using the old system by increasing its costs by 0.02 percent (one-fifth of 1 percent), the IRIS costs would have been repaid. Using a different type of analysis, DHS sometimes uses an investment-to-cost ratio to define the change in risk (probability) necessary to break even (Farrow & Shapiro, 2009). Using data for the cost of IRIS and the consequence used by Steward and Mueller, that reduction in probability is 0.0035 percent, a relatively small number. Finally, using the layered security approach, one can ask what level of consequence would result in a zero NPV, or breaking even? The result is $19.1 million, a relatively small consequence given that DHS uses a value per statistical life of about $10 million (DHS, 2014) and aviation equipment and system disruption are expensive, although the economy has resilient systems as well (Rose & Blomberg, 2010).

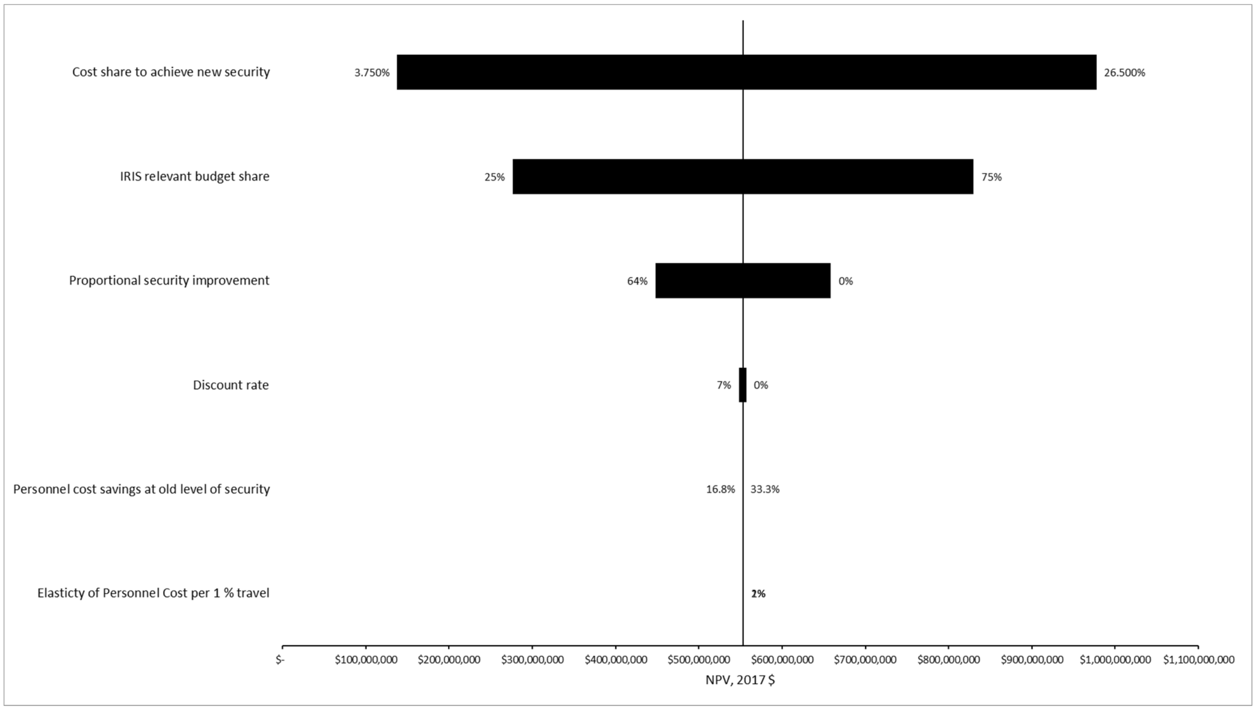
Tornado and Sensitivity Analysis. Sensitivity analysis, and later simulation, are driven by assumptions for uncertain variables. Section 3 above provides the reasoning for the uncertain distributions for parameters in the NPV model. The costs of developing and transitioning IRIS are relatively well-known, but the many of the parameters affecting benefits are quite uncertain. Table A-3 below summarizes the parameter values for these variables, noting that later simulation adds the assumption of a triangular distribution using the values below. The direction of impact (slope) is indicated by High or Low Output. For instance, a high cost share (26.5 percent) to achieve the new security level results in a high NPV, but a high proportional security improvement (64 percent) results in the low NPV (Output) case. The latter result occurs because the higher the security improvement in the stand-alone model, the more that is subtracted as area F in Figure A-2.

Table A-3. Ranges of IRIS Inputs for Sensitivity Analysis

Input Variable	Low Output	Base Case	High Output
Cost share to achieve new security	3.750%	15.000%	26.500%
IRIS relevant budget share	25%	50%	75%
Proportional security improvement	64%	32%	0%
Discount rate	7%	3%	0%
Personnel cost savings at old level of security	16.8%	25.0%	33.3%
Elasticty of Personnel Cost per 1 % travel	1%	1%	2%

Source: CREATE

The key determinants of the NPV are investigated using a structured sensitivity approach using data in Table A-3. Figure A-3 presents these results as a tornado diagram, with the width of the bars representing the impact on NPV. Given these ranges of uncertainty, both the proportional cost to achieve the new level of security with the old technology and the share of FAMS budget to which IRIS is applied—the international component—are seen to be key determinants of the NPV. Increases from the base case for both variables increases the NPV, and vice versa. Uncertainties in the other parameters are shown to have a relatively smaller impact on the NPV, although all low output (NPV) tests result in a positive NPV.



Source: CREATE using TreePlan/Sensit

Figure A-3. Tornado Diagram: IRIS

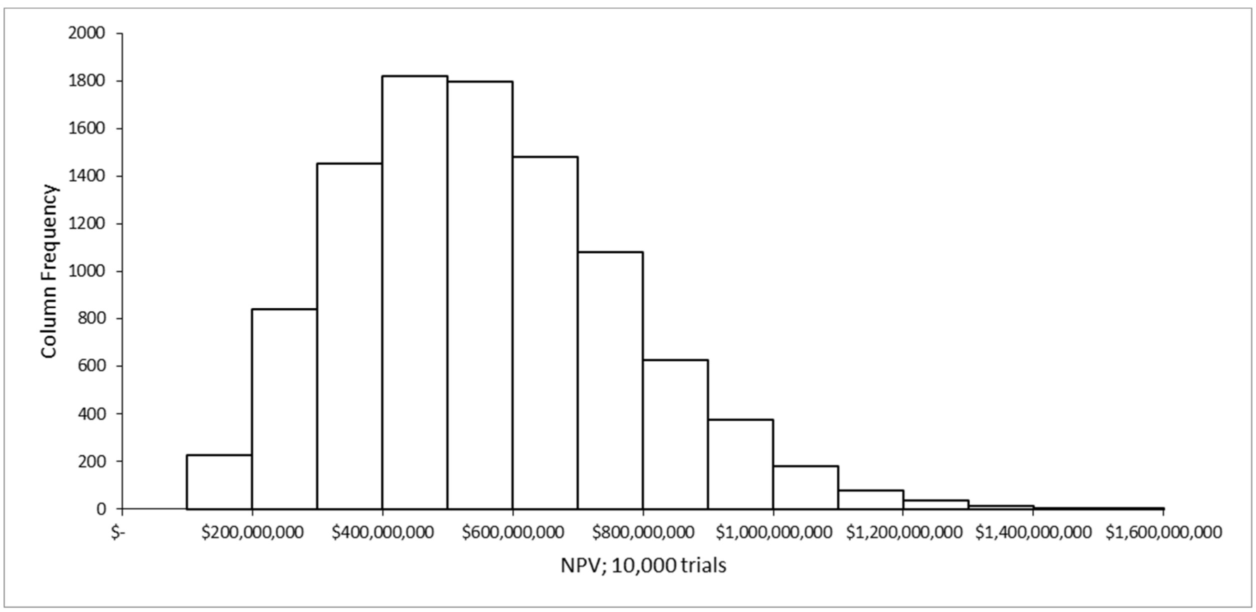
Uncertainty Analysis. To further explore the uncertainties of some of the input variables, we assumed that these uncertainties can be characterized by triangular distributions, with a minimum being the low value in Table A-3, the mode being the base case value, and the maximum being the high value. We used an Excel add-in, SimVOI (TreePlan, 2017) 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 A-4 presents results of the simulation for the NPV from IRIS, while Figure A-4 charts a more detailed histogram of those results. The mean, median, and 5th and 95th percentile NPV values are $555.5 million, $535.8 million, $241.1 million and $940.4 million, respectively, all in 2017 present value dollars. There were no negative values in the simulation. While uncertainty substantially spreads the estimated value of the NPV from IRIS, the returns are large in any case.

Table A-4. Statistics of the IRIS NPV Distribution

Mean	$555,538,954
St. Dev.	$ 213,489,212
5th Percentile	$241,085,777
25th Percentile	$398,971,857
Median	$535,794,141
75th Percentile	$690,658,006
95th Percentile	$940,368,342

Source: CREATE



Source: CREATE using TreePlan/SimVOI

Figure A-4. IRIS Simulation Results for the Net Present Value, in 2017 Dollars

8. Assumptions and Limitations

Two classes of assumptions and limitations primarily affect this analysis: 1) model specification and 2) parameter values. Commonly accepted models do not exist in the homeland security literature, although the two models presented here, an organization-based expected net benefits analysis and a layered expected net benefit decision tree analysis, are well-established in the general purpose literature and have been used in security applications. The stand-alone model assumes rational behavior for finding the level of security expenditures and linearity in its security cost function. Removing the rationality assumption calls for additional areas to be added or subtracted from Figure A-2 to compute the NPV. The NPV estimate could increase or decrease if the rationality assumption were dropped, in part because cost savings occur at the existing level of security whether there is too much or too little security. Removing the linearity assumption is likely to increase the estimated NPV with a non-linear marginal cost function, as area C would become larger and area F smaller. The layered model assumes a number of independent, two outcome events (attack foiled or not foiled) and an expected value framework, each of which can become more complicated.

The second source of assumptions and limitations primarily involve parameter values. Support exists in the published literature and in communications from FAMS for the base case parameters and distributions of the several costs, discount rate, and expenditure parameters of FAMS, even if each is not known exactly. A number of values may or may not have improved documentation if access to classified information was available, but that could limit public dissemination. Of these parameter assumptions, the most influential, and also among the most uncertain, are the proportional security cost savings resulting from IRIS and the proportion of expenditures (international) to which IRIS is relevant. The effect of uncertainty in other parameters is small in comparison to these two values, with the security improvement due to IRIS the largest among the remaining factors. Nonetheless, IRIS appears to generate large NPV values from the simulation results, even when parameter values are used from the lower end of their distributions. The layered security analysis involves more parameter assumptions than the stand-alone analysis, and relatively modest changes were made to published assumptions to correspond to the use of IRIS in international applications.

9. Recommendations for Collecting Additional Information and Analysis

An improved evaluation of the NPV from the use of IRIS would benefit from additional information, although there are also limitations to such information.

- Access to information from evaluation studies of IRIS carried out by FAMS and to more precise parameter information from FAMS operations. However, such information is not available to CREATE and the public due to the data being classified. Were it made available, the results of the analysis could not be made public.
- Additional effort could be expended to review and revise as appropriate the Stewart and Mueller analyses, but based on the model sensitivity analysis conducted here, the use of a layered analysis only seems to enhance the estimated NPV from IRIS.
- Development of a non-linear version of the linear security model, although that may involve expanding the information necessary to solve the model.

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Benefit-Cost Analysis of the Wait Time Study for Customs and Border Protection

Developer: Center for Risk and Economic Analysis of Terrorism Events (CREATE)
Analyst: Scott Farrow[7] (UMBC/CREATE)

1. Summary

Description of the Wait Time study. The Center for Risk and Economic Analysis of Terrorism Events (CREATE) carried out a quantitative study of the economic benefits attained by increasing the number of Customs and Border Protection Officers (CBPOs) at U.S. ports of entry. CBPOs are the front-line inspectors who are critical to the normal flow of people and trade across the U.S. border by enforcing customs, immigration. and agricultural laws.[8] To the extent that inspection times become long, costs are incurred; too short, and inspection time may compromise enforcement. The Wait Time study was commissioned by U. S. Customs and Border Protection (CBP) (Roberts et al., 2013) and was followed by peer-reviewed publications (Roberts et al., 2014a; Avetisyan et al., 2015). The study combined micro- and macroeconomic information and models to estimate the change in Gross Domestic Product (GDP), the cost of wait-time at the borders, and changes in jobs as a result of an increase or decrease in the number of CBPOs. The Wait Time study (Roberts et al., 2014a; 2014b) was used in congressional budget testimony, which was followed by an increase in the authorized number of CBPOs.

Results. The Wait Time study is credited with a portion of the increased economic benefits from the congressionally approved expansion of CBPOs, which also comes with increased personnel costs. This analysis focuses on the 10-year period from Fiscal Year (FY) 2014 to FY 2023. Five of these years are retrospective, in that data were made available on the hiring that actually occurred. Five years are prospective and assumed to be the same in nominal value as 2018, the last year for which actual data are available.

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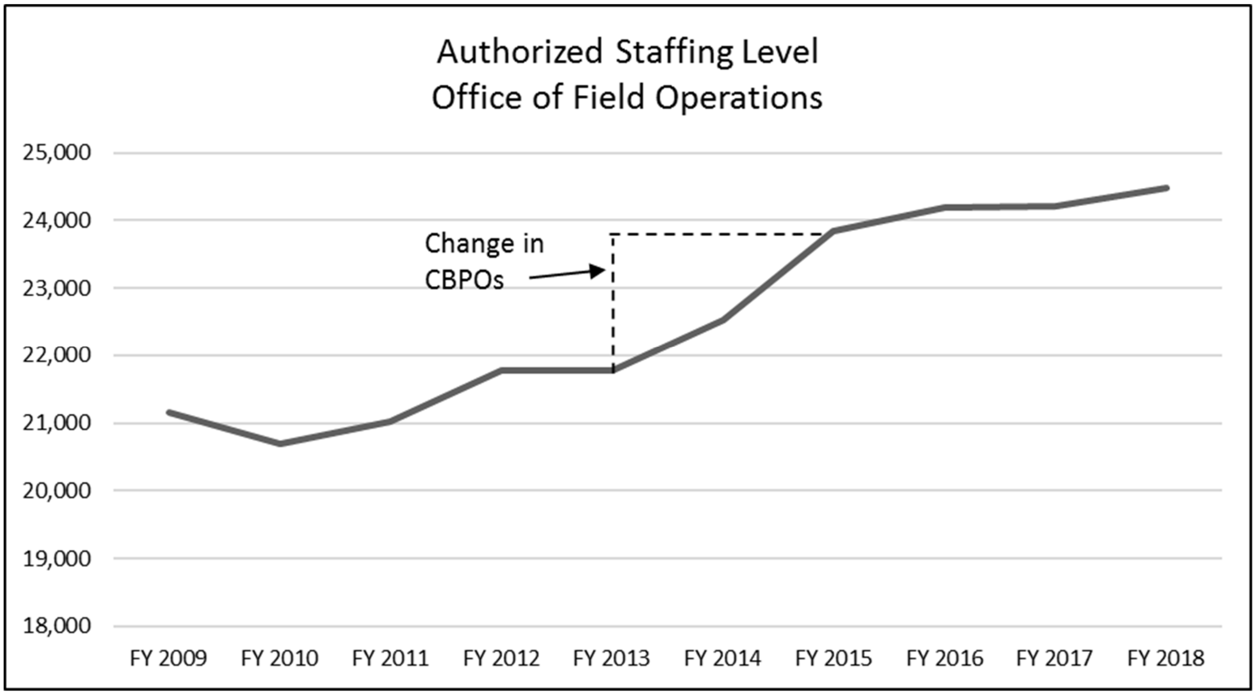
[7] Appreciation is extended to Georgia Harrigan, Jody Hardin, Ryan Kearns, Tricia Kennedy and Adam Wolf among others in DHS and CBP for feedback and support although all analysis remains the responsibility of the author.
[8] Enforcement between ports of entry is carried out by a different organization, the U.S. Border Patrol.

Study costs are estimated at $0.4 million (in 2017 dollars), which includes the cost of research and transition efforts at CREATE, university overhead and oversight cost by the Department of Homeland Security (DHS) Office of University Programs (OUP), and associated development and use costs at CBP. The estimated base case benefits are $173.5 million in present value 2017 dollars. The change in net benefits in the base case are based on valuing the changes in wait times for U.S. residents at ports of entry and deducting the full costs of the increase in number of CBPOs. Note that costs are incurred by the government, but benefits are received by a wide range of citizens and businesses. That change in benefits yields net present value (NPV) returns of $173.1 million (in 2017 dollars), for a rate of return of 42,361 percent (the net benefits are about 424 times the cost). Break-even and uncertainty analyses are carried out. The break-even share of benefits for the Wait Time study that results in NPV just equaling zero is 0.02 percent. Benefits are substantially higher when macroeconomic impacts are included, a sometimes controversial analysis but frequently used in the economics literature (U.S. OMB, 1992; 2003; Rose et al., 2017; Farrow & Rose, 2018). Median NPV, taking into account all quantified sources of uncertainty, is $282.3 million.

2. Background

The CBP Office of Field Operations manages the flow of trade and people at U.S. ports of entry and employs over 20,000 CBPOs. As conditions at the borders and other factors change, the authorized size of the CBPOs changes based on congressional appropriations. The Wait Time study was called out in some detail in the FYs 2014-2016 congressional budget testimony of CBP (Roberts et al., 2014a; 2014b). Numerous other factors and information were also involved in such complex budgetary requests. In FY 2014, CBP received authorization to increase the number of CBPOs by about 10 percent (2,000 personnel) over FYs 2014 and 2015, the large jump shown in Figure A-5. This analysis estimates the net benefits of the Wait Time study, using the benefit estimates for additional CBPOs embedded within the study and the budgetary change initiated in FY 2014. Exact attribution of the role of the Wait Time study to the decision to increase the number of CBPOs is not known, but the analysis, to be described in more detail in later sections, assumes that time and space in congressional budget testimony is scarce, and as such, the amount of space devoted to an issue is commensurate with the subjective belief that the information provided is valuable enough to affect a budgetary decision. Although not exactly the same, related approaches to the impact of information have been used in such studies as Burstein and Hirsch (2007), Diermeier and Feddersen (2000), and Farrow and Larson (2012), among others.



Source: CBP (2019)

Figure A-5. Authorized Staffing Level, CBP

3. Baseline

The benefits and costs to be reported here are driven by personnel changes from the baseline as reported by CBP (personal communications, 2018).[9] The baseline level of personnel is the authorized level in FY 2013, prior to the increased authorization provided in FY 2014.

More conceptually, the effect of the Wait Time study was to influence a change in the authorized number of CBPOs. It is difficult to qualitatively or quantitatively characterize the baseline political conditions. It is no secret that Executive Office budget planning and congressional budget actions are complex. Numerous competing and complimentary interests converge within the annual process (Schick, 2007). There does not seem to be an agreed-upon model of the detailed causes of budgetary changes, although there is reasonable agreement that

[9] Similar information from a public source can be found in the DHS Budget-in-Brief (various years).

major budget categories are consistent with a punctuated equilibrium such that budgets are relatively stable for periods of time, followed by sudden changes as the balance of interests or new information results in a sizable shift (Jones et al., 2009; Jones & Baumgartner, 2012). A related literature focuses on the role of information among other factors in congressional hearings, although not specifically pertaining to budget hearings (e.g. Burstein & Hirsch, 2007; Diermeier & Feddersen, 2000).

The punctuated equilibrium theory is consistent with the modest changes in CBPO staffing between FYs 2009 and 2013, as shown in Figure A-5, followed by a sudden increase in staffing (budgeted over two years) in FYs 2014 and 2015. CBP and others have stated (CBP personal communication, 2018) that there were numerous internal and external events within the Executive Branch and action by Congress that culminated in the successful proposal for a budget increase. For instance, an ongoing labor demand model for CBP was regularly reported to Congress starting with FY 2013 (CBP, 2013). The Wait Time study was commissioned by CBP to investigate the economic impacts of changes in the number of CBPOs in order to address the interests of some stakeholders. Ultimately, the Wait Time study was part of the process starting in FY 2014 that led to an increase of 2,000 CBPOs from the authorized baseline number of officers.

4. Cost Analysis

The base case total study cost was $408,561 (in 2017 dollars), which includes development and transition costs for the Wait Time study as reported in Table A-5. Incurred costs, including costs for professional time to communicate project results, were recorded and reported by CREATE for the study, which appeared in 2013. Additional oversight and overhead costs, applied consistently across a set of case studies in this project, were allocated to DHS. CBP also provided an estimate of the personnel time and full-time equivalent (FTE) cost for contracting and for contextual information exchange with CREATE during the development process. The available cost information is reported in Table A-5, where nominal (as-spent) dollars are reported along with present value 2017 dollars as discussed in the introduction to these cases.[10] CBP also funded a second, related study which primarily provided additional

[10] COE stands for the Center of Excellence that carried out the work; OUP stands for Office of University Programs, which funded the project.

detail on changes due to increases in CBPOs at more airports (Prager, 2015; Roberts et al., 2014b) and investigated the decline in benefits per CBPO hired at three locations. The base case cost excludes this second study, although the uncertainty analysis to follow incorporates the additional costs for the second study resulting in a total, higher cost estimate of $835,528 in 2017 dollars (not shown in Table A-5).

Table A-5. Cost of the Wait Time Study

Cost Category	Start	End	Amount	2017 Dollars
Pre-project costs (COE)				$0
Pre-project costs (other fund				$0
Project costs (COE)	2013	2013	$200,000	$209,798
Project costs (university cost				$0
Oversight cost at the COE	2013	2013	$46,221	$48,485
Oversight cost at OUP	2013	2013	$20,000	$20,980
Transition development cost	2013	2013	$31,103	$32,626
Implementation start up cost				$0
Implemementation cost (User	2013	2013	$92,158	$96,673
Implementation cost (COE)				$0
Implementation cost (Other u				$0
TOTAL COST			$389,481	$408,561

Source: CREATE, CBP

5. Benefit Analysis

The benefits of the Wait Time study depend on the benefits from hiring additional CBPOs. The primary benefit used here is the reduction in the opportunity "wait time" cost of U.S. residents. A second benefit based on macroeconomic (GDP) impacts will be used in sensitivity analysis. The Wait Time study estimated the economic impact of hiring the first cohort of 33 CBPOs, each at a different air or land and port of entry location, among several hundred in total. Economic indicators reported in the study are changes in Gross Domestic Product (GDP), the lost value of U.S. residents' time spent waiting at ports of entry, the lost value of wait time for non-U.S. residents, and changes in employment. Thus, the study directly addresses the economic changes from additional hiring authorized by Congress. The primary estimates of the study cannot, however, be used directly in a benefit-cost analysis of total change due to several issues. Four issues to be resolved are: 1) the appropriate measure of social benefits, 2) the expected decline in incremental social benefits as more CBPOs are added, 3) the portion of the benefits that can be attributed to the Wait Time study as part of complex information set within a multi-stakeholder process, and relatedly, 4) the duration of benefit from the study. Each issue is addressed in turn.

The Office of Management and Budget (U.S. OMB, 1992; 2003) allows a number of ways to estimate benefits from a small-scale project but guides that large-scale macroeconomic effects shall not be considered, based in part on an assumption of full employment. While this limitation has been criticized (e.g., Farrow & Rose, 2018), the base case benefit measure used here is the value of lost time (opportunity cost) when U.S. residents wait at ports of entry, as highlighted in the Executive Summary of the study. The Wait Time study further estimated the increase in value (benefit) to U.S. residents from avoiding lost time as $640,000 (in 2011 dollars) for each member of the first cohort of 33 CBPOs hired.[11] In small or partial equilibrium benefit-cost analyses, the opportunity cost savings are the benefits which would be expected to decline as more personnel are hired. Beyond this base case value, the macroeconomic effects on constant purchasing power Gross Domestic Product are estimated at an additional $2 million in 2011 dollars per CBPO in the first cohort hired (Roberts et al., 2013; U.S. CBP, 2014) and are included in the uncertainty analysis as the high value. Key drivers of these effects were increases in foreign spending in the U.S. and lower freight transportation costs, and hence production costs, in the U.S. These separate macroeconomic impacts were estimated using an input-output model and a computable general equilibrium model for different components of the economy and considered only the impacts on US residents (Roberts et al., 2014a; Avetisyan et al., 2015). When macroeconomic effects are included in a benefit-cost analysis, they are typically the change in real GDP plus any additional social benefits or costs, such as the value of time saved (Jorgenson, 2018). Employment benefits are not usually included separately from the GDP measure. The low value in the uncertainty analysis was assumed to be two-thirds of the base case, similar to the uncertainty considered in a key part of the Wait Time study (Roberts et al., 2013, p. 4-20).

A second issue is how benefits decline as more CBPOs are hired, due to an expectation of diminishing incremental productivity. In the standard profit (or social welfare) maximizing

[11] Additional information was provided on wait-time benefits for non-U.S. residents, which was approximately six times that of U.S. residents reported here (Roberts, et al., 2013, p. 1-10).

framework common in economics, CBPOs should continue to be hired until the incremental benefit of hiring a person equals the full cost of a new hire (e.g., including fringe and other benefits and potential costs, such as the effect of budget limitations). While neither Congress nor the Executive Office should be presumed to be exact social welfare optimizers, that framework suggests that each government branch might consider at what point should hiring stop. In the base case, which will be investigated with much uncertainty analysis later, the last person authorized to be hired is assumed to generate an added social benefit just equal to the full cost of their hiring—a cost which was provided by CBP (personal communication, 2018).

The social benefit of the average hire in each cohort of 33 people is assumed to decline linearly, from the initial benefit level to the full cost of hiring, if all 2,000 initial officers are hired, an assumption generally consistent with the few cases in Roberts et al. (2014b), which also illustrated significant differences across locations. As less than 2,000 additional CBPOs have actually been hired, a portion of the (estimated) potential gains have not been realized.[12] Figure A-6 illustrates this decline in benefits, showing the (gross) benefits and their decline to the full cost of hiring. The horizontal axis is the number of cohorts hired.[13] Total potential net benefits are the sum of areas A and B. These benefits are net of the cost of hiring new CBPOs. When fewer CBPOs are hired than authorized, the actual net benefits appear only in area A, as area B is not realized. Estimation of these areas is possible by first estimating the total of areas A plus B, and then subtracting area B. Note that the source of funding (whether through tax-funded expenditures or user fees) is not considered in this analysis, as the social cost is represented by the full cost of hiring.[14]

[12] The number of increased hires is based on actual "onboard" officers as compared to authorized levels for 2013, the year before the budget increase in question. A different approach, based on trend growth in authorized hires, yields a larger change in hiring, and hence a larger benefit, than used here.
[13] The continuous line drawn is a simplification of the discrete number of cohorts hired, although fully authorized hiring would be about 61 cohorts.
[14] Some benefit-cost analyses add an additional cost for the burden of taxation of about 25 percent of direct costs. Such an adjustment will be immaterial as shown through the uncertainty analysis later.

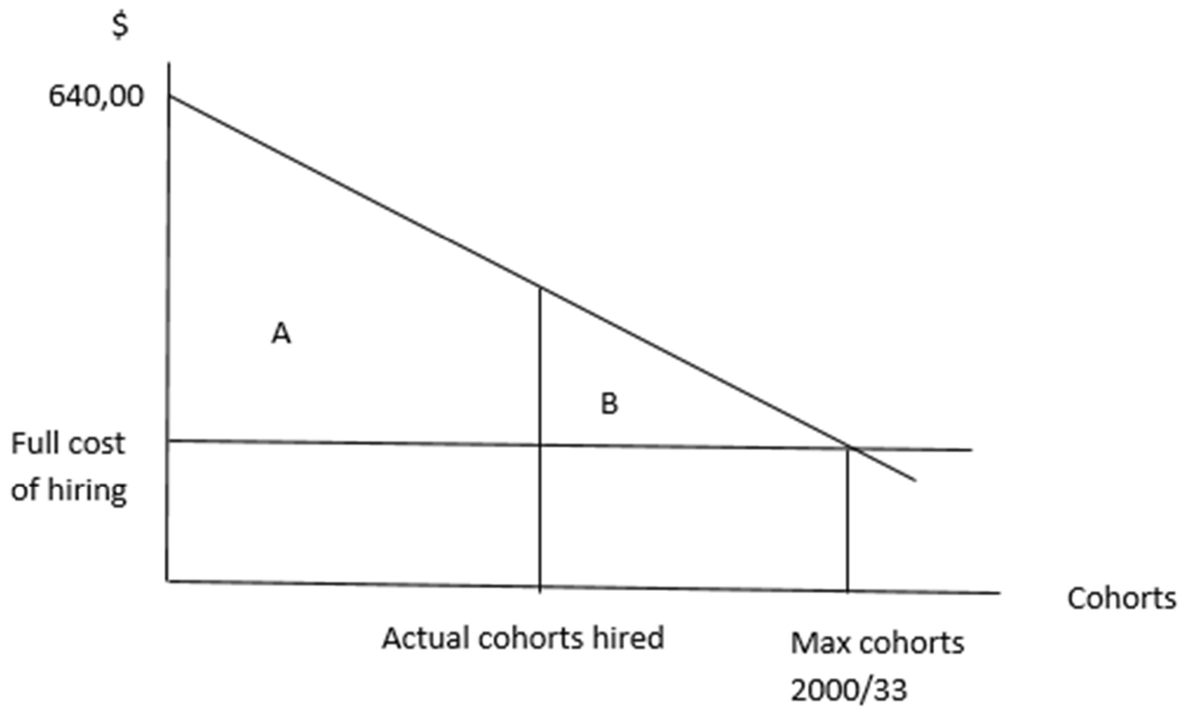


Figure A-6. Net Benefits from Additional CBPO Hiring: Wait Time Value

The final two issues are the portion of credit attributable to the Wait Time study and the duration of those benefits. The credit issue asks, what portion of the benefits measured in area A are attributable to the Wait Time study, given that there were many participants and pieces of information contributing to the budget process? The approach taken here has two elements. The first are the budget activities of the executive branch, including CBP, and stakeholder input into that process. The executive branch budget process was largely complete for FY 2014 as the Wait Time study analysis occurred generally between October 2012 and April 2013. However, the study appeared in time to inform the congressional process and was an important part of CBP's budget testimony for FY 2014 and for the next several years.

The approach taken here assigns, somewhat arbitrarily, 50 percent of the budget process to the executive branch actions, which were already completed, and 50 percent to the ensuing budget process, primarily congressional, that occurred after the release of the study. The effect of the study on the congressional process, around which wide sensitivity analyses are conducted, is assumed to be based on the share of word CBP used in their budget testimony to Congress.[15] No doubt words, space, and time are carefully considered.[16] CBP chose to devote a substantial portion of its testimony to Congress to the Wait Time study in FY 2014 (the year in which the major increase was authorized for FY 2015 as well).[17] Additional space was devoted to the study in FYs 2015-2016, by which time, consistent with a punctuated equilibrium approach, the increase may be effectively embedded.

Table A-6 below presents the number of words in FYs 2014-2016 devoted to the Wait Time study and to the operation of the ports of entry by CBP. The Wait Time share is computed as a share of the total words CBP used to discuss operations at ports of entry, including a request for additional staffing (U.S. CBP Testimony, various years). Such budget testimony makes CBP's final case for changes in funding to the congressional authorizers. In the base case analyzed below, the Wait Time study is attributed with 50 percent of its share of words in FY 2014, or 8.4 percent. In the sensitivity analysis, the share ranges from a low of 3.2 percent in the following year to a high value of 10 percent.

The benefits of the Wait Time study are thus computed as the Wait Time study share of the total benefits using the actual increase in hiring and its forecast continuation. These (net hiring) benefits are valued using the estimates from the Wait Time study and the declining incremental benefit function in Figure A-6. The total Wait Time benefits per year are calculated by multiplying the actual net benefits shown in area A by the weighted Wait Time study share of words from the testimony.

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[15] A more complex quantitative approach to assigning credit, the Shapley value, would require an enumeration of information, stakeholders, and their marginal contribution to the "payoff" of having more CBPOs, which is not known. An alternative qualitative approach might interview participants and elicit estimates or somehow synthesize an estimate from verbal responses. Some initial discussions with participants included suggestions ranging from zero to 100 percent credit to the Wait Time study.

[16] A time or word constraint on testimony directly implies a value for each word in an optimization model.

[17] Testimony on April 17, 2013, was given by representatives of the DHS Border Patrol, CBP Air and Marine Operations, and CBP, including portions relevant to ports of entry. As there was no additional testimony, the focus is on CBP testimony.

Table A-6. Text Analysis: Testimony of CBP Before the House Authorization Committee

	FY 2014	FY 2015	FY 2016
Total Port of Entry words	859	1,960	1,126
Wait Time study words	144	125	86
Wait Time share of words	16.8 %	6.4 %	7.6 %
Weighted share for Congressional process (50%)	8.4 %	3.2 %	3.8 %

Source: CBP, various years

The final issue is the number of years of benefits derived from the Wait Time study, an issue of the hypothetical baseline of what would have happened in the absence of the study. Had there been no study, it's conceivable that stakeholder pressure would have resulted in an equivalent increase in authorized staffing the following year, or in five years, or not occurring until after the 10-year time frame of this analysis. The base case is that the study benefits would continue for half the period of this analysis, five years. In other words, if the study had not occurred, it would have taken five years for stakeholder pressure to lead to equivalent authorization. The sensitivity analysis allows for wide variation such that the benefits from the Wait Time study stop, with equal probability, in each of the following nine years so there is a minimum of one year of benefits and a maximum of 10 years of benefits.

Table A-7 below presents the base case benefits, costs, NPV, and return on investment estimated for the Wait Time study for the period between 2014 and 2023. The present value (2017) benefits are estimated as $173.5 million from hiring additional CBPOs.

6. Benefit-Cost Analysis – Base Case

Given the base case inputs and the present value (in 2017 dollars) of the costs and the benefits from Table A-5 above and Table A-7 below, the net present value (NPV) for the Wait Time study is $173.1 million. This results in a base case return on investment (ROI) of 42,361 percent, meaning that the study is estimated to have returned on net about 424 times its cost in present value terms.

Table A-7. Estimated Base Case Benefits and NPV for the Wait Time Study

PV Benefit (2017 dollars)	$ 173,478,274
PV Cost (2017 dollars)	$ 408,561
NPV (2017 dollars)	$ 173,069,713
Return on Investment	42361%

Source: CREATE

7. Sensitivity and Uncertainty Analysis

Break-even Analysis. The equation for the net benefits of hiring in the base case depends importantly on the share of estimated benefits credited to the Wait Time study in the complex process of executive and congressional branch budgeting processes. The share of credit that results in breaking even, an NPV of zero, is 0.02 percent or two-hundredths of 1 percent, a relatively small amount given the study's prominence in congressional testimony.

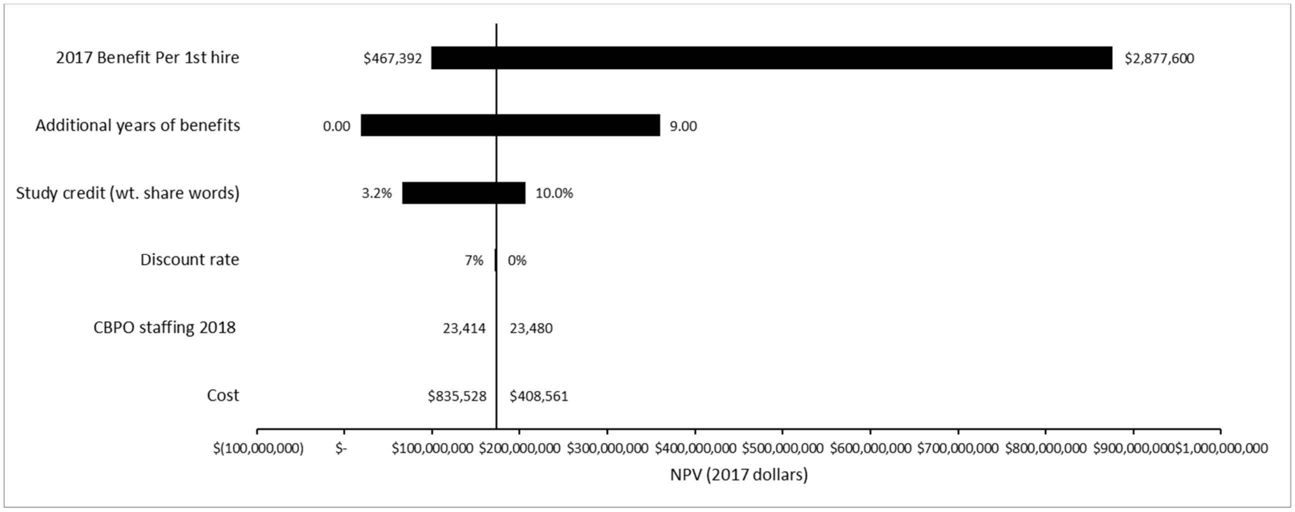
Tornado and Sensitivity Analysis. Sensitivity analysis and, later, simulation are driven by assumptions for uncertain variables. Section 3 above provides the reasoning for the uncertainty distributions for parameters in the NPV model, with the exception of uncertainty in CBPO staffing. The uncertainty presented is plus or minus one cohort to estimate the marginal impact of an additional cohort being hired or not. Table A-8 below summarizes the parameter values for uncertainty in key cost and benefit variables.

Table A-8. Ranges of the Wait Time Study Inputs for Sensitivity Analysis

	Base	Low	Base	High
CBPO staffing 2018	23,447	23,414	23,447	23,480
2017 Benefit Per 1st hire	$ 697,600	$ 467,392	$ 697,600	$ 2,877,600
Study credit (wt. share words)	8.4%	3.2%	8.4%	10.0%
Additional years of benefits	4.00	0.00	4.00	9.00
Discount rate	3%	0%	3%	7%
Cost	$ 408,561	$ 408,561	$ 408,561	$ 835,528

Note: values in 2017 dollars

The key determinants of NPV are investigated by applying a structured sensitivity approach using the values in Table A-8. Figure A-7 presents these results as a tornado diagram, with the width of the bars representing the impact on NPV. Given these ranges of uncertainty, the key determinants of the Wait Study NPV are seen to be the benefit per first person hired, the number of years of benefits and the share of credit allocated to the Wait Time study. Uncertainty in other parameters, including costs not shown separately, have a relatively small impact on NPV.



Source: CREATE, using TreePlan/Sensit

Figure A-7. Tornado Diagram: the Wait Time Study

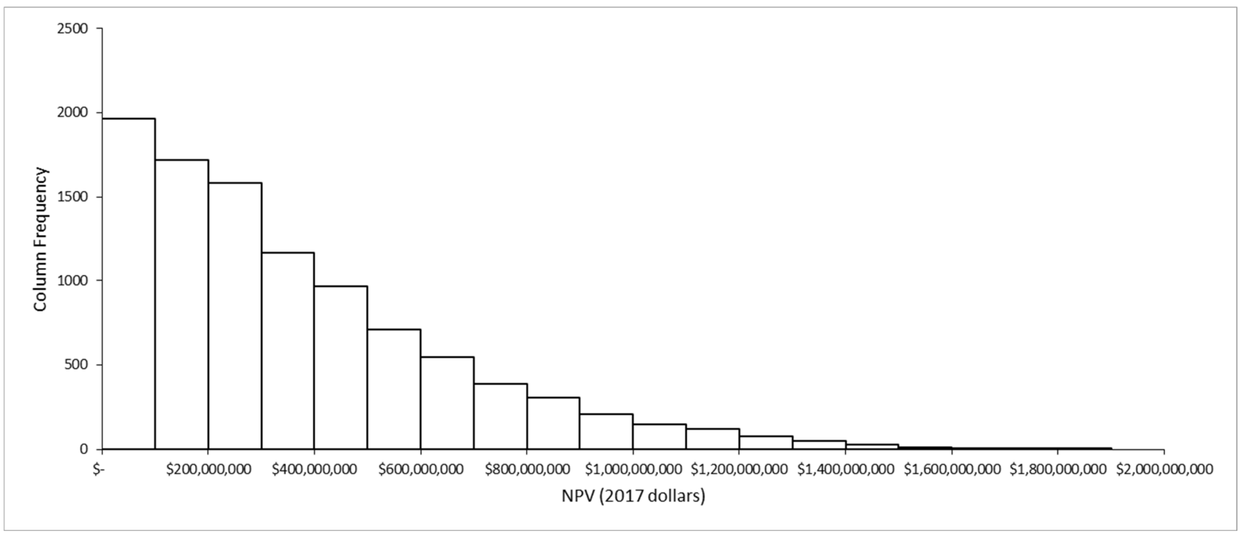
Uncertainty Analysis. To further explore the uncertainties of some of the input variables, we assumed that these uncertainties can be characterized by triangular distributions, with a minimum being the low value in Table A-8, the mode being the base case value, and the maximum being the high value. A uniform integer distribution is used for the number of years of benefits. We used an Excel add-in, SimVOI (TreePlan, 2017), 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 A-9 presents results of the simulation for the NPV from the Wait Time study, while Figure A-8 charts a more detailed histogram of those results. The mean, median, 5th percentile and 95th percentile NPV values are $360.5 million, $282.3 million, $31.0 million, and $963.2 million, respectively, all in present value 2017 dollars. There were no negative values in the simulation. The mean and median are substantially larger than the base case outcome because of the large potential benefit when economy-wide impacts are included which are not included in the base case. While uncertainty substantially broadens the estimated value of the NPV from the Wait Time study, the returns are generally large.

Table A-9. Statistics of the Wait Time Study NPV Distribution

Mean	$ 360,515,998
St. Dev.	$ 297,863,925
5th Percentile	$ 30,962,073
25th Percentile	$ 131,553,038
Median	$ 282,331,032
75th Percentile	$ 511,589,299
95th Percentile	$ 963,227,633

Source: CREATE



Source: CREATE, using TreePlan/SimVOI

Figure A-8. Simulation Results: Wait Time Study Net Present Value, in 2017 Dollars

8. Assumptions and Limitations

Three primary classes of assumptions and limitations affect this analysis: 1) model specification, 2) who has standing, and 3) parameter values. Regarding model specification, commonly accepted quantitative models do not exist for the information that changes programmatic budget decisions in the executive branch and Congress, although existing models provide general conceptual guidance. The discrete change in budgeting to increase the number of CBPOs is consistent with a theory of punctuated equilibrium, but the effect of specific information, such as the Wait Time study, is not known. Consequently, the model attributing causation, a share of impact and duration of benefits to the Wait Time study is uncertain, although informed by data from the budget process. With regard to standing, this analysis concentrated solely on benefits to U.S. residents, based on historical OMB guidance and the focus of much of the Wait Time study. Extending the benefit analysis to include non-U.S. residents would substantially increase the returns to the Wait Time study.

The third source of assumptions and limitations primarily involve parameter values. Continuing with the ambiguity surrounding executive branch and congressional roles in the budgeting process, the parameter used here that assigns influence weight equally to both branches is highly uncertain. The Wait Time study is given no credit for influencing the executive branch process, but is given credit for influencing the congressional process based on the study's share of words in budget testimony. The conceptually correct measure for the influence share is highly uncertain, even if the share of words is easily documented. Further, the unobserved baseline of when an equivalent authorization may have passed Congress without the Wait Time study is unknown. Finally, the benefits of hiring additional CBPOs were the specific output of the Wait Time study, but such parameters are themselves uncertain and that uncertainty was little investigated in the study. Instead, one could consider a new retrospective study which revises the estimated benefits that were internal to the Wait Time study. However, generating new values of impact was beyond the scope of this project. The effect of uncertainty in other parameters is small in comparison to these four issues.

9. Recommendations for Collecting Additional Information and Analysis

An improved evaluation of the NPV from the use of the Wait Time study would benefit from additional research and information, although there are also limitations to such information. New information and research in the following areas may improve the estimates provided here.

- Improved quantitative modeling of the executive and congressional branch budgeting processes and the role and impact of different types of information.
- Improved data on the diminishing social benefits from hiring additional CBPOs.

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Benefit-Cost Analysis of Enhanced Millimeter-Wave Scanner (EMWS)

Developer: Awareness and Localization of Explosives-Related Threats (ALERT)
Analyst: Jonathan Eyer (USC/CREATE)

1. Summary

Description. The Enhanced Millimeter-Wave Scanner (EMWS) tool is a product developed by the Awareness and Localization of Explosives-Related Threats (ALERT) Center of Excellence (COE). The EMWS tool is a result of two projects that improve detection capabilities of the existing millimeter-wave imaging technology. Millimeter-wave scanners are used in U.S. airports by the Transportation Security Administration (TSA) to detect objects, such as weapons or explosives, that are concealed underneath clothing. Existing millimeter-wave scanners are unable to distinguish the type of object that is concealed and often mistakenly identify innocuous material as aberrations. The EMWS provides a method to differentiate between innocuous material and contraband.

The valuation of the EMWS tool is driven by the cost savings associated with reducing the amount of time that is spent investigating false alarms. A false alarm results in delays to passengers who are directed to secondary screening (pat-downs) as well as TSA agent time to perform the screening.

Results. The development of the EMWS tool resulted in costs of $3,260,599 (in 2017 dollars). These costs were primarily from direct project costs and associated oversight costs at OUP. The cost of the EMWS devices are comparable to the cost of existing alternatives, so additional deployment costs will be minor if the deployment of the EMWS follows the existing deployment and replacement schedule.

The benefits of the EMWS tool are derived from a reduction in false alarms relative to the existing scanning technology, which can incorrectly flag skin folds, colostomy bags, and other innocuous aberrations as potential threats. This results in secondary screening for passengers which increases passenger wait time. It also requires a TSA agent to provide the secondary screening. The value of the EMWS is derived from the reduced passenger wait time and the reduced TSA staffing time associated with reducing the likelihood that a false alarm is triggered. Benefits are evaluated under a 10-year time horizon of future product usage.

The EMWS tool results in base case total benefits of approximately $99 million (in 2017 dollars). Sensitivity analysis was conducted to identify the parameters that are most important in driving the value of the EMWS tool. The duration of the secondary pat-down and the value placed on traveler time under Department of Transportation guidelines are key drivers of total value. The value of the EMWS is also sensitive to the false alarm rate of existing technology and the reduction in false alarms from the EMWS tool relative to existing alternatives, but these parameters are highly uncertain. A break-even analysis was also conducted which indicated that the EMWS benefits would exceed the development costs if the baseline false alarm rate is above 0.6 percent or if the EMWS tool reduces false alarms by more than 1 percent. A simulation analysis of all of the uncertainty in the model finds a range of net benefits, with a 5th percentile value of $51 million, a 95th percentile value of $264.7 million, and a median value of $123.2 million.

2. Background

Problem Context. Millimeter-wave scanners are in use in U.S. airports to provide a whole-body image of passengers. Millimeter-wave scanners send electromagnetic waves that penetrate clothing but reflect off of skin and concealed objects to reveal a three-dimensional image of the body (Sheen, McMakin & Hall, 2001). Millimeter-wave scanners are not associated with any health risks that have been identified for alternative scanning technologies, such as X-rays. Millimeter-wave scanners are unable to differentiate between dangerous abnormalities in the scan, such as explosives or weapons, and innocuous ones, such as skin folds or colostomy bags. False alarm rates (FARs) for millimeter-wave scanners are high relative to alternative detection methods (Hofer & Wetter, 2012). A false alarms results in a secondary screening, which delays the affected passenger and requires a TSA agent's time to perform. While each individual screening is relatively quick, false alarms can result in substantial costs when aggregating across the hundreds of millions of airline passengers screened by the TSA each year.

The EMWS Tool. The EMWS project is a tool developed by the ALERT COE that reduces the FAR from existing millimeter-wave scanning. The project entails both updated hardware to provide simultaneous scanning from multiple vantage points and a software component that quickly categorizes the information from the scanners. This allows for the identification of the specific material of an abnormality detected under clothing because different materials reflect the millimeter waves in different ways. This allows the scanner to rule out innocuous abnormalities, such as water or skin folds, that have a recognized reflection pattern (Gonzalez-Valdes et al., 2015).

3. Baseline

In our baseline, the costs of the millimeter-wave scanners are determined by the number of false alarms that occur each year and the associated cost of the foregone time.[18] The total costs associated with false alarms from the existing technology is calculated as

$$N * p * T * (V_t + V_{tsa}),$$

where N is the number of innocuous passengers who go through the millimeter-wave scanner, p is the probability of a false positive, T is the amount of time associated with the secondary screening, and V_t and V_{tsa} are the values of time for the traveler and for the TSA agents.

Table A-10 shows the baseline parameter assumptions (specific sources of parameter values are discussed later in Section 5). Under the baseline assumptions, approximately 231 million passengers experience false positives each year and are diverted to secondary screening. This results in $34.6 million in time costs that accrue to passengers and TSA agents.

Table A-10. Baseline Analysis Without the EMWS Tool

Input Variable	Base
Number of Scanned Passengers	655,775,000
Baseline False Alarm Rate	0.15
Pat Down Time (in seconds)	30
Value of Passenger Time (in dollars per hour)	$25.27
Value of TSA Time (in dollars per hour)	$16.00
Number of False Positives	77,150,000
Value of False Positives (in millions of 2017 dollars)	$11.3

[18] While there are benefits associated with detecting true positives, the EMWS tool is unlikely to change the rate at which true threats are detected, so the security benefits themselves are unchanged between existing technology and the EMWS tool and drop out of the calculation.

4. Cost Analysis

Table A-11 shows the cost of developing the EMWS tool, including direct project costs, COE overhead, and OUP oversight costs. Most of the $3.3 million in total costs were either accrued directly through the COE or were associated with oversight at OUP. Implementation costs are likely to be relatively minor. The operation of the EMWS by TSA agents is comparable to the operation of existing technology, so it is unlikely that additional training will be required. As the costs of the updated scanners are comparable to the costs of the existing millimeter-wave scanners, there would be no additional user implementation costs if the EMWS scanners are added in lieu of existing scanner technology or they replace existing scanners on the expected time scale. If EMWS scanners are used to replace existing scanners prior to the expected replacement time of the scanner, this would result in additional implementation costs borne by the user.[19]

Table A-11. Development Cost of the EMWS Tool (in 2017 Dollars)

Cost Category	Amount	Source
Pre-project costs (COE)		
Pre-project costs (other funding)		
Project costs (COE)	$1,821,695	COE/OUP
Project costs (university cost share)		
Oversight cost at the COE	$211,334	COE/OUP
Oversight cost at OUP	$1,227,570	COE/OUP
Transition development cost		
Implementation start-up cost		
Implementation cost (User)		
Implementation cost (COE)		
Implementation cost (Other users)		
Total cost (in 2017 Dollars)	$3,260,599	

[19] The costs would be the difference between the depreciated value of the scanners at the time of replacement minus the depreciated value of the scanners at the time of replacement if the EMWS scanners were unavailable.

5. Benefit Analysis

The primary benefit of the EMWS tool is the reduction in the passenger and TSA time associated with reducing the number of false alarms. We assume that the use of the EMWS will result in a percentage reduction in the overall FAR, so that the total cost of time associated with false alarms in the presence of the EMWS scanners is calculated as

$$N * p * q * T * (V_t + V_{tsa}).$$

Thus, the difference in total costs between the existing technology and the EMWS scanners can be determined as

$$N * p * T * (V_t + V_{tsa}) - N * p * q * T * (V_t + V_{tsa}),$$

where:

N: The number of passengers who are tested using the millimeter-wave scanner

p: The probability of a false alarm in existing millimeter-wave scanners

q: The relative probability of a false alarm using the EMWS tool compared to existing scanners

T: The time spent in secondary screening (5-15 seconds)

V_t: The value of passenger time

V_{tsa}: The cost of the TSA agent wages associated with the secondary scanning

Note that this formulation makes the implicit assumption that the likelihood of detecting security threats is unchanged when the EMWS tools are used. The TSA makes decisions about the stringency with which to apply its scanning technology and takes into account the fact that very sensitive scanning procedures will increase false alarms and wait times. The EMWS may allow the TSA to increase their stringency in ambiguous cases in which it is unable to classify material (e.g., small abnormalities) because the EMWS tool will reduce the overall FAR.

Number of Scanned Passengers. Most airports in the United States already use millimeter-wave scanners for security, so the upper limit for the number of millimeter-wave scans is the total number of passenger trips each year. In 2017, there were 771 million trips that were subject to TSA security (TSA, 2017). In practice, not all passengers are subject to the millimeter-wave scanners. Specifically, those with a TSA PreCheck membership—who fly more frequently than those without a PreCheck approval—are exempted from the scanners. We consider a range of scanning from 579 million scanned passengers (75 percent of all passengers are scanned) to 771 million scanned passengers (all passengers are scanned), with a baseline estimate of 655 million (85 percent of all passengers are scanned).

Baseline False Alarm Rate. We choose a baseline FAR of 10 percent on the basis that it is the midpoint between the low and high FAR values we use in our sensitivity analysis. While there is no published or publicly available research on the FAR of an existing millimeter wave scanner, ProPublica (2011) cited a 54 percent FAR based on a statement from a German parliamentarian and an 11 percent FAR based on an online poll. Rappaport and Silevitch (2019) also suggest that the false alarm rate is "at least 10 percent." We consider a wider range of 5 to 15 percent to account for the sensitivity of the net benefits to a high assumption of the baseline FAR (Burns, 2019).

Percentage Reduction in False Alarm Rate. The relative reduction in the FAR due to the EMWS tool is uncertain given the classified nature of the existing technology and the fact that the tool has not yet been deployed. As such, we consider a large range—from 25 percent to 75 percent, with a baseline at 50 percent—to show the sensitivity of the results to these uncertainties. The upper end of the range, 75 percent, corresponds to the percentage of false alarms cited in ProPublica (2011) that are attributable to sweat, buttons, and folds in clothing.

Value of Time. Passenger travel time is based on the Department of Transportation (DOT) guidance about incorporating travel time into cost-benefit analyses of the value of TSA time. Specifically, we consider a range from $19.04 per hour (the DOT's value of personal time for surface travel with their recommended 70 percent adjustment factor for personal travel) to $63.20 per hour (the DOT's value of business time for air travel), with a baseline of $25.27 per hour (DOT's value for personal air travel with their recommended 70 percent adjustment factor for personal travel). The value of TSA agent time is based on a range of $11 to $21 per hour for TSA agent pay, according to Glassdoor. The baseline value is $16 per hour.

Table A-12. Annual Benefits of the EMWS Tool

Input Variable	Base Case Value
Number of Scanned Passengers	655,775,000
Baseline False Alarm Rate	0.1
Pat Down Time (in seconds)	30
Value of Passenger Time (in dollars per hour)	$25.27
Value of TSA Time (in dollars per hour)	$16.00
Number of False Positives	65,577,500
Value of False Positives (in millions of 2017 dollars)	$22.5
Relative False Positive Rate	0.5
Number of False Positives with Tool	38,575,000
Value of False Positives with Tool (in millions of 2017 dollars)	$11.3
Total Value of EMWS/Year (in millions of 2017 dollars)	$11.3
Discount Factor	0.03
10-Year Discounted Total Benefits (in millions of 2017 dollars)	$98.7
Net Present Value (in millions of 2017 dollars)	$95.4

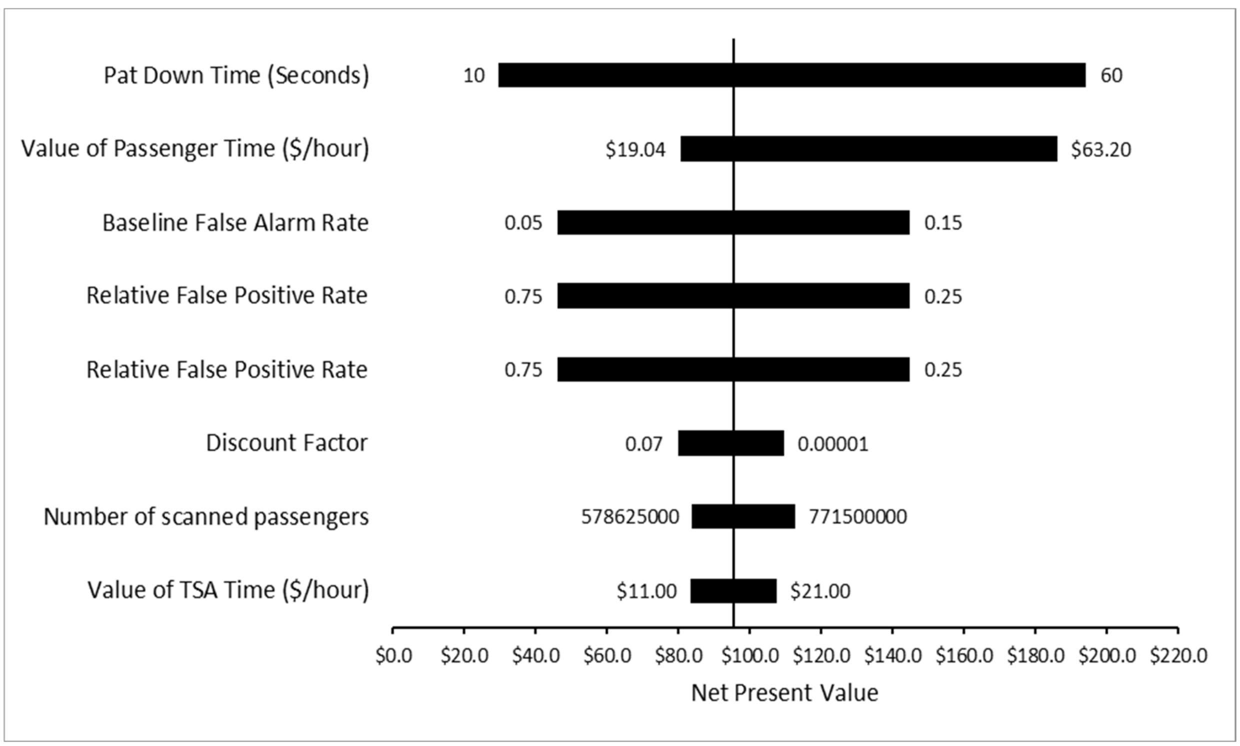
6. Benefit-Cost Analysis – Base Case

Under the baseline parameters, the annual benefit of the EMWS tool is $11.3 million. The parameter values associated with this case are shown in Table A-12. In the base case, total false positives are cut by half – a reduction of 38 million secondary screening procedures each year. Under the baseline assumption of a 3 percent annual discount factor, the net benefits accruing over a period of 10 years is $95.4 million, easily exceeding the initial investment. Comparing this value to the $2.3 million investment in the EMWS program suggests a benefit-cost ratio (BCR) of 30 and a return on investment (ROI) of 2,927 percent.

7. Sensitivity and Uncertainty Analysis

Break-even Analysis. The value of the EMWS is sensitive to a number of parameters. Most critically, the benefits of the project depend heavily on the baseline FAR and the relative reduction in FAR that will occur if the EMWS tools are adopted. Holding all other parameters constant, the EMWS project will break even (i.e., result in an NPV of zero) if the baseline FAR is above 0.3 percent or if the false alarm rate of the EMWS scanner relative to the existing technology is below 99 percent (i.e., the EMWS scanners reduce false alarms by at least 1 percent).

Tornado Analysis. The net benefits associated with the EMWS tool are sensitive to the underlying parameter assumptions. Figure A-9 presents a tornado diagram showing how the 10-year net present value of the EMWS tool varies with the parameter assumptions. The results are sensitive to the baseline FAR as this is the parameter that determines the current costs of false alarms (and, therefore, the maximum possible benefit from reducing false alarms). The duration of a pat-down due to a false alarm and the relative reduction in the FAR due to the EMWS tool are also important drivers of the uncertainty about the total value of the tool. The value of passenger time also shows substantial sensitivity, but this is an artifact of the relatively wide range of travel time valuation provided by the DOT.



Source: CREATE, using TreePlan/Sensit

Figure A-9: Tornado Diagram for the NPV of the EMWS Tool (in Millions of 2017 Dollars)

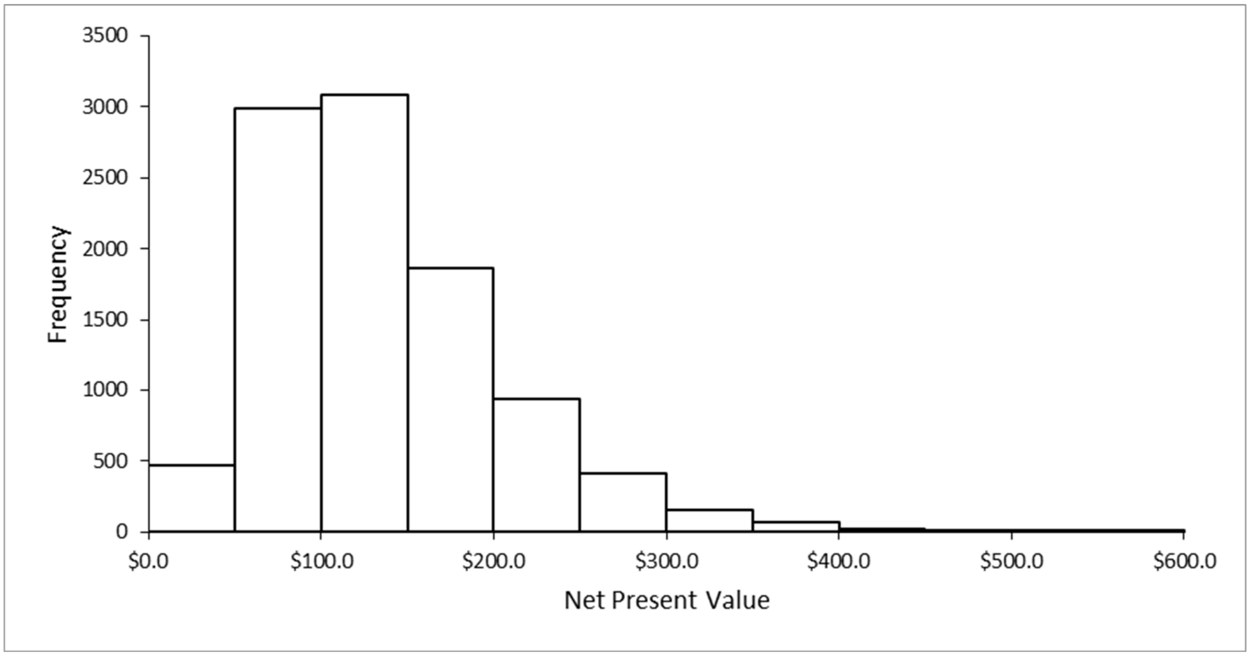
Uncertainty Analysis. Next, we conduct a formal sensitivity analysis of the value of the EMWS tool by varying the values from each parameter and calculating the associated 10-year net present value. In most cases, we assume a triangular distribution. The high, low, and base values are shown in Table A-13. We evaluated the 10-year net present value of the EMWS tool under 10,000 simulations of each of the key parameter values.

Table A-13: Ranges for the EMWS Tool

Input Variable	Base Case Value	Low Value	High Value
Number of Scanned Passengers	655,775,000	578,625,000	771,500,000
Baseline False Alarm Rate	0.1	0.05	0.15
Pat Down Time (in seconds)	30	10	60
Value of Passenger Time (in dollars per hour)	$25.27	$19.04	$63.20
Value of TSA Time (in dollars per hour)	$16.00	$11.00	$21.00
Relative False Positive Rate	0.5	0.25	0.75
Discount Factor	0.03	0.00001	0.07

Figure A-10 shows the density of the net present value of the EMWS tool across the simulations. Most of the simulations indicated an NPV between $50 and $200 million, with some simulations indicating substantially larger benefits. A small proportion of the simulations suggested an NPV below $50 million, but none of the simulations indicated a negative NPV.

Table A-14 shows the summary statistics across the simulations. The 5th percentile is approximately $51 million, while the 95th percentile is nearly $265 million. The range of this distribution is driven by variation in the current FAR and the relative rate if the EMWS tool is adopted. The minimum NPV value across 10,000 simulations was $16 million.



Source: CREATE, using TreePlan/Sim VOI

Figure A-10. Net Present Value of the EMWS Tool for 10 Years (in Millions of 2017 Dollars)

Table A-14. Statistics of the EMWS Tool NPV Distribution (in Millions of 2017 Dollars)

Mean	$135.7
St. Dev.	$67.4
5th Percentile	$51.0
25th Percentile	$85.9
Median	$123.2
75th Percentile	$172.1
95th Percentile	$264.7

8. Assumptions and Limitations

This analysis relies on a number of assumptions underlying the model. Primarily, we assume that the likelihood of detecting attacks (and the likelihood of a successful attack) are unchanged with the introduction of the EMWS program. It is possible that the TSA will increase security stringency as a result of the lowered FAR. It is also possible that because the TSA will better be able to detect some types of false alarm, they will increase scrutiny on other types of false alarms which are currently ignored. While this would reduce some of the benefits associated with the value of time, it would result in additional safety benefits that are not included in the current model.

Many of the parameters underlying the model are highly uncertain. This is particularly true for the baseline FAR and the relative reduction in the FAR with the EMWS tool. These are critical parameters driving the value of the product.

9. Recommendations for Collecting Additional Information and Analysis

The primary limitation of this analysis is the highly uncertain parameters surrounding the baseline FAR and the relative improvement due to the EMWS tool. If classified information related to the FAR of current technology could be obtained, the NPV of the project could be specified with greater accuracy. Similarly, after the project is completed, the EMWS tool should be compared against existing millimeter-wave scanners in a controlled test to identify the relative false alarm rate.

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Benefit-Cost Analysis of 3D Computed Tomography (CT) Datasets and Automatic Threat Recognition Algorithm

Developer: Center for Awareness and Localization of Explosives-related Threats (ALERT)
Analyst: Detlof von Winterfeldt (CREATE)

1. Summary

Description. ALERT created a dataset and advanced threat recognition (ATR) algorithms for use in three-dimensional (3D) computed tomography (CT) detection equipment that is scheduled to be deployed at 2,500 TSA checkpoints for carry-on luggage. The datasets have been developed to optimize threat recognition algorithms without using sensitive or classified information. The ATR was developed by a subcontractor of ALERT using the ALERT data sets. The ATR algorithm is licensed to a vendor of the 3D CT scanners for a one-time fee. ALERT staff estimates that the vendor will capture 25 percent of the market of checkpoint scanners (Silevitch, 2017; 2018; 2019). The main benefit from using the datasets and the optimized ATR algorithm is a reduction of false alarms due to the new scanners. While it also may have benefits from increasing detection rates (or reducing misses), the benefit cost-analysis (BCA) in this report focuses on reduction of false alarms.

Results. The costs of the development of the datasets and the ATR is estimated at \$4,898,926 (in 2017 dollars). This includes \$740,000 in funding by the Office of University Programs (OUP), COE and OUP overhead, and \$3,555,000 in transition-development funding by the Science and Technology Directorate (S&T) and the Transportation Security Agency (TSA).

The benefits are primarily due to a reduction of false alarm rates (FARs), which result in time savings of TSA staff and travelers. The baseline FAR of current 2D X-ray scanners is around 10 percent, which includes both real false-positives (i.e., nothing is found during secondary inspection) and nuisance alarms (i.e., a prohibited, but non-threat item is found during secondary inspection, e.g., a large water bottle or a computer). A report by the National Research Council (NRC, 2013) mentions that the benefits of a 1 percent reduction of false alarms throughout the TSA system would result in a savings of \$20 million per year. In this BCA, we take a different approach to estimating benefits by first estimating the reduction in false alarms due to the optimized ATR and then calculating the time savings due to this reduction. We estimate a reduction in false alarms of 25 percent, ranging between 20 and 30 percent. We estimate that the time spent in secondary search is about 7.5 minutes (ranging from 5 to 10 minutes) due to the process of waiting for the carry-on luggage and for searching and re-packing the luggage. We use Department of Transportation (DOT) guidance on valuing travelers' time savings. We use the approximate cost of a TSA staff member to estimate the value of officers' time savings.

TSA is planning replace about 2,500 scanners with 3D CT scanners (Washington Examiner, 2018). The 3D CT vendor that uses the ALERT-funded ATR is expected to capture 25 percent of this market, or about 625 scanners (Silevitch, 2019). TSA estimates the cost of each scanner at about $330,000 (FCW, 2019). Since the TSA will purchase the new scanners in any case, we do not include the scanner costs. We only take a portion of the credit of reducing false alarms as the marginal benefit of reducing the false alarms (30 percent in the base case, with a range from 20 to 40 percent).

In the base case, the net benefits are $10,717,594 per year or $107,175,938 for 10 years. Due to the substantial uncertainty about several of the input variables of the benefit model, we conducted sensitivity and uncertainty analyses, which resulted in a median net benefit of $117,741,020 for 10 years of use, with a range from $62,076,958 ($5^{th}$ percentile) to $209,045,620 ($95^{th}$ percentile).

2. Background

The current technology to scan checked and carry-on baggage at airports is a 2D X-ray scanner. The TSA is planning to replace these 2D scanners with 3D CT scanners at all 2,500 checkpoints at U.S. airports. In 2019 alone, the agency signed a contract with a 3D CT vendor for $98.6 million to purchase 300 scanners (FCW, 2019). Over the coming five years, TSA is planning to deploy the 3D CT systems at all passenger checkpoints at U.S. airports.

The advantages of these new scanners have been described by many sources, most notably the National Academy of Sciences (NRC, 2013). Among the features of the new equipment are the ease of use, the 3D view, and, most importantly, the reduction of false alarm rates and the increase in detection rates. Of course, with the increase in detection comes the decrease in misses, i.e. missed cases of true threat objects, thereby reducing risks to the airline industry, the airline passengers, and the national economy. The NRC report includes a reference to the "often-cited approximate number of annual savings of $25 million per percentage drop in the false alarm rate" (NRC, 2013, page 82).

3D CT scanners consist of the scanning equipment, which is not unlike a medical CT scanner, and an automatic threat recognition (ATR) software that assists the TSA officer in determining whether an object viewed on the 3D screen poses an actual threat (e.g., explosive materials, guns, knives, etc.). One issue with developing an ATR is the lack of available data on threat objects, because most of this data is classified or deemed law enforcement sensitive. It is therefore important to optimize an ATR without access to classified or sensitive information though datasets that mimic the types of threat materials and shapes that can be found in carry-on or checked baggage.

Since about 2010, ALERT conducted research that contributed to the creation of an unclassified dataset for testing and developing ATRs and funded the development of a new ATR through a subcontract to an ATR vendor. The ATR developer has, in turn, teamed up with a CT equipment vendor and established a licensing agreement with this vendor. In this BCA, we are restricting the analysis to:

1. the benefits and costs due to the development of the dataset and the ATR;
2. the benefits due to reducing false alarms and subsequent savings in wait time for passengers and secondary investigation time for TSA agents; and
3. the benefits applied to the equipment vendor that has a relationship with the ALERT funded ATR developer, with only a partial market of the 2,500 scanners that will eventually be purchased.

We are thus not taking credit for:

1. other wait time benefits, like improved flows of passengers through the checkpoint system due to the fact that the new system will no longer require removal of computers and liquids; or
2. improved detection rates due to the CT scanner and associated ATR.

Due to these parameters, we expect the benefits in this BCA to be on the low side.

3. Baseline

As stated above, this BCA considers the main benefit of 3D CT scanners to be the reduction of false alarms and the resulting decrease in wait time for passengers and time spent by TSA officers on secondary inspections of baggage. Information about FARs is sensitive, but informal interviews with passengers and airport officials suggest that the current base rate using 2D X-rays is between 5 and15 percent. In the base case, we used a FAR of 10 percent. Alarms trigger a manual inspection of the carry-on baggage, which involves wait time for the passenger and inspection time for the TSA officer. The actual time is also a sensitive number, but experience with air travel suggests that this time varies between 5 and 10 minutes. The longer times usually occur when there are several alarms close to each other. In the base case, we used 7.5 minutes.

The cost of unproductive wait time for travelers has been determined by the U.S. Department of Transportation to be $0.79 per minutes (DOT, 2017). The cost of an additional minute of secondary inspection time was derived from the annual burdened salary of a TSA officer, estimated at $100,000/year. This cost results in $0.27 per minute of effort.

Using 719,000,000 passengers in 2017 and the above estimates for percentages of false alarms and the cost of wait time per false alarm, we arrived at a base case estimate of the cost of false alarms to be $571,605,000. Note that this corresponds to $57,160,500 per percent of false alarms, about twice the cost that the NRC referred to. When using low-end estimates, we calculate a cost of $122,230,000 or $12,223,000 per percent of false alarms, about one-half the NRC estimate.

4. Cost Analysis

The costs of the ALERT-funded development of the dataset and the ATR were provided by the Director of the ALERT Center of Excellence, Michael Silevitch. They are shown in Table A-15.

Table A-15. Cost of the Development of the Dataset and ATR

Cost Category	Start	End	Amount in Real Dollars	Amount in 2017 Dollars	Source
Pre-project costs (COE)					
Pre-project costs (other funding)					
Project costs (COE)	9/1/13	6/30/18	$ 740,000	$ 748,315	COE/OUP
Project costs (university cost share)					
Oversight cost at the COE	9/21/10	6/30/18	$ 210,000	$ 216,987	COE/OUP
Oversight cost at OUP	9/21/10	6/30/18	$ 160,000	$ 165,324	OUP Overhead
Transition development cost	9/21/10	2/27/15	$ 3,555,000	$ 3,768,300	S&T, TSA
Implementation start up cost					
Implementation cost (User)					
Implementation cost (COE)					
Implementation cost (Other users)					
TOTAL COST			$ 4,665,000	$ 4,898,926	

Note that these cost estimates stop with the transition development costs, up to the deployment in the equipment marketed by the CT vendor. We do not include the cost of the CT scanning equipment, which the TSA would have to buy anyway, regardless of the ATR used. Thus, we only consider the marginal cost of the dataset development and the ATR, and we are also careful to only consider the marginal benefits of these developments, expressed as a percentage of the benefits of the combined equipment, ATR, and dataset development (see next section for explanation of the marginal benefits).

The cost estimates were converted to 2017 dollars by assuming that the costs were equally distributed in the time period referred to by the ALERT COE staff and then either inflated to 2017 dollars using the consumer price index or deflated at 3 percent for costs incurred in 2018.

5. Benefit Analysis

Table A-16 shows the inputs and outputs of the benefits analysis. In addition to the inputs for the baseline analysis discussed in section 3, the analysis required three inputs:

1. The percent reduction of false alarm rates relative to baseline false alarms
2. The percent of market share captured by the CT vendor
3. The percent of the false alarm reduction attributable to the CT equipment vs. attributable to the datasets and the ATR

These estimates and ranges were elicited in an interview with Michael Silevitch and Carl Crawford on April 3, 2019.

Note that this table also shows estimates that can be used to determine additional benefits from increasing the detection rate (i.e., the baseline detection rate, the increase in the baseline detection rate, and the cost of a successful attack in case of a missed threat object). Because the data required for firming up these estimates are sparse or classified, we did not use them in our benefits calculations.

All benefit estimates were first calculated for the first year of use in 2017, and then we calculated the discounted benefits for 10 years of use and subtracted the costs in 2017 dollars to arrive at the net 10-year benefits.

Table A-16. Benefit Analysis

Input Variable	Base
Number of Travelers/Year	719,000,000
Current False Positive Rate	10.0%
Decrease in False Positives	25%
Time in Secondary (Min)	7.5
Cost of One Minute of Wait Time	$0.79
Cost of One Minute of TSA Time	$0.27
Percent attributable to CT Vendor	25%
Percent attributable to ATR	30%
Current Cost of False Positives/Year	$ 571,605,000
3D Cost of False Positives/Year	$ 428,703,750
Attributabe Benefits/Year	$ 10,717,594
Discount Factor	0.030
Total Value of 3D CT Scanners for 10 Years	**$ 107,175,938**
Total Net Benefits for Ten Years	**$ 102,277,012**

6. Benefit-Cost Analysis – Base Case

Table A-17 shows the results of this analysis in terms of benefits and costs in 2017 dollars, net present value (NPV) benefits, and the return on investment.

Table A-17. Estimated Base Case Benefits and NPV for ALERT's Dataset and ATR

PV Benefits (2017 dollars)	$ 107,175,940
PV Costs (2017 dollars)	$ 4,898,926
NPV (2017 dollars)	$ 102,277,014
Return on Investment	2088%

7. Sensitivity and Uncertainty Analysis

Break-even Analysis. There are several ways to conduct break-even analyses for the ALERT dataset and ATR tool. For example, the benefits just equal the costs when the reduction of the FAR is 1.1425 percent, a very small reduction that will certainly be exceeded by the CT equipment and ATR. Another example is the share of attributable benefits of the datasets and ATR versus the CT equipment. The break-even point here is 1.37 percent.

Tornado Analysis. To conduct a tornado sensitivity analysis, we elicited ranges of input values around the base case displayed in Table A-18. Data regarding the low and high values of the percentage of false alarm reduction attributable to the ATR, the percentage reduction in false alarms, and the percentage of market share of the CT equipment vendor came from interviews with the COE Director and the Principal Investigator of the projects. The low and high values for the current false alarm rate, the time in secondary search, the cost of passenger wait time, and the cost of TSA officers' time were not elicited from experts but assigned to cover a wide reasonable range. Using these ranges results in a wide range of net benefits, from $7,324,074 to $693,969,074.

Table A-18. Base Case and Ranges of Input Parameters Values

Input Variable	Low	Base	High
Number of Travelers/Year	719,000,000	719,000,000	719000000
Number of Attack Attempts Per Year	0.1	0.2	0.4
Detection probability with current system	0	0	0
Current False Positive Rate	5.0%	10.0%	20%
Decrease in False Positives	20%	25%	30%
Time in Secondary (Min)	5	7.5	10
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
Percent attributable to CT Vendor	20%	25%	30%
Percent attributable to ATR	25%	30%	40%
Current Cost of False Positives/Year	$ 122,230,000	$ 571,605,000	$1,941,300,000
Current Cost of False Negatives	$ -	$ -	$ -
3D Cost of False Positives/Year	$ 97,784,000	$ 428,703,750	$1,358,910,000
Attributabe Benefits/Year	$ 1,222,300	$ 10,717,594	$ 69,886,800
3D Cost of False Negatives	$ -	$ -	$ -
Discount Factor	0.000	0.030	0.070
Total Value of 3D CT Scanners for 10 Years	**$ 12,223,000**	**$ 107,175,938**	**$ 698,868,000**
Total Net Benefits for Ten Years	**$ 7,324,074**	**$ 102,277,012**	**$ 693,969,074**

Figure A-11 shows the resulting tornado diagram. It illustrates that the current FAR is the most important input parameter, followed by four other parameters. The cost of TSA officers' time is the least important one considered in this analysis. The other parameters were either fixed (number of travelers per year) or not considered in this BCA, which solely focused on false alarms (parameters related to detection).

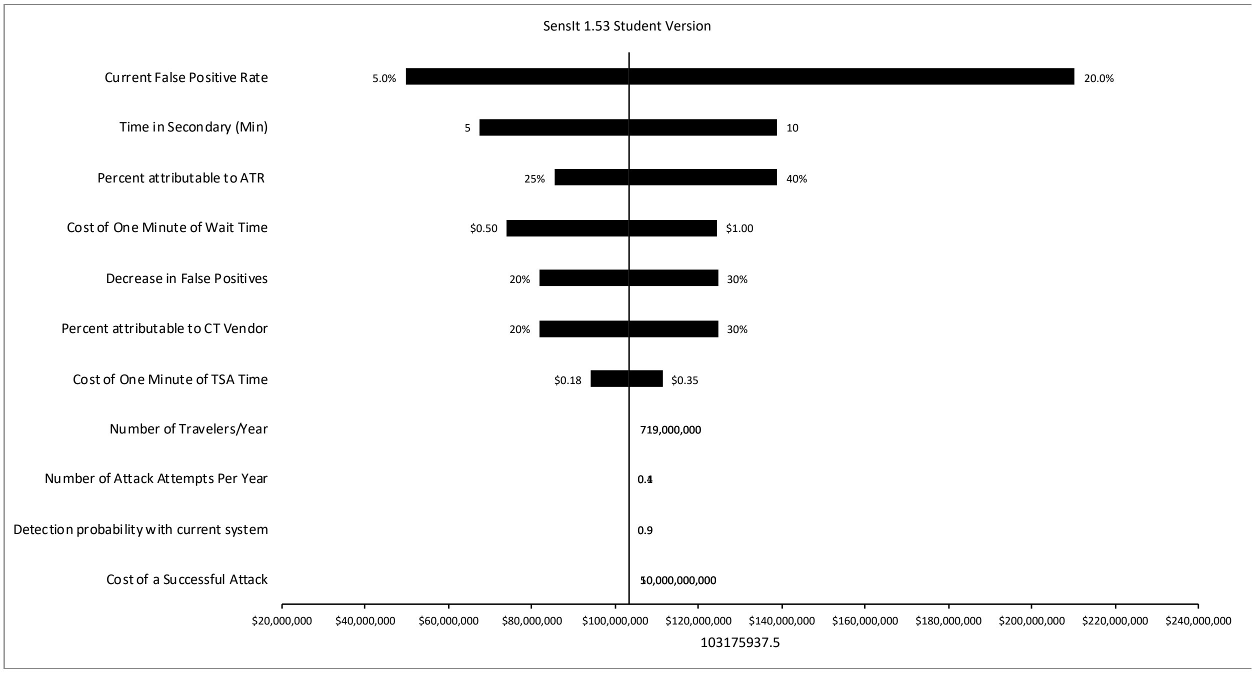

Figure A-11. Tornado Analysis of the Input Parameters for the ALERT Dataset and ATR Project

Uncertainty Analysis. To conduct an uncertainty analysis, we used triangular distributions, with the minimum set at the low value of Table A-18, the mode at the base case, and the maximum at the high end. The results are shown in Figure A-12. Table A-19 shows the statistics of this distribution, with a 5th percentile of $62,076,958, a median of $117,741,020, and a 95th percentile of $209,045,620.

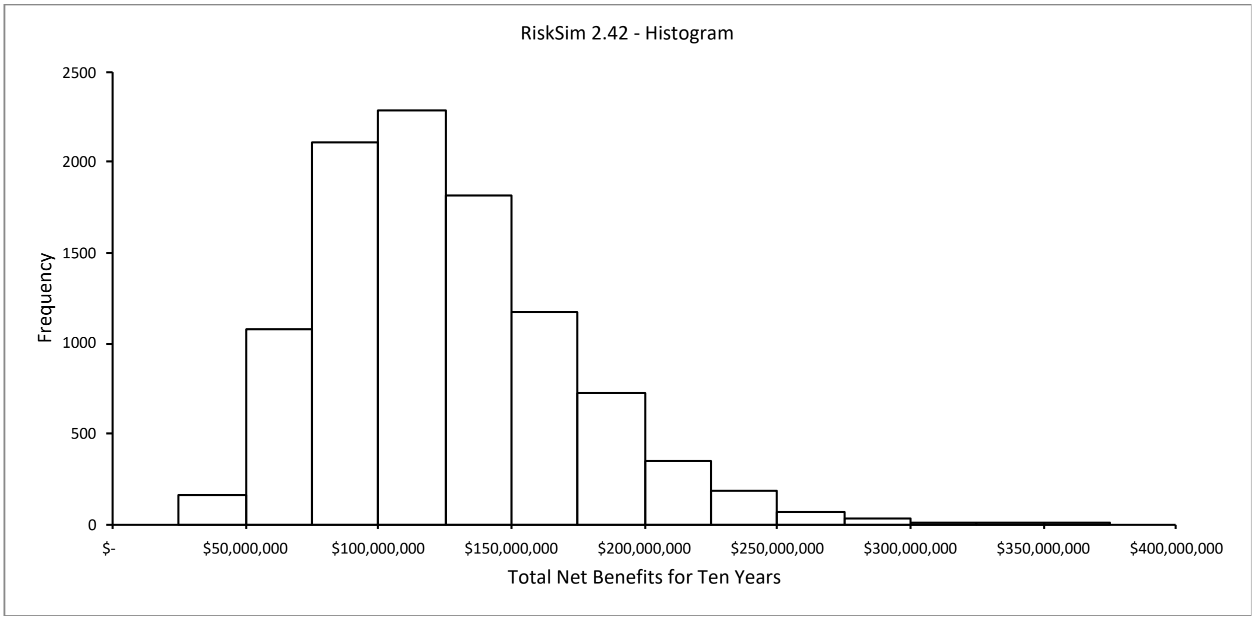

Figure A-12. Results of the Uncertainty Analysis

Table A-19. Statistics of the NPV Simulation

Mean	$124,454,313
St. Dev.	$ 45,828,173
5th Percentile	$ 62,076,958
Median	$117,741,020
95th Percentile	$209,045,620

8. Assumptions and Limitations

The main assumption in this BCA is that all costs and benefits are marginal, i.e., we don't count the total lifecycle costs and benefits of converting the current 2D scanners to 3D scanners, but only the costs and benefits of the ALERT datasets and ATR project. A key assumption in this analysis is the percent of false alarm reduction attributable to this project by ALERT.

We received communication from the ALERT team (Crawford, 2019) that the ATR developer is receiving $5,000 per scanner as a license fee by the CT vendor, with a market of 25 percent of the CT scanners, or 625 scanners. This is a one-time fee only. If we were to apply this license fee as the only benefit of the ATR software, this would result in a benefit of only $3,125,000, less than the cost of development. If applied to all 2,500 scanners, the benefits as measured by the license fee would be $12.5 million, exceeding the cost of development. These numbers establish a lower bound of benefits. Most of the other input parameters can be ascertained by collecting additional information.

9. Recommendations for Collecting Additional Information and Analysis

It should be easy to collect additional information on the most important parameter value: the baseline false alarm rate. This is available from TSA but considered law enforcement-sensitive. Similarly, the reduction of the false alarm rate can be ascertained after tests with the CT scanners are completed. Time in secondary (wait time by passengers) and time for secondary inspections by TSA officers can also be determined more precisely using TSA data. The percent of market share captured by the CT vendor won't be known for some time but will be known in a few years to refine this BCA.

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Benefit-Cost Analysis of the Passive Acoustic Sensors System for Low Flying Aircraft Detection

Developer: Maritime Security Center
Analysts: Dan Wei and Detlof von Winterfeldt, CREATE

1. Summary

Description. As an alternative technology to the widely used radar systems to monitor and detect illicit low-flying aircraft, the passive acoustic detection and tracking system provides several appealing features, including its simplicity and relatively low cost. The Passive Acoustic Sesnsors (PAS) system was developed by the Maritime Security Center at the Stevens Institute of Technology. The system was designed to automatically detect, track, and classify low-flying aircraft by using a network of passive acoustic sensors. The system captures signals and images of the passing aircraft by its sensors, microphones, cameras, and other electronics, and sends the pre-processed signals wirelessly to the central processing station to determine the location of the aircraft. Although the system has not been deployed by U.S. Customs and Border Protection (CBP), it has been tested for an extended period in mountainous areas.

Results. The estimated total development cost of the PAS system was about $4.0 million. This estimate only includes the development and implementation costs of the technology. In addition, the system cost of each field station is about $125,000, which is projected to be able to adequately function for at least 10 years. The annual operation and maintenance costs for each station are estimated at $2,000.

To estimate the benefits of the PAS, we assume that it will be utilized as a supplemental detection and tracking technology to the current Tethered Aerostat Radar System (TARS) operated by CBP in Rio Grande City, Texas, the location where the most active detection and seizure activities by TARS are recorded. The main benefits of the PAS system are estimated as the market value of intercepted illegal drugs from additional seizures that the system can help achieve. In the base case, it is estimated that the total net benefits for 10 years of deployment of the PAS system are about $18.1 million.

There is substantial uncertainty in terms of additional number of seizures that result from the deployment of the PAS system, the quantity of narcotics intercepted per seizure, and the market values of the narcotics. We conducted sensitivity analyses on these variables and found that the net benefit could range from $8.5 million (5th percentile) to $39.7 million (95th percentile), with a median of $20.9 million.

2. Background

Problem Context. Low Flying Aircraft (LFA), including small airplanes, helicopters, and ultralight aircrafts, have been increasingly used, primarily by drug smugglers, to engage in illicit activities across the U.S. borders. These low-flying aircrafts are difficult to detect because they are capable of flying below the detection altitude of the radar systems operated by air traffic control, and they can easily hide behind complex terrains, such as mountains and valleys (Salloum et al., 2015; Sedunov et al., 2016; Sedunov et al., 2018). Between Fiscal Years (FYs) 2011 and 2016, 534 ultralight aircraft incursions were recorded by CBP (GAO, 2017).

Most of the efforts to-date to detect the LFAs are concentrated on the development of advanced and complex radar systems, such as the Tethered Aerostat Radar System (TARS) that CBP has been using along the southern border (CBP, 2018). As an alternative means to monitor and detect LFAs incursions, the acoustic detection system provides several advantages. The system is simple and easy to deploy, and the equipment used is of low cost. It can be used to detect targets at any altitude, as well as those that move slowly or are stationary (Sutin et al., 2013).

The Passive Acoustic Sensors (PAS) System. The PAS system was designed to automatically detect, track, and classify low-flying aircrafts by using a network of passive acoustic sensors. The system includes several sensor nodes, which pre-process the signals captured through a microphone cluster, cameras, and electronics, and send the results wirelessly to a central station for further processing. Triangulation techniques are used by the central processing station to determine the location of the aircrafts based on the directions of arrival captured from two or more sensor nodes (Salloum et al., 2015; Sedunov et al., 2016).

A two-year extended test of the system was conducted, especially in mountainous areas. During the testing period, the system was operated without interruption and successfully detected a significant number of targets of interest (Salloum et al., 2015). The detection and tracking performance of the system for different types of aircraft was tested and verified by comparing the coordinates provided by the PAS system to the aircraft's true position as measured by GPS carried onboard (Sedunov et al., 2016; Sedunov et al., 2018).

3. Baseline

The Tethered Aerostat Radar System (TARS), which is the most cost-efficient radar detection capacity that CBP owns, is used as the reference technology to estimate the detection and interception of illicit low-flying small aircrafts in the baseline. TARS operates with eight special giant aerodynamic blimps flying at 10,000 feet (but moored to ground), stretching over the southern U.S. border from Yuma, Arizona to Lajas, Puerto Rico. Each blimp is equipped with radar and other sensors weighing more than 2,000 pounds and has the capability to detect aircraft within the range of 200 miles (CBP, 2018).

In late 1970s, the U.S. Customs Service started using the tethered aerostats to deal with the increasing number of illicit low-flying small aircrafts primarily used by drug smugglers. The first TARS site was established in Cudjoe Key, Florida. For more than 25 years, the U.S. Air Force managed the TARS program. The program was transferred to CBP in 2013.

Between FY 2013 and FY 2016, TARS helped detect 1,989 tracks of interest (TOI), which accounted for about 44 percent of all border-related radar detections. Among these 1,989 detections, 377 were with violations. The majority of these were violations relating to the Federal Aviation Regulations for entering, exiting, and flying in U.S. airspace. These detected violations resulted in 14 arrests and 40 seizures (GAO, 2017). This translates to an average of 10 seizures per year.

We next make the link between the number of seizures and the quantity of narcotics seized. GAO (2017) provided the number and quantity of seizures that can be attributed to CBP aerostats between May 2014 and FY 2016. However, the data do not distinguish seizures that can be attributed to the tactical aerostats from those attributed to the TARS program. The GAO data indicated that 681 seizure events were attributed to aerostat activity in this time period. Moreover, 674 out of the 681 seizures took place in the Rio Grande Valley sector, resulting in seizures of 257,692 pounds of marijuana and 129.01 pounds of cocaine. This can be translated to about 382.3 pounds of marijuana and 0.19 pounds of cocaine per seizure in the Rio Grande Valley sector.

To measure the value of the narcotics seized, we used the retail (street) price of these drugs. The average price of cocaine per gram (not adjusting for purity) in 2016 was $93.00 (UNODC, 2018). The average price of marijuana per ounce in 2018 was $247.50 (Forbes, 2018). Therefore, the average market value of the narcotics seized per seizure event is about $1.49 million. Since on average TARS contributes to 10 seizures in each year, the total market value is estimated to be $14.9 million.

4. Cost Analysis

Table A-20 presents the cost of developing, transitioning, and limited implementing the PAS system. The total project costs were $3.5 million, with a $0.25 million university cost share. There was funding from Navy (about $2 million) and the Maritime Security Center at Stevens Institute of Technology ($0.5 million) between 2004 and 2008 to support the initial developments of techniques on signal processing for detection, tracking, and classification of acoustic targets. These initial costs of knowledge developments and the application of the techniques in other application areas (including passive acoustic sensors for small boats, submersibles, invasive species, etc.) are not included in the costs of this project. Oversight costs at COE and OUP are counted as well for the entire period of development. The total costs amounted to $4,006,100 in 2017 dollars.

5. Benefit Analysis

For the analyses in this and the following sections, we assume that the PAS system will be deployed to serve as a supplemental technology to the TARS radar system currently operated by CBP. This deployment is expected to result in increased number of detections and captures of small aircrafts used in drug smuggling. The benefits of the acoustic system are estimated in terms of the total market values of the illegal drugs that can be captured above the current baseline level. We assume that the acoustic sensor system will be deployed in the Rio Grande City location, where the majority (over 80 percent) of narcotics seizure events took place in the past several years.

Table A-20. Costs for Development and Initial Implementation of the PAS System

Cost Category	Start Year	End Year	Amount ($)	Source of Funding	2017 Dollars
Pre-project costs (COE)	n/a	n/a	n/a	n/a	n/a
Pre-project costs (other funding)[a]	n/a	n/a	n/a	n/a	n/a
Project costs (COE)	2013	2016	$3,500,000	DHS S&T	$3,613,750
Project costs (university cost share)	2013	2016	$250,000	Stevens	$258,125
Oversight cost at the COE	2013	2016	$50,000	DHS S&T	$51,625
Oversight cost at OUP	2013	2016	$80,000[b]	OUP	$82,600
Transition development cost	2016	2016	$350,000[c]	DHS S&T	$361,375[c]
Implementation startup cost	n/a	n/a	n/a	n/a	n/a
Implementation cost (User)	n/a	n/a	n/a	n/a	n/a
Implementation cost (COE)	2016	2016	$500,000[c]	DHS S&T	$516,250[c]
Implementation cost (Other users)	n/a	n/a	n/a	n/a	n/a
TOTAL COST			**$3,880,000**		**$4,006,100**

[a] The $2 million funding from Navy and $0.5 million from Stevens between 2004 and 2008 to support the initial development of the passive acoustic sensors that were also used in other application areas are not included in the costs of this project.
[b] Assume $20,000 per year.
[c] Part of the $3.5 million project costs (COE), thus is not included separately in the total cost.

The current coverage range of each acoustic station is about 100 square kilometers, which translates to a detection range of about 11.3 kilometers. However, more stations can be added to scale up the total area covered. The radar system in each TARS has a detection range of about 200 miles (CBP, 2018). We assume that a group of 28 (=200*1.6/11.3) acoustic stations would be able to cover a similar range of area that is currently covered by the TARS in the Rio Grande City location. Based on our consultation with the PI of the passive acoustic sensor system, we also estimate that the total system cost of each station is $125,000 (which has a useful life of at least 10 years) and the annual O&M costs are $2,000 per station.

Table A-21 presents the input numbers that are used in the base case benefit calculations. We assume that the group of 28 acoustic stations can result in two additional seizures each year in the Rio Grande City location. This represents about a 25 percent increase of the baseline annual number of seizures in this location. In addition, we use the average amount of cocaine and marijuana seized per seizure of the TARS system at the Rio Grande City station, as well as the average market prices of cocaine and marijuana to estimate the total value of the narcotics seized for the 25 percent increase in seizures.

Based on the above assumptions, we estimated that the total 10-year net benefits of the PAS system are about $18.1 million in 2017 dollars.

Table A-21. Base Case Analysis of the Benefits of the PAS System

Variable	**Base Case**
System Cost Per Field Station ($)	$125,000
Number of Field Stations to Cover a Similar Detection Area of the Rio Grande City Location TARS	28
Useful Life of PAS System (years)	10
Total System Cost of All Field Stations ($)	$3,500,000
Annual O&M Cost per Station ($)	$2,000
Total Annual O&M Cost ($)	$56,000
Average Marijuana Seized per Seizure by TARS (lbs)	382
Average Cocaine Seized per Seizure by TARS (lbs)	0.19
Market Value of Marijuana ($/ounce)	242.65
Market Value of Cocaine ($/gram)	94.86
Number of Seizures per Year above Baseline	2
Discount Rate	3%
10-Year Discounted System and O&M Costs ($)	$3,990,142
Total Annual Benefits ($)	$2,985,170
10-Year Discounted Benefits ($)	$26,127,788
10-Year Net Benefits (in 2017 dollars)	$18,131,546

6. Benefit-Cost Analysis – Base Case

Table A-21 shows that the total annual benefits of using the PAS system as a supplementary detection system to the baseline radar technologies used by CBP are nearly $3 million. The 10-year discounted benefits are about $26.1 million. After subtracting the initial development costs, the upfront system cost, and the discounted O&M costs over the 10-year period, the net present value (NPV) of the net benefits are estimated to be \$18.1 million in the base case analysis. Given the \$4 million initial development investment costs of the PAS system, the benefit-to-cost ratio is 6.52 and the return on investment (ROI) is 552.2 percent.

7. Sensitivity and Uncertainty Analysis

Break-even Analysis. One way to evaluate the cost-effectiveness of the PAS system is to determine how many interceptions of illegal drugs above the baseline the system needs to assist to make it worthwhile. In other words, how many seizures on an annual basis are needed for the PAS system to pay back the total development costs of the system (\$4,006,100), as well as the component and labor costs associated with the production of the system and the operation and maintenance costs of the field stations over a 10-year period.

Again, for the system costs and O&M costs, we consider a group of 28 acoustic stations that have a similar coverage range as TARS in the Rio Grande City location. Given the average quantity of marijuana and cocaine that were seized per TARS seizure event in the Rio Grande City location and the respective average market price of these drugs, the PAS system would pay for its \$4 million development cost and an NPV of \$4 million system and O&M costs if it can lead to 0.612 additional seizures per year over the next 10-year period. Since on average TARS led to about 8 seizure events each year in the Rio Grande City location, 0.612 additional seizures translate to a 7.65 percent increase in the number of seizures from the baseline at the Rio Grande City location.

Sensitivity Analysis. The estimated net benefits associated with the deployment of the PAS system are sensitive to some of the assumed parameters. There are nine parameters with uncertainty in the net benefits calculation. Table A-22 shows the range for each of the nine parameters we adopted in the sensitivity analysis. Three parameters are related to the total system and O&M costs of the acoustic sensor field stations: (1) the number of stations required to cover a similar detection area covered by TARS in the Rio Grande City location, (2) system costs for each field station, and (3) annual O&M costs for each station. Five parameters are related to the total market values of the narcotics intercepted: (1) number of seizures per year, (2) quantities of marijuana and cocaine intercepted per seizures, and (3) market values of marijuana and cocaine. The remaining parameter is the future discount rate.

The ranges for the parameters relating to the total system cost and O&M cost was determined based on the information obtained from the PI of the aviation passive acoustic sensor technology. The high and low average amounts of marijuana and cocaine seized per seizure are assumed to be 20 percent higher or lower than the base case levels. For the market price of marijuana, the range roughly represents the price ranges across the states in the U.S. (Statista, 2019). For the market price of cocaine, we use the price range over the past 10 years for the U.S. (UNODC, 2018). Finally, for the most important parameter—the number of seizures per year above the baseline level that can be achieved by utilizing the PAS systems at the Rio Grande City location in addition to the TARS system—we assume one additional seizure each year in the lower-bound case and four additional seizures in the upper-bound case, which represent about a 12.5 percent and a 50 percent increase of the baseline annual number of seizures in the Rio Grande City location, respectively.

Table A-22. Ranges for the Passive Acoustic Sensors System

Input Variables	Low	Base	High
System Cost Per Field Station ($)	100,000	125,000	150,000
Number of Acoustic Sensor Field Stations to Cover a Similar Detection Area of the Rio Grande City Location TARS	25	28	31
Annual O&M Cost per Station	1,800	2,000	2,500
Average Amount of Marijuana Seized per Seizure (lbs)	306	382	459
Average Amount of Cocaine Seized per Seizure (lbs)	0.15	0.19	0.23
Market Value of Marijuana ($/ounce)	169.85	242.65	315.44
Market Value of Cocaine ($/gram)	85.68	94.86	100.98
Number of Seizures per Year	1	2	4
Discount Rate	0%	3%	7%

Figure A-13 presents the tornado diagram, which shows how changes in the underlying input parameters affect the net benefit estimate of the PAS system. In the tornado diagram, the length of the bar for each input variable represents the range of the 10-year net benefits, calculated by using the low and high values of this variable while holding the other variables at the base values. The most important parameters are those with the longest bars in the diagram.

The sensitivity analysis indicates that the estimates of the 10-year net benefits are most sensitive to the variable of the number of seizures above the baseline level that the deployment of the acoustic system can achieve. Other important variables include the market value and the average seized quantity of marijuana.

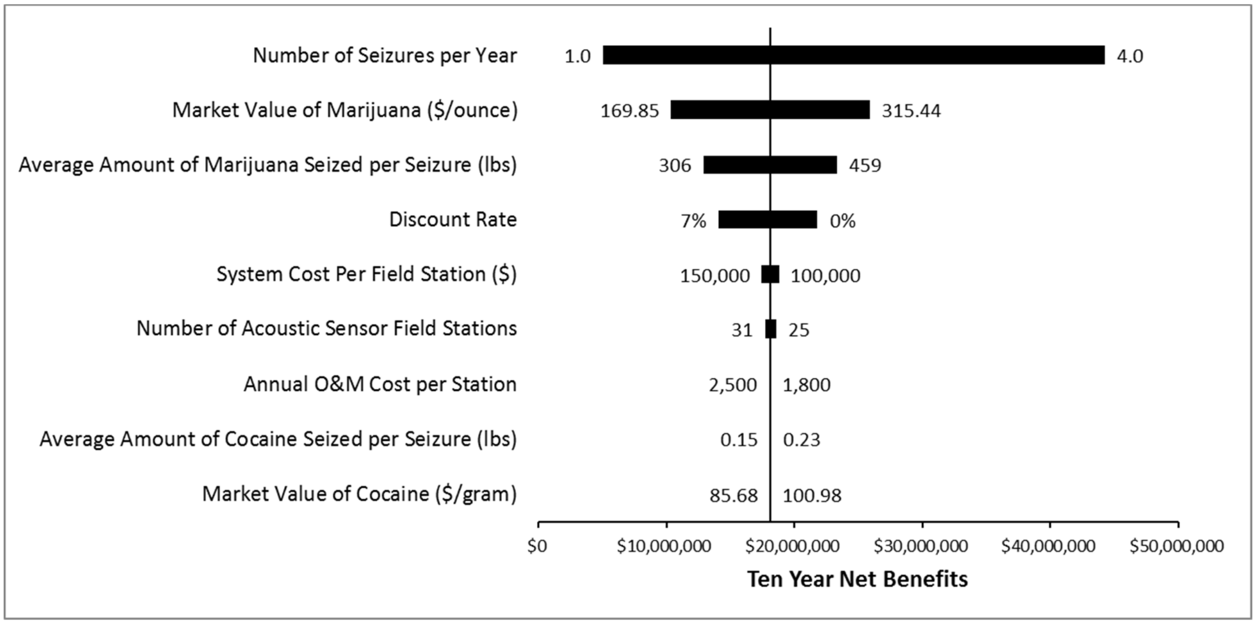

Figure A-13. Tornado Diagram for 10-Year Net Benefits of the PAS System

Uncertainty Analysis. To explore the uncertainty associated with the estimates of the 10-year net benefits, we conducted a Monte Carlo simulation. We assumed triangular probability distributions for all variables listed in Table A-22, using the low and high values as the minimum and the maximum, respectively, of the triangular distribution, and the base case value as the mode. Next, 10,000 simulations were run to obtain the distribution of the 10-year net benefits as presented in Figure A-14. The 5th, 50th, and 95th percentiles, as well as the mean and median of the distribution, are presented in Table A-23.

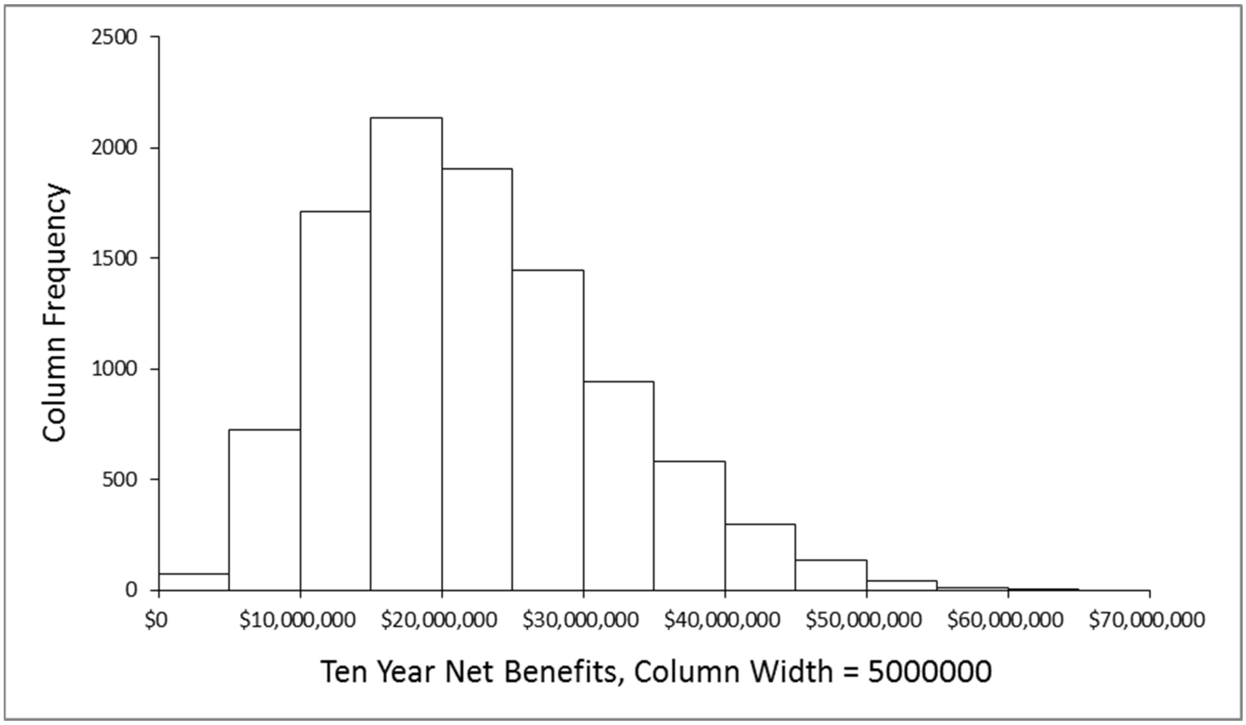

Figure A-14. Distribution of Ten-Year Net Benefits of the PAS System

Table A-23. Statistics of the Net Benefits Distribution

Mean	$22,107,844
St. Dev.	$9,549,383
5th Percentile	$8,494,934
25th Percentile	$14,992,526
Median	$20,893,771
75th Percentile	$28,002,456
95th Percentile	$39,675,882

8. Assumptions and Limitations

Since the PAS system has not been formally deployed by CBP, many assumptions have to be adopted in this study to evaluate the net benefits of potential deployments of this technology. First of all, we assume that the PAS system will be utilized as a supplemental technology to the TARS radar detection systems that are currently operated by CBP. We further assume that the deployment of the PAS system will take place in the Rio Grande City location, where the most active detection and seizure activities by TARS are recorded. The base case estimates are largely based on the field test performance data provided by the PI of the PAS system and our collection of data on the average quantity of drugs intercepted per seizure event by TARS in the past a few years and the market values of these narcotics. The uncertainty analysis indicates that the estimates of the 10-year net benefits are most sensitive to the assumption on the additional number of seizures that can be achieved by the PAS system. The sensitivity analysis indicates that the PAS system has the potential to provide substantial net benefits over a 10-year period.

9. Recommendations for Collecting Additional Information and Analysis

Since the PAS system has not been deployed by CBP, our analysis is primarily based on the performance data collected during the field testing period of the system, and various assumptions in terms of the potential location of the deployment and possible incremental seizures and interceptions of narcotics that can result if the PAS system is used as a supplemental detection system to the current TARS radar system operated by CBP. We note that system performance is environment- and application-specific. To improve the accuracy of the evaluation, data can be collected after the actual deployment of the PAS system or similar systems, and its performance compared with the baseline technologies. Additional areas of future research also include the evaluation of false alarm rates between the passive acoustic technology and the radar technology. Generally speaking, while radar cannot tell the difference between two objects with similar radar cross-section (RCS), the former tends to have a relatively lower false alarm rate since the acoustics focus on the frequency content of the sound source. Such a comparison should be conducted based on the clear specifications of the application environment and the definition of the performance requirements. Moreover, in addition to the market values of the intercepted illegal drugs, health benefits associated with the reduced use of these drugs can also be evaluated in future studies.

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Benefit-Cost Analysis of the Trafficking Risk Modeling Tool

Developer: Giant Oak Inc. through the Center for Border Security and Immigration
Analysts: Dan Wei and Detlof von Winterfeldt, CREATE

1. Summary

Description. Giant Oak Inc., through funding support from the National Center for Border Security and Immigration, developed a Bayesian model to predict the likelihood of an individual being trafficked based on specific information such as age, gender, race, country of origin, etc., that is available when the individual enters the U.S. at border crossings. The tool was developed based on two major databases of trafficking victims, the Human Trafficking Reporting System and the Trafficking Information Management System, which contain more than 2,200 individual trafficking cases. The objective of this predictive model is to identify more potential trafficking victims with a given number of screens. Currently, the tool has not been deployed by CBP or any other government agencies. Therefore, its performance in real-world applications still needs to be determined.

Results. The total development cost of the Trafficking Risk Modeling tool is $139,050 in 2017 dollars. Since the tool has not been deployed, there are no transition development or implementation costs. In addition, we assume that there will be costs for using the tool on an annual basis if it is deployed in the future, which is assumed at $100,000 in the base case analysis. Both of these costs are counted in the analysis of the net benefits of the tool.

The benefits of using the Trafficking Risk Modeling tool include the values of saving additional trafficking victims and convicting additional traffickers above the baseline levels. In the base case, we estimate that the discounted net benefits from using the tool for 10 years is $7.2 million.

There is considerable uncertainty in terms of the baseline number of trafficking victims identified by CBP at border crossings, the percentage of additional victims who can be identified above the current baseline levels if the Trafficking Risk Modeling tool is deployed, as well as the values of saving one trafficking victim and convicting one trafficker. We conducted sensitivity analyses on these and other key variables and found that the net benefit could range from \$3.0 million (5th percentile) to \$18.0 million (95th percentile), with a median of \$8.3 million.

2. Background

Problem Context. "Human trafficking is modern-day slavery and involves the use of force, fraud, or coercion to obtain some type of labor or commercial sex act. Every year, millions of men, women, and children are trafficked in countries around the world, including the United States" (DHS, 2019). Human trafficking has become the second-most profitable form of transnational crime, only after drug trafficking.

According to the estimates by U.S. Department of State, around 14,500 to 17,500 foreign nationals were trafficked into the U.S. each year (DOS, 2004). Assuming the lower-bound conservative estimate, this means fewer than 40 trafficked victims enter the U.S. each day. A study conducted by Northeastern University and the Urban Institute on Labor Trafficking in the U.S. found that a large proportion of trafficking victims entered the U.S. through ports of entry (POEs) with valid visas, likely without realizing that they would become victimized. Only less than one-third of the victims entered the U.S. without authorization (Owens et al., 2014). Therefore, there is a potential that, through better filtering of individuals at border crossings, U.S officials can identify more victims at border checkpoints. On a typical day in FY 2018, however, CBP processed 1,133,914 passengers and pedestrians at POEs (CBP, 2019). Consequently, it is very challenging to identify the less than 40 trafficked victims among the over one million regular visitors crossing the border.

Trafficking Risk Modeling Tool. Currently, detecting human trafficking victims at the border depends on the human judgment of law enforcement officials. While those officials, through training and practice, may have become experienced in assessing the risk level and spotting the victims, it is still a highly challenging task, and it is reasonable to believe that a risk factor model based on existing data about the characteristics of foreign-national trafficking victims can be used to improve the judgment of the law enforcement officials (Shiffman & Borowitz, 2015).

Based on two existing data sources, the Human Trafficking Reporting System, with 487 human trafficking cases, and the Trafficking Information Management System, with 1,789 cases, the Giant Oak Inc., through funding support from the National Center for Border Security and Immigration, developed a Bayesian model to predict the likelihood of an individual being trafficked based on specific information such as age, gender, race, country of origin, etc., of the individual. This risk scoring tool can be supplemented by more in-depth questionnaires or interviews to further evaluate non-intuitive cases (Shiffman & Borowitz, 2015). The objective of this predictive model is to identify more potential trafficking victims with a given number of screens.

3. Baseline

In the U.S., there are several federal government agencies that carry out investigations on federal trafficking offenses. These include the Department of Justice (DOJ), Department of Homeland Security (DHS), and Department of State (DOS). In FY 2017, DHS initiated 833 investigation cases, DOJ initiated 782 cases, and DOS initiated 169 cases. DOJ is the federal agency that prosecutes all the federal human trafficking cases (DOJ OVC, 2018). As for the 833 investigations initiated by DHS, 518 human trafficking victims were identified and assisted. These investigations also resulted in 1,602 criminal arrests and 578 convictions at federal, state, and local levels. In addition, from 2016 to 2017, 34 percent of trafficking victims served by the DOJ OVC program were foreign nationals (DOJ, 2018). Therefore, if we apply this percentage to the DHS-related number of identified trafficking victims and the number of trafficker convictions, we can estimate that 176 victims of foreign nationals were identified and 197 traffickers were convicted resulting from DHS-initiated investigations.

Currently at various ports of entry, foreign nationals who are being, or have a high risk of being, trafficked are screened and identified primarily based on the human judgement of CBP officers, ICE agents, and Border Patrol agents. It is unclear the proportion of the aforementioned trafficking victims identified and traffickers convicted through DHS investigations that can be directly linked to CBP inspection and screens at the POEs. With a conservative assumption of 10 percent that can be attributed to CBP, this translates to 18 foreign national trafficking victims identified and 20 traffickers convicted in the baseline in each year.

4. Cost Analysis

Table A-24 presents the cost of the Trafficking Risk Modeling tool. There are only the model development costs ($115,000) and OUP oversight costs ($20,000), since the model has not been transitioned and deployed by CBP or other government agencies. The total costs amounted to $139,050 in 2017 dollars. There can also be an annual cost associated with using the tool to identify individuals entering the border at high risk for trafficking. Due to the lack of information, we assume the Trafficking Risk Modeling tool incurs a using cost of $100,000 per year. These costs are counted in the net benefit calculations.

Table A-24. Costs for Development of the Trafficking Risk Modeling Tool

Cost Category	Start Year	End Year	Amount ($)	Source of Funding	2017 Dollars
Pre-project costs (COE)					
Pre-project costs (other funding)					
Project costs (COE)	2014	2015	$115,000	DHS S&T	$118,450
Project costs (university cost share)					
Oversight cost at the COE					
Oversight cost at OUP	2014	2015	$20,000	OUP	$20,600
Transition development cost					
Implementation startup cost					
Implementation cost (User)					
Implementation cost (COE)					
Implementation cost (Other users)					
TOTAL COST			**$135,000**		**$139,050**

5. Benefit Analysis

Table A-25 presents the numbers of the input variables for the base case benefit calculations. Based on the statistics of the number of trafficking victims identified and traffickers convicted resulting from DHS investigations, and the assumption that 10 percent of these can be attributed to CBP inspections and screens at border crossings, 18 trafficking victims can be identified and 20 traffickers will be convicted in each year. In the base case, we assume that the use of the Trafficking Risk Modeling tool can help identify six more trafficking victims and result in seven more traffickers convicted, each representing about a one-third increase from the baseline level.

Other important assumptions adopted in the benefit calculation include the value of saving a trafficking victim at $100,000, representing the avoidance of one-year loss of life from other causes.[20] The value of convicting one human trafficker is assumed to be $50,000 (the estimate is relatively low because the value of saving the victims has been considered separately).

Based on the above assumptions, the annual benefits of using the Trafficking Risk Modeling tool is estimated at $932,892.

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[20] Martin and Lotspeich (2014) conducted a comprehensive study on the government budgetary benefits of early intervention to prevent domestic sex trafficking, which were estimated at the range of $20,000 to $100,000 per victim. However, several potential harms associated with sex trafficking, including, for example, pain and suffering from assaults, risk of homicide, diminished life-time earnings, physical and mental health problems, and increased need for public program supports, are not included in the evaluation.

Table A-25. Base Case Analysis of the Benefits of the Trafficking Risk Modeling Tool

Variable	Base Case
Cost of using the Trafficking Risk Modeling tool	$100,000
Total human trafficking victims identified by DHS each year	518
Percent identified trafficking victims that are foreign nationals	34%
Number of identified victims that are foreign nationals	176
% DHS identifications can be linked to CBP inspections and screens at POEs	10%
Victims identified through CBP inspections and screens at POEs w/o Risk Modeling tool	18
Additional victims identified and traffickers convicted w/ Risk Modeling tool (% above baseline level)	34%
Additional victims identified w/ Risk Modeling tool	6
Total number of convictions resulting from DHS initiated cases each year	578
Number of convictions relating to foreign nationals	197
Number of convictions attributed to CBP inspections and screens at POEs w/o Risk Modeling tool	20
Additional convictions w/ Risk Modeling tool	7
Value of saving one victim	$100,000
Value of convicting one trafficker	$50,000
Discount Rate	3%
10-Year discounted cost of using Risk Modeling tool	$875,253
Annual benefits of the Trafficking Risk Modeling tool	$932,892
10-Year discounted benefits	$8,165,164
10-Year net benefits (in 2017 dollars)	$7,150,861

6. Benefit-Cost Analysis – Base Case

The estimated 10-year discounted benefits of the Trafficking Risk Modeling tool are about $8.2 million. After subtracting the development costs of the tool and the using costs over the 10-year period, the discounted net benefits are estimated to be $7.15 million in the base case analysis. Given the $139,050 development investment costs of the Risk Modeling tool, the benefit-to-cost ratio is 58.7 and the return on investment (ROI) is 5,772.1 percent.

7. Sensitivity and Uncertainty Analysis

Break-even Analysis. One way to evaluate the cost-effectiveness of the Trafficking Risk Modeling tool is to determine the numbers of trafficking victims who need to be saved and traffickers who must be convicted in each year above the baseline levels over a 10-year period to make it worthwhile.

Again, based on the assumptions elaborated in Section 3, 18 foreign national trafficking victims are identified and 20 traffickers are convicted each year in the baseline that can be attributed to CBP inspections and screens at the border crossings. Given the assumed value of $100,000 for each identified trafficking victim and $50,000 for each convicted trafficker, to break even the Trafficking Risk Modeling tool would have to help save at least 7.44 victims from trafficking and convict 8.3 traffickers over 10 years, which represents 3.9 percent above the baseline level.

Sensitivity Analysis. The estimated net benefits of the Trafficking Risk Modeling tool are sensitive to some of the assumed parameters. There are nine parameters with uncertainty in the net benefits calculation. Table A-26 presents the range for each of the nine parameters we adopted in the sensitivity analysis. The first parameter is the cost of using the tool. Four parameters relate to the baseline numbers of CBP identifications of trafficking victims at the border crossings and the resulted convictions of traffickers: (1) total human trafficking victims identified by DHS each year, (2) total number of convictions resulted from DHS-initiated cases each year, (3) percentage of DHS-identified trafficking victims that are foreign nationals, and (4) percentage of DHS identifications linked to CBP inspections and screens at POEs. The next key assumption is the number of additional victims identified and traffickers convicted from the use of the Risk Modeling tool, as a percentage, with respect to the baseline level. The two parameters on the values of saving one victim and convicting one trafficker are also with uncertainty. The final parameter we included in the sensitivity analysis is the discount rate.

Table A-26. Ranges for the Trafficking Risk Modeling Tool

Input Variables	Low	Base	High
Cost of using the Trafficking Risk Modeling tool	$50,000	$100,000	$200,000
Total human trafficking victims identified by DHS each year	414	518	622
Percentage of identified trafficking victims that are foreign nationals	30%	34%	40%
Percentage of DHS identifications linked to CBP inspections and screens at POEs	5%	10%	20%
Additional victims identified and traffickers convicted w/ Risk Modeling tool (% above baseline level)	10%	34%	50%
Total number of convictions resulting from DHS-initiated cases each year	462	578	694
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 A-15 presents a tornado diagram, which shows how changes in the underlying input parameters presented in Table A-26 affect the net benefit estimate of the Trafficking Risk Modeling tool. In the tornado diagram, the length of the bar for each input variable represents the range of the 10-year net benefits calculated by using the low and high values of this variable while holding the other variables at their base values. The most important parameters are those with the longest bars in the diagram. The sensitivity analysis indicates that the most important variables are the percentage of DHS identifications of trafficking victims that can be linked to CBP inspections and screens at POEs, as well as the percentage of additional victims who can be identified from using the Trafficking Risk Modeling tool. Other important variables include the values of saving one victim and convicting one trafficker.

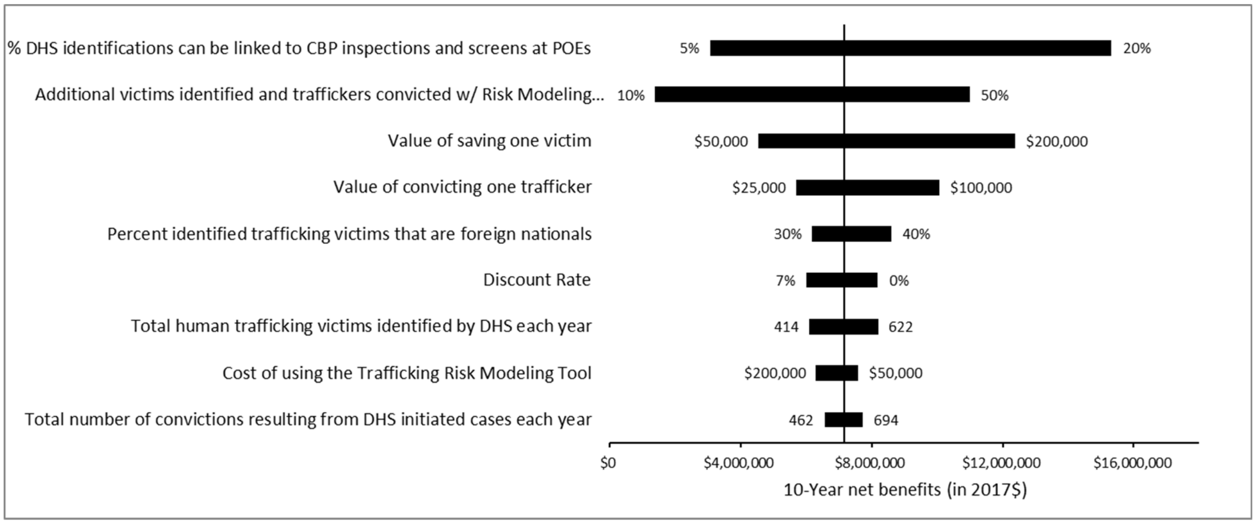

Figure A-15. Tornado Diagram for 10-Year Net Benefits of the Trafficking Risk Modeling Tool

Uncertainty Analysis. To explore the uncertainty associated with the estimates of the 10-year net benefits of the tool, we conducted a Monte Carlo simulation. We assume triangular probability distributions for all variables listed in Table A-26, using the low and high values as the minimum and the maximum of the distribution, respectively, and the base case value as the mode. Next, 10,000 simulations were run to obtain the distribution of the 10-year net benefits as presented in Figure A-16. The 5th, 50th, and 95th percentiles, as well as the mean and median of the distribution, are presented in Table A-27

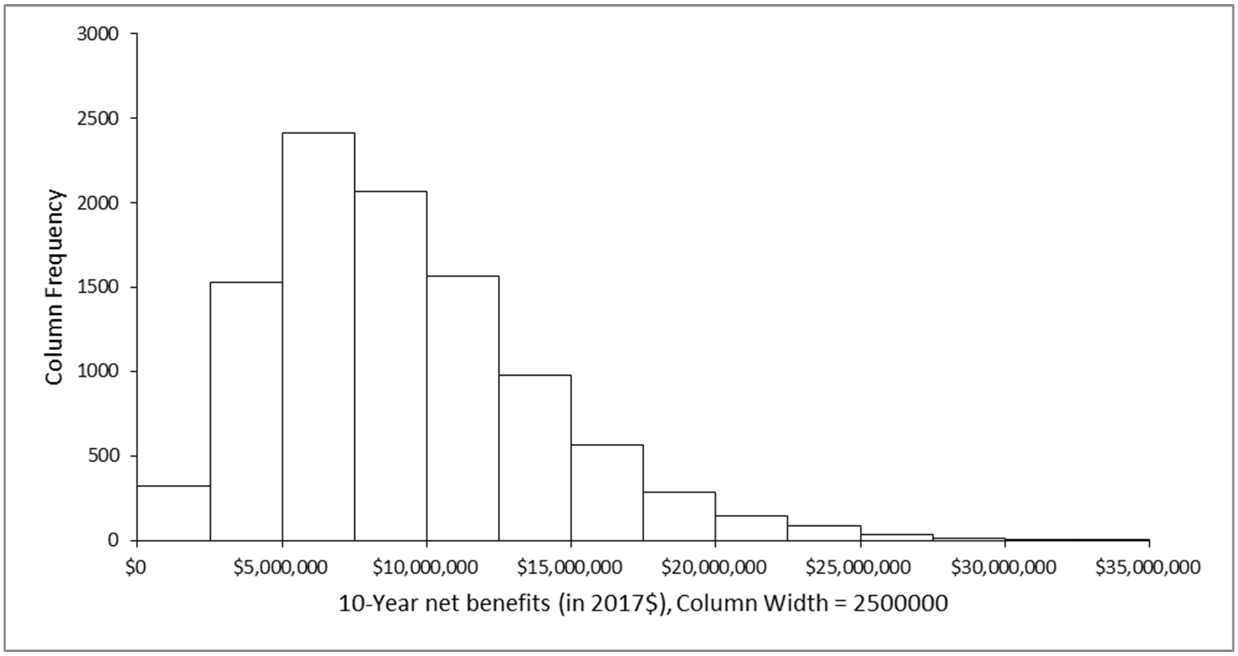

Figure A-16. Distribution of 10-Year Net Benefits of the Trafficking Risk Modeling Tool

Table A-27. Statistics of the Net Benefits Distribution

Mean	$9,144,988
St. Dev.	$4,684,355
5th Percentile	$2,993,538
25th Percentile	$5,703,741
Median	$8,300,061
75th Percentile	$11,808,316
95th Percentile	$17,970,519

8. Assumptions and Limitations

Since the Trafficking Risk Modeling tool has not been deployed by CBP or any other government agencies, many assumptions have to be adopted in this study to evaluate the net benefits of the potential applications of this tool. In addition, we estimated the baseline number of foreign-national trafficking victims that are currently identified on an annual basis when they enter the U.S. through the POEs based on very limited data. We then made assumptions in terms of the percentage of additional victims that can be identified above the current baseline levels if the Risk Modeling tool is deployed. The other major assumptions include the values of saving one trafficking victim and convicting one trafficker.

We used a wide range of assumed values for the above key variables, leading to a wide range of distribution of the net benefit estimates in the uncertainty analysis. Note that the combination of these variables at the low end (low baseline number of victims identified, low number of incremental victims who can be identified from using the Risk Modeling Tool, low values of saving one victim, and high cost of using the tool) can actually result in a negative net benefit.

9. Recommendations for Collecting Additional Information and Analysis

To improve this analysis, it would be most important to collect data on the performance of border law enforcement officials in identifying trafficking victims, with and without using the Trafficking Risk Modeling tool. Specifically, a side-by-side experiment can be carried out to evaluate to what extent the tool can help CBP officers identify additional foreign-nationals that are trafficking victims.

It would also be useful to conduct research on the value of saving an individual from becoming a sex or labor trafficking victim. In this study, we used a wide range, from $50,000 to $200,000, primarily based on the value of one life-year saved. These values may be at the low end, without including the values of avoided harms associated with pain and suffering resulting from being a trafficking victim and any potential long-term physical and mental health problems.

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Benefit-Cost Analysis of the Remote Power Module (RPM)

Developer: Arctic Domain Awareness Center (ADAC)
Principal Investigator: Hank Statscewich, Univ. of Alaska, Fairbanks
Analyst: Richard S. John (USC, CREATE)

1. Summary

Description. The Remote Power Module (RPM) is a fully automated, renewable hybrid power station that uses wind, solar, and diesel power. The RPM is equipped with a comprehensive power monitoring system that helps protect against spurious failures, optimize its three power sources, and allows for remote control and access to its operation. This TTKP allows high frequency radar (HFR) to be deployed in areas off the main power grid. These HFRs collect important information about ocean circulation, wave height, U.S. Coast Guard search and rescue conditions, vessel tracking, contaminant spills, marine navigation, and the marine ecosystem/fisheries. The capability to collect this information in remote areas may be increasingly beneficial moving forward, especially in light of the fact that this technology can be deployed rapidly.

Results. The total estimated funding for the RPM was $1.7 million (in 2017 dollars) and includes all OUP funding from 2008 to 2014. The primary benefit of the RPM is the cost savings as compared to the initial cost, delivery, maintenance, fuel, and fuel delivery for a conventional diesel power source. Benefits, defined as RPM cost savings, are largely dependent on the number of past and projected RPM deployments through 2027; the base case analysis indicates a benefit of $6.4 million (in 2017 dollars). The total net benefit was estimated to be $4.6 million (in 2017 dollars), resulting in a 269 percent return on investment (ROI) and a benefit-cost ratio of 3.69. A sensitivity analysis indicated a great deal of uncertainty in net benefits, with a median of $5.5 million and a range from $1.9 million (5th percentile) to $15.1 million (95th percentile).

2. Background

The RPM was developed to allow for reliable and cost-effective remote installations of HFR in locations not on the power grid, thus expanding the coverage of HFR data collection. Over 350 global coastal HFR platforms provide real-time information on ocean current speed and direction data over a wide area, ocean wave heights, vessel identification and tracking, wind speed and direction data, inputs to drift prediction models, and targeting of local assets (skimmers and boom deployments). The RPM also allows the potential for rapid deployment of HFR to remote locations in response to search and rescue emergencies and contamination spills (Statscewich, 2018; Statscewich et al., 2011; Statscewich et al., 2014; Eicken et al., 2018). A picture of a deployed RPM is displayed in Figure A-17.

Figure A-17. Remote Power Module (RPM) Picture.

The RPM is summarized in more detail by Statscewich et al. (2011):

> "The RPM is a fully automated, hybrid (solar, wind, and diesel) power station designed for Arctic and sub-Arctic maritime environments. It is a remotely deployable platform with a compact footprint congruent with permitting requirements in many coastal areas. A rugged, durable, and climate-controlled shelter houses HFR electronics, communications equipment, and electrical system components of the power plant….
>
> The guiding principles behind our RPM design are that it be portable, flexible, and capable of providing sufficient and redundant power needed for the HFR, communications, and system self-monitoring components.
>
> Portability requires that the system be deployable at remote sites without expensive logistic support. In particular, we required that no component be heavier (or bulkier) than two people could carry…. We employ system components that are <200 lbs. and sized for accommodation in skiffs, trailer-equipped four-wheelers, or snow machines with a cargo sled….
>
> The system is designed to reduce operating costs by generating power from renewable energy. Reliance upon fossil fuel generators as the primary power source is costly due to frequent maintenance requirements, limited life expectancies, and logistics and fuel costs" (pp 60-61).

3. Baseline

Prior to RPM development, HFR was typically deployed to non-remote locations that were on the electrical grid. More wide-spread deployment of HFR required costly installation, maintenance, and fueling of a power source. In practice, such installations were rare, and typically operational for a very limited time period. The benefits of the RPM are conceptualized as the cost savings from using RPMs to power remote HFR systems as compared to the use of more conventional power sources—e.g., diesel generators—with limited life-spans that require monitoring, regular maintenance, and frequent fuel delivery. As these pre-RPM installations are not standard, the baseline for comparison is a conventional power system that would be plausible for remote deployment. Note that each remote HFR deployment, whether powered by RPM or conventional means, could be "optimized on a site-specific basis that takes into account regulatory constraints and the availability of renewable energy" (Statscewich et al., 2011, p. 61). Our analysis takes this flexibility into account via several model parameters which capture the cost differences between the RPM and a conventional power source.

4. Cost Analysis

RPM cost estimates were provided by the ADAC COE for a 6-year period of funding, from July 2008 through June 2014. Table A-28 provides a summary of the RPM development costs supported by OUP. In addition to the project costs ($1.2 million), we included 20 percent for oversight costs at ADAC and $20,000 per year for oversight costs at OUP. The total costs to develop and test the RPM were calculated at $1.7 million (in 2017 dollars).

Table A-28. RPM Cost Estimate; COE and OUP Funding Only (July 2008-June 2014)

Cost Category	Start	End	Amount	Source	2017 Dollars
Pre-project costs (COE)					
Pre-project costs (other funding)					
Project costs (COE)	July, 2008	June, 2014	$ 1,219,700	ADAC	$ 1,325,049
Project costs (university cost share)					
Oversight cost at the COE	July, 2008	June, 2014	$ 243,940	ADAC	$ 266,098
Oversight cost at OUP	July, 2008	June, 2014	$ 120,000	OUP	$ 130,900
Transition development cost					
Implementation start up cost					
Implemementation cost (User)					
Implementation cost (COE)					
Implementation cost (Other users)					
TOTAL COST			**$ 1,583,640**		**$ 1,722,047**

5. Benefit Analysis

As indicated in Section 3, the primary benefit of the RPM is derived from the reduced costs for HFR deployed in remote locations. Cost savings from reduced installation, maintenance, and fuel costs are calculated annually for each remote RPM installation. Annual cost savings (ACS) for each RPM installation depends on the annual installation and maintenance savings (IMS) per site, the quantity of fuel required for a conventional (diesel) generator (QF), and the annual cost of each gallon of fuel delivered (CGF). The annual cost savings for each RPM is calculated as follows:

$$ACS = IMS + QF*CGF$$

Base case values for all three parameters are provided in Table A-29. As indicated in Section 3, these base case estimates are for a generic baseline conventional power alternative. Each installed RPM system is assumed to run from installation through 2027, and cost savings are calculated annually for each installation. The base case analysis includes five initial RPM installations in 2010 and 2011 (10 total) and two additional installations per year between 2012 and 2017; it also projects two future installations per year for the next 10 years (2018-2027). A 3 percent discount rate is assumed. Furthermore, a benefit adjustment factor is applied to the total benefits to reflect an expectation that more HFR systems will be deployed because of the RPM than would have otherwise been deployed in the absence of RPM development, relying on conventional (diesel) power sources. A base case value of .050 for the benefit adjustment factor is assumed, suggesting that only half of the HFR systems would have been deployed had there been no development of the RPM technology.

The analysis indicates an annual cost savings (benefit) of $16,000 per installed RPM. Based on two RPM installations per year for the past eight years (2010-2017), a benefit of $1.9 million (in 2017 dollars) has already been realized. Assuming two RPM installations per year over the next 10 years (2018-2027), the annual benefit accrued from all installed RPMs (included those installed prior to 2018) through 2027 totals $4.4 million (in 2017 dollars). The total benefits estimate for the entire period, 2010 through 2027, is estimated to be $6.4 million (in 2017 dollars).

Table A-29. RPM Base Case Benefit Analysis and Benefit-Cost Summary

Variable	Base Case
Annual Installation & Maintenance Savings per Site	$ 10,000
Price of fuel delivered for non-renewable generator (per gallon)	$ 10.00
Gallons of fuel required for non-renewable generator per year	2190
Avg Annual # of RPM Installations 2012 thru 2017	2
Avg Annual # of RPM Installations 2018-2027	2
Average Discount Rate 2018-2027	3.00%
Benefit Adjustment	50.00%
	Calculated
Annual Benefits per unit	$ 15,950
Past Benefits 2010-2017 (2017 $)	$ 1,937,287
Future Benefits 2018-2027 (2017 $)	$ 4,423,612
Total Benefits 2010-2027 (2017 $)	$ 6,360,899
Net Benefits (2017 Dollars)	$ 4,638,852
Return on Investment (ROI)	269%
Benefiit to Cost Ratio	3.69

6. Benefit-Cost Analysis – Base Case

The RPM base case benefit-cost analysis, which is summarized at the bottom of Table A-29, is calculated using OUP costs from 2008 through 2014 and the combined benefits (cost savings) of previous RPM installations over the past eight years (2010 through 2017) and projected RPM installations for the next 10 years (2018 through 2027). The RPM base case net benefits are estimated to be $4.6 million (in 2017 dollars). The RPM is estimated to have an ROI of 269 percent through 2027 and a benefit cost ratio of 3.69.

7. Sensitivity and Uncertainty Analysis

Break-even Analysis. A break-even analysis was conducted to determine the number of RPM installations required to realize a total cost savings benefit equal to the OUP investment. Using base case estimates for installation, maintenance, and fuel cost savings, cumulative benefits with continuous operation through 2027 would surpass the initial OUP investment with only seven installations over the 2010-2011 installation time frame. (Note: A total of 10 RPMs were actually installed over this two-year period.) With only five installations in 2010 and two more in 2011, total cumulative benefits through 2027 are estimated to be $1.86 million (in 2017 dollars), surpassing the OUP cost estimate of $1.72 million.

Sensitivity Analysis. A sensitivity analysis was conducted for net benefits, varying all seven input parameters to the model. Table A-30 summarizes the ranges for each of the seven input variables in the benefit calculation; the base case values are also included for reference. Note that the "High Output" column represents the value that produces the greatest net benefit, and the "Low Output" column represents the value that produces the lowest net benefit. The net benefit is greater for a higher benefit adjustment (where the parameter is closer to 100 percent), higher fuel costs, and a greater required quantity of fuel for a conventional power source, greater savings for the installation and maintenance of a RPM as compared to a conventional power source, a greater annual number of past and future RPM installations, and a lower future discount rate. The ranges selected are intentionally broad and are expected to span nearly all feasible values for these parameters.

Table A-30. Ranges for Seven Parameters in Net Benefit Calculation Sensitivity Analysis

Variable	Low	Base	High
Ann Install & Maint Savings	$ 0	$ 10,000	$ 20,000
Avg fuel and delivery cost per gal.	$ 5.00	$ 10.00	$ 20.00
Ann fuel req (gallons)	1000	2190	4000
Avg # RPM 2012 thru 2017	0	2	4
Avg # RPM after 2017	0	2	4
Avg Discount Rate	0.00%	3.00%	7.00%
Benefit Adjustment	25.00%	50.00%	100.00%

Results of the sensitivity analysis are presented in Figure A-18 as a tornado diagram. The vertical line represents the base case net benefit ($4.6 million) when all seven variables are fixed at their base case values (see Table A-30). The horizontal bars represent the range of RPM net benefits when the variable indicated on the left is varied from the low to high values specified. The variables are arranged from top to bottom in relation to their impact on RPM net benefits.

By far, the greatest impact is from the benefit adjustment factor, which considers the likelihood of greater deployment of HFR systems in remote locations with the RPM than would have been the case when using conventional power sources. Net benefits range from $1.5 million, if only 25 percent of HFR installations would have occurred without the RPM, to $11.0 million, if all of the HFR installations would have occurred even without the availability of the RPM. Net benefit swings are considerable, ranging from a high of $9.5 million (benefit discount factor) to a low of $1.7 million (future discount rate).

Note that the net benefit ranges are not symmetric around the base case net benefits whenever the variable ranges around the base case are asymmetric, i.e., benefit adjustment factor, annual quantity of fuel required, and cost of fuel (per gallon). This analysis demonstrates that even the most pessimistic assumption for any one of the seven input variables still results in a net benefit of greater than $1.5 million. Likewise, this analysis demonstrates that, given more optimistic estimates of the benefit adjustment factor or higher conventional fuel costs, RPM net benefits can approximately double those estimated in the base case.

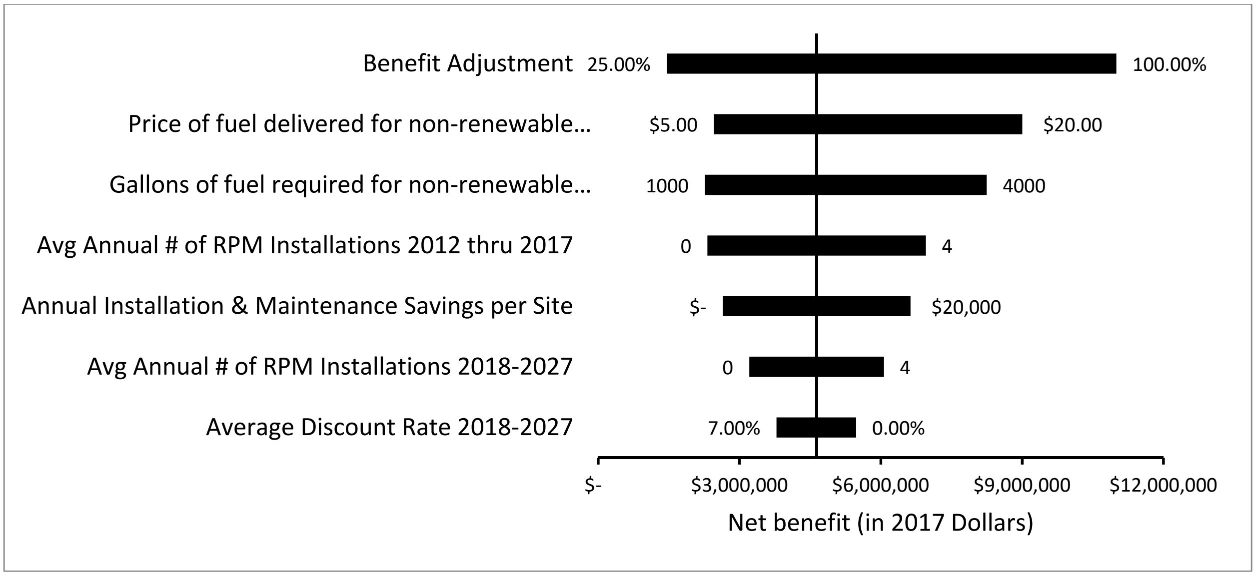

Figure A-18. Tornado Diagram Results of Sensitivity Analysis

Uncertainty Analysis. A Monte Carlo simulation was used to estimate a probability distribution over the net benefits of the RPM. For five of the seven input variables in the benefit calculation, a triangular distribution was constructed using the base case estimate as the mode, and the low and high values as defined in Table A-30.

The distributions for the annual mean number of RPM installations were modeled using an exponential distribution (lambda = 1/base case number of installations per year = ½); this distribution is right skewed with mean = 1/lambda = 2. [Note: The exponential distribution is here only to model the mean number of RPM installations per year; there is no attempt to model time between RPM installations.] In addition, variation in the year-to-year number of RPM installations was modeled using a Poisson distribution, with mean determined by the sampled exponential distribution for the overall annual mean. Note that the Poisson distribution produces an integer number of RPM installations per year, and that the number of installations each year is drawn independently. This modeling approach accounts for uncertainty in the overall annual mean number of RPM installations, as well as the year-to-year variability in the actual number of installed RPMs. Autocorrelation across years in the number of RPMs installed was assumed to be zero.

All input probability distributions are constructed to be independent and thus uncorrelated. A total of 5,000 trials were sampled using Latin hypercube sampling, which is more efficient than random sampling.

Summary statistics for the RPM uncertainty analysis are presented in Table A-31. The RPM mean net benefit ($6.9 million) is greater than the median ($5.5 million), indicating a positively skewed distribution. The RPM interquartile range (IQR) is $5.8 million ($3.2 million to $9.0 million). The RPM 90 percent credible interval is over $16 million ($1.1 million to $17.2 million).

Table A-31. Summary Statistics for RPM Net Benefit Uncertainty Analysis

Mean	$ 6,875,612
St. Dev.	$ 5,325,601
Mean St. Error	$ 75,315
5th %-tile	$ 1,131,027
First Quartile	$ 3,232,941
Median	$ 5,541,829
Third Quartile	$ 8,992,204
95th %-tile	$ 17,164,044
Skewness	1.8764

A histogram of RPM net benefits (in 2017 dollars) is presented in Figure A-19. The distribution is single-peaked and highly skewed, with a long right tail. A cumulative distribution of RPM net benefit (in 2017 dollars) is presented in Figure A-20. The cumulative distribution graphically displays all percentiles as cumulative probabilities, including those summarized in Table A-31. Figures A-19 and A-20 both convey graphically the large RPM net benefit uncertainty.

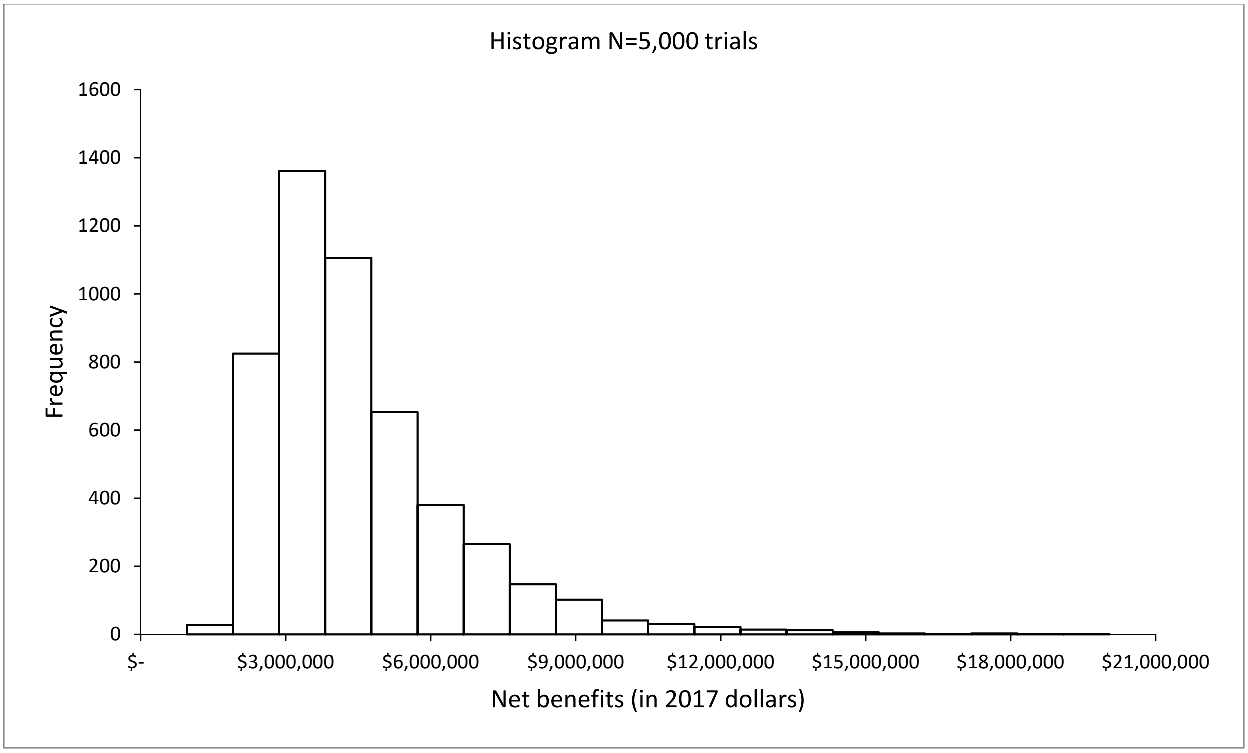

Figure A-19. Histogram of RPM Net Benefits (N=5,000 trials)

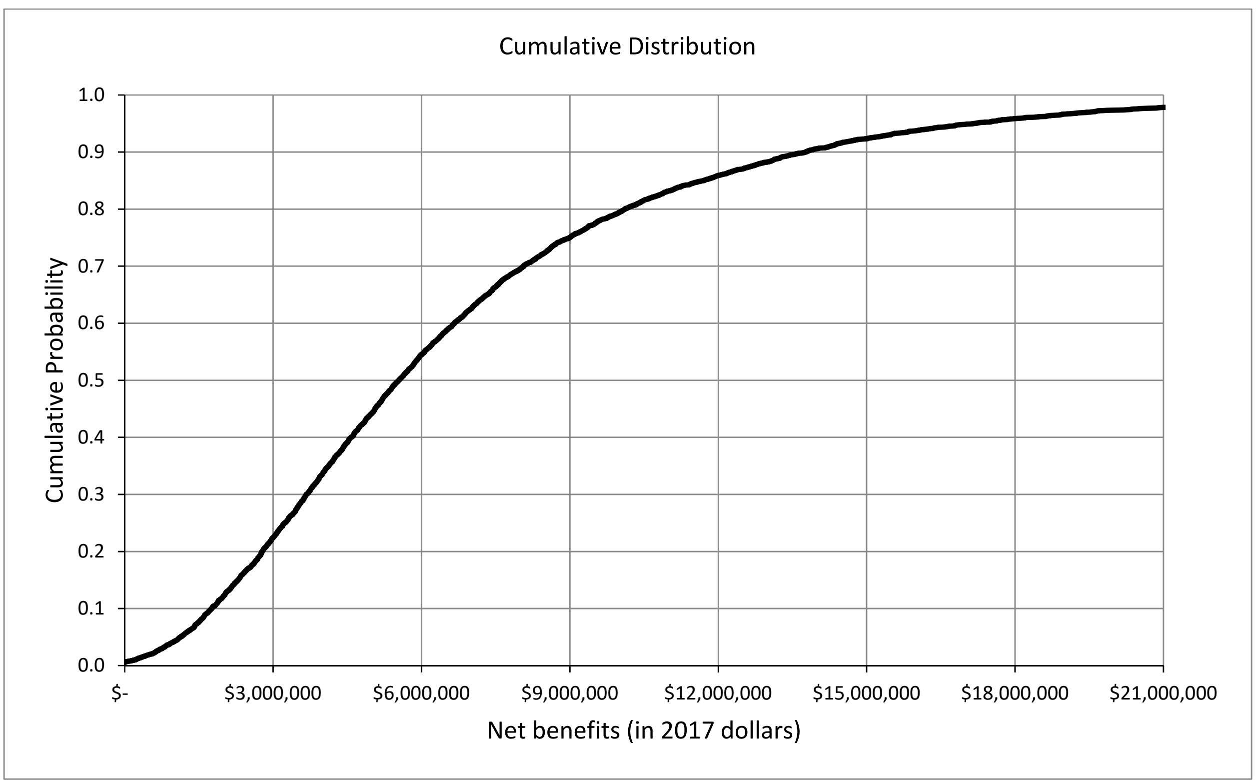

Figure A-20. Cumulative Distribution of RPM Net Benefits

8. Assumptions and Limitations

This analysis depends on a number of assumptions. First, costs are restricted to OUP investments through the ADAC COE. Second, benefits are conceptualized as annual cost savings, comparing the RPM to a generic conventional power source. This cost savings is restricted to differences in the installation, maintenance, and fuel costs between the RPM and a conventional power source. The generic conventional power source is assumed to require a new generator installation annually, with regular maintenance and frequent deliveries of fuel to remote, potentially harsh locations. The analysis does not include potential benefits from the increased reliability of the RPM and the greater flexibility and speed of deployment afforded by the RPM. The analysis also does not include benefits of the lessons learned from the RPM design that will enhance and improve future designs of next-generation remote power units. Base case estimates and ranges for the benefit adjustment factor and the number of future RPM installations are speculative and are included primarily to allow for sensitivity and uncertainty analyses spanning a range of possible values.

9. Recommendations for Collecting Additional Information and Analysis

The most useful information to sharpen this analysis is a more precise count of the number of RPM installations to date, including their years of operation, and an informed estimate of the number of future RPM installations. As the tornado diagram indicates, RPM net benefits depend heavily on the number of installations since there are cost savings for every year of deployment for every RPM installed. The greater number of installed-RPM years, the greater the net benefits; in addition, early installations that continue throughout the period have greater influence on net benefits.

A better estimate of the cost savings would be possible if more detailed information was collected regarding the exact costs of producing, installing, and maintaining each RPM. With this additional data, a more precise estimate of annualized costs for both the RPM and a conventional power source could be used to calculate net benefits, rather than focusing on specific additional costs for the conventional power source and assuming other costs are similar.

10. References

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Benefit-Cost Analysis of the Gang Graffiti Automatic Recognition and Interpretation Tool (GARI)

Developer: Center for Visualization and Data Analytics (CVADA)
Analyst: Richard S. John (CREATE)

1. Summary

Description. The Center for Visualization and Data Analytics (CVADA) developed a computerized support tool, the Gang Graffiti Automatic Recognition and Interpretation (GARI), for law enforcement officers and first responders to identify, monitor, and track gangs. Users simply take a photo of graffiti (or gang tattoos) on their phone or tablet, wirelessly upload the image to the comparison database, and receive expert-level intelligence in the field instantaneously. (There is also a community version of the app that works similarly, but only allows for the reporting of graffiti.) The resulting information identifies the specific gang(s) affiliated with the graffiti symbol(s) captured in the image and provides the user with the gang's geolocation and historical data.

This information can then be used to track gang movements, activity, affiliation, growth, and to create an easily accessible record of different graffiti markings and their significance (e.g. challenges, warnings, or intimidation/threats) for further analysis and reference. This helps law enforcement officers identify and target youth who are at risk of gang recruitment and prepare for potential outbreaks of gang violence, creating unique prevention opportunities.

Results. The total estimated funding for GARI, $372,000 (in 2017 dollars), includes all OUP funding from August 2010 through December 2016. The primary benefits of GARI are the worker cost-savings, as compared to manual database management, and the expert interpretation of gang-related images. The cost savings attributed to GARI are related to projected GARI deployments through 2027; the base case estimate of total benefits is $1.8 million (in 2017 dollars). The total net benefit was estimated to be $1.4 million (in 2017 dollars), resulting in a return on investment (ROI) of 378 percent and a benefit-cost ratio of 4.78. A sensitivity analysis indicated a great deal of uncertainty in GARI net benefits, with a median of $1.1 million and a range from $94,000 (5th percentile) to $5.5 million (95th percentile).

2. Background

The National Gang Threat Assessment estimated that, as of April 2011, there were 33,000 criminally active gangs in the U.S., comprised of approximately one million gang members. Gang activity has a major impact on many communities, accounting for up to 80 percent of crime. Gangs commonly use street graffiti to communicate challenges and warnings and to intimidate rival gangs. Law enforcement, however, has found street graffiti an efficient mechanism for tracking gang affiliations and growth, as well as membership information (Parra, Boutin, & Delp, 2012; Parra, Boutin, & Delp, 2017; Parra, Zhao, Kim, & Delp, 2013).

GARI is a system that can be used on a mobile device, utilizing location-based services combined with image analysis to automatically populate a database of graffiti images, including information that can be used by law enforcement to identify, track, and mitigate gang activity. The GARI system, described by Parra, Boutin, and Delp (2017), "includes the ability to acquire images in the field using the camera in the mobile telephone and a networked back-end database system that uses the metadata available at the time the image is acquired (geoposition, date, and time) along with some basic image analysis functions (e.g., color features.) … to extend the image analysis to include segmentation, matching, retrieval, and classification of gang graffiti images and gang graffiti components.…including the objects and shapes contained in a gang graffiti image, such as stars, pitchforks, crowns, and arrow. … The information in the database of gang graffiti can be queried to extract information based on parameters, such as date and time of capture, upload or modification of the graffiti image, or radius from a given location. The data include not only the images but the information related to it, such as date and time, geoposition, gang, gang member, colors, or symbols."

A schematic overview of the GARI system is displayed in Figure A-21.

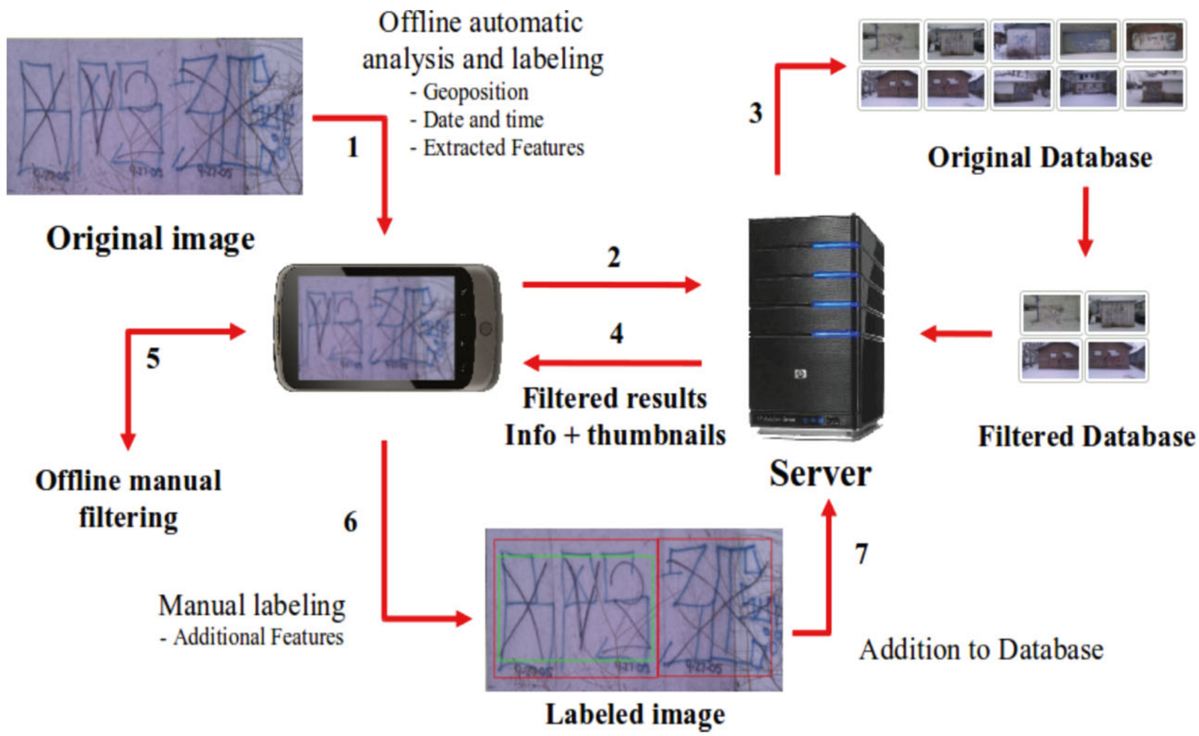

Figure A-21. Schematic Diagram of the GARI System

3. Baseline

Historically, law enforcement has collected street gang graffiti images and manually stored and retrieved them to track gang activity. This task is quite labor intensive, although use of standard image databases mitigates the time and effort required as compared to manual storage and retrieval of paper images. The primary benefit of GARI is the ability to store, retrieve, and interpret gang related images quickly and reliably, with reduced requirements for highly experienced law enforcement personnel. The benefits analysis is based on cost savings realized from utilizing the GARI system to perform tasks that ordinarily would require highly trained and experienced law enforcement personnel. We estimate the cost savings realized from a reduction in force (or diversion of the workforce to other high-priority activities) that would be required to approximately match the performance of GARI.

Currently, there are several other commercially available gang graffiti systems comparable in some ways to GARI. Parra, Boutin, and Delp (2017) compare GARI with seven other systems (Graffiti-ID, Graffiti Tracker, TAGRS, GRIP, GTS, GAT, and TAG) on nine relevant features. The most advanced unique feature of the GARI system is the ability to perform a component analysis of the images. While other systems use pattern matching to match entire images, GARI has the capability to recognize components of images and match different images that share those particular components. This unique GARI capability is not available with any of the seven other systems described by Parra et al. (2017). Given this powerful and exclusive GARI feature, it is not clear that any of the other seven systems can match the identification accuracy rate of GARI. We make an implicit assumption that with enough experience, training, and standard hardware and database software, law enforcement personnel could match the capabilities of GARI. This is the baseline we utilize for the benefits analysis.

4. Cost Analysis

GARI cost estimates were provided by the CVADA COE over a six-and-a-half year funding period from August 2010, through December 2016. Table A-32 provides a summary of the GARI development cost supported by OUP. In addition to the project costs ($225,000), we included 20 percent for oversight costs at CVADA and $20,000 per year (for four years only) for oversight costs at OUP. The estimated total cost to develop GARI equaled $372,000 (in 2017 dollars), as shown in Table A-32.

Table A-32. GARI Cost Estimate – COE and OUP Funding Only (August 2010 through December 2016)

Cost Category	Start	End	Amount	Source	2017 Dollars
Pre-project costs (COE)					
Pre-project costs (other funding)					
Project costs (COE)	Aug 2010	Dec 2016	$134,744	CVADA	$142,543
Project costs (university cost share)	Aug 2010	June 2014	$90,140	Purdue	$95,881
Oversight cost at the COE	Aug 2010	June 2014	$44,977	CVADA	$47,685
Oversight cost at OUP	Aug 2010	June 2014	$80,000	OUP	$85,760
Transition development cost					
Implementation start-up cost					
Implementation cost (User)					
Implementation cost (COE)					
Implementation cost (Other users)					
TOTAL COST			**$349,861**		**$371,869**

5. Benefit Analysis

Benefits are defined as the cost savings achieved from reducing the number of law enforcement personnel required to manually perform the tasks performed by GARI. These cost savings depend heavily on the number and length of GARI implementations. This analysis includes three previous implementations of GARI, summarized in Table A-33. Cost savings include one full-time equivalent (FTE) in Cook County, Ill., and half an FTE in the other two locations, Indiana and Stockton, California. These estimates are based on the number of users and the average number of images acquired over the period of use. In all three cases, the implementation is for a fixed period of time over which the annual cost savings are calculated.

Table A-33. Summary of Previous GARI Implementations

•State of Indiana
–2011 thru 2016
–3682 images; 227 users (~ 14 images/wk)
•Cook County (Chicago)
–2013 thru 2016
–6332 images; 114 users (~ 32 images/wk)
•Stockton, Ca.
–2015 thru 2016
–568 images; 17 users (~ 11 images/wk)

Annual total cost savings (ACS) is calculated based on the total number of FTE reductions (FTER = 0.75 per installation in the base case) attributable to GARI installations in place during the year and the annual cost of an FTE (FTEC = $100,000 in the base case):

$$ACS = FTER * FTEC$$

The discounted ACS are computed for previous years (for the three installations summarized above) as well as for projected future installations over the next 10 years (2018-2027). The base case assumed one new GARI installation per year over the next 10 years. All future installations are assumed to continue to the end of the 10-year time interval in 2027. A benefit adjustment factor is applied to the total benefits to reflect an expectation that additional gang graffiti analysis and interpretation will be conducted because of the GARI technology than would have otherwise been deployed in the absence of GARI, which would have required relying on scarce personnel resources. A base case value for the benefit adjustment factor of 0.50 is assumed, suggesting that only half of the enhanced gang graffiti intelligence efforts would have been launched had there been no development of the GARI technology.

Table A-34 summarizes the base case estimates of the five input parameters described above for calculating GARI benefit, including those from previous implementations that have ended and future projected deployments. Past benefits from the three previous installations total $415,000 (in 2017 dollars), and future projected benefits (over 10 years) total $1.4 million (in 2017 dollars), based on base case assumptions for all variables. The total base case benefit estimate is $1.8 million, including all three previous installations and projected installations through 2027.

Table A-34. GARI Base Case Benefit Analysis and Benefit-Cost Summary

Variable	**Base Case**
Avg # FTEs replaced by one GARI Deployment	0.75
Avg FTE salary w/Fringe	$ 100,000
Avg Annual # GARI Deployments per year 2019 -2027	1
Average Discount Rate 2018 -2027	3.00%
Benefit Adjustment	50.00%
	Calculated
Past Benefits 2010 -2017 (2017 $)	$ 415,000
Future Benefits 2018 -2027 (2019 $)	$ 1,361,580
Total Benefits 2010-2027 (2017 $)	$ 1,776,580
Net Benefits (2017 Dollars)	$ 1,404,711
Return on Investment (ROI)	378%
Benefit to Cost Ratio	4.78

6. Benefit-Cost Analysis – Base Case

The GARI base case benefit-cost analysis is summarized at the bottom of Table A-34 for OUP costs from 2010 through 2016 and benefits (cost savings) of three previous GARI installations and those projected for the next 10 years (2018 through 2027). The GARI base case net benefits are estimated to be $1.4 million (in 2017 dollars). GARI is estimated to have an ROI of 378 percent through 2027 and a benefit-cost ratio of 4.78.

7. Sensitivity and Uncertainty Analysis

Break-even Analysis. A break-even analysis was conducted to determine the number of GARI installations required to realize a total cost savings benefit equal to the OUP investment. Using base case estimates for annual cost savings, a cumulative benefit within the previous operation time frame would surpass the initial OUP investment with only the first two of the three previous GARI installations. Assuming base case estimates and only the first two previous GARI installations, total cumulative benefits through 2027 are estimated to be $418,000 (in 2017 dollars), surpassing the OUP cost estimate of $372,000.

Sensitivity Analysis. A sensitivity analysis was conducted for net benefits, varying five input parameters in the model. Table A-35 summarizes the ranges for each of the five input variables in the benefit calculation; the base case values are also included for reference. Note that the "High Output" column represents the value that produces the greatest net benefit, and the "Low Output" column represents the value that produces the lowest net benefit. Net benefits are greater for higher benefit adjustment (where the parameter is closer to 100 percent), higher law enforcement personnel costs, greater annual number of future GARI installations, and a lower future discount rate. The ranges selected are intentionally broad and are expected to span nearly all feasible values for these parameters.

Table A-35. Ranges for Five Parameters in Net Benefit Calculation Sensitivity Analysis

Variable	Low	Base Case	High
Avg # FTEs repl. by 1 GARI Deploy.	0.50	0.75	1.00
Avg FTE salary w/Fringe	$ 80,000	$ 100,000	$ 120,000
Avg # GARI Deploy per yr 2019-2027	0	1	3
Avg Discount Rate 2018-2027	0.00%	3.00%	7.00%
Benefit Adjustment	25.00%	50.00%	100.00%

Results of the sensitivity analysis are presented in Figure A-22 as a tornado diagram. The vertical line represents the base case net benefit ($1.4 million) when all five variables are fixed at their base case values (see Table A-35). The horizontal bars represent the range of GARI net benefits when the variable indicated on the left is varied from the low to maximum values specified. The variables are arranged from top to bottom in relation to their impact on GARI net benefits.

By far, the greatest impact is from the average annual number of future GARI installations over the next 10 years. Net benefits range from $343,000, if there are no future GARI installations, to $4.1 million, assuming an average of three new GARI installations per year. Net benefits for GARI range from $516,000, if only 25 percent of the street gang graffiti intelligence efforts would have occurred without GARI, to $3.2 million, if all of the gang graffiti tracking efforts would have occurred even without the availability of GARI. Net benefit swings are considerable, ranging from a high of $4.1 million (the average annual number of future GARI installations) to a low of $648,000 (the future discount rate).

Note that the net benefit ranges are not symmetric around the base-case net benefits whenever the variable ranges around the base-case are asymmetric, i.e., annual average number of future GARI installations, benefit adjustment factor. This analysis demonstrates that even the most pessimistic assumption for any one of the five input variables still results in a net benefit greater than $300,000. Likewise, this analysis demonstrates that net benefits which are approximately double those estimated in the base case are feasible given the more optimistic estimates of the average annual number of future GARI installations or the benefit adjustment factor.

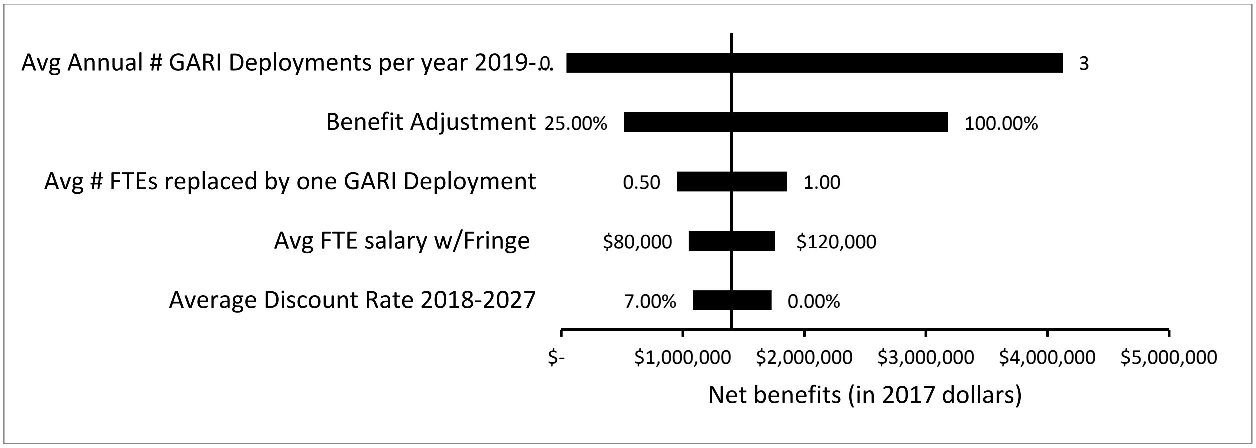

Figure A-22. Tornado Diagram Results of Sensitivity Analysis

Uncertainty Analysis. A Monte Carlo simulation was used to estimate a probability distribution over GARI net benefits. For four of the five input variables in the benefit calculation, a triangular distribution was constructed, using the base case estimate as the mode and the minimum and maximum values as defined in Table A-35.

The distribution for the annual mean number of future GARI installations was modeled using an exponential distribution (lambda = 1/base case number of installations per year = 1); this distribution is right skewed with mean = 1/lambda = 1. [Note: The exponential distribution is here only to model the mean number of future GARI installations per year; there is no attempt to model time between GARI installations.] In addition, variation in the year-to-year number of future GARI installations was modeled using a Poisson distribution, with the mean determined by the sampled exponential distribution for the overall annual mean. Note that the Poisson distribution produces an integer number of GARI installations each year, and that the number of installations each year is drawn independently. This modeling approach accounts for uncertainty in the overall annual mean number of future GARI installations, as well as in the year-to-year variability in the actual number of GARI systems installed in the next ten years. Autocorrelation across years in the number of new GARIs installed was assumed to be zero.

All input probability distributions are constructed to be independent and thus uncorrelated. A total of 5,000 trials were sampled using Latin hypercube sampling, which is more efficient than random sampling.

Summary statistics for the GARI net benefits uncertainty analysis are presented in Table A-36. The mean net benefit ($1.7 million) is greater than the median ($1.1 million), indicating a positively skewed distribution. The interquartile range (IQR) is $1.9 million ($432,000 to $2.3 million). The 90 percent credible interval is over $5.4 million ($47,000 to $5.4 million).

Table A-36. Summary Statistics for GARI Net Benefit Uncertainty Analysis

Mean	$1,694,572
St. Dev.	$1,890,942
Mean St. Error	$26,742
5th Percentile	$47,478
First Quartile	$432,544
Median	$1,097,247
Third Quartile	$2,283,346
95th Percentile	$5,424,325

A histogram of GARI net benefits (in 2017 dollars) is presented in Figure A-23. The distribution is single-peaked and highly skewed, with a long right tail. A cumulative distribution of GARI net benefits (in 2017 dollars) is presented in Figure A-24. The cumulative distribution graphically displays all percentiles as cumulative probabilities, including those summarized in Table A-35. Figures A-23 and A-24 both convey graphically the moderately large GARI net benefits uncertainty.

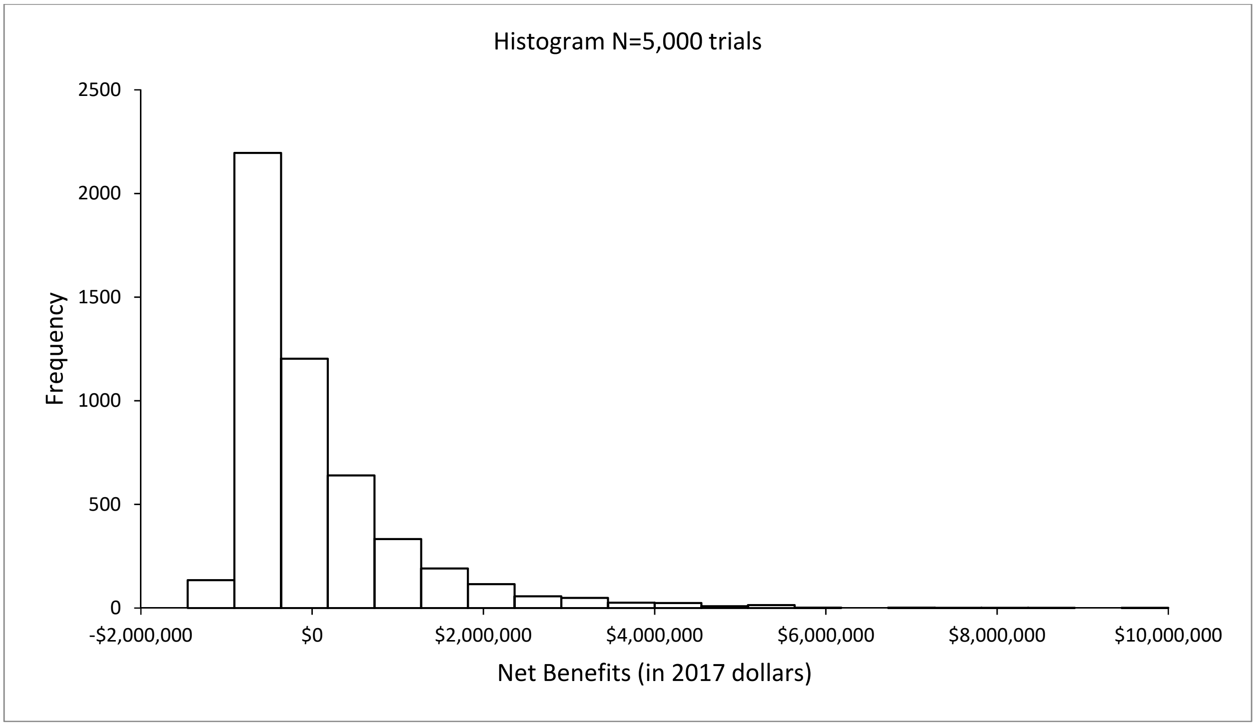

Figure A-23. Histogram of GARI Net Benefits (N=5,000 trials)

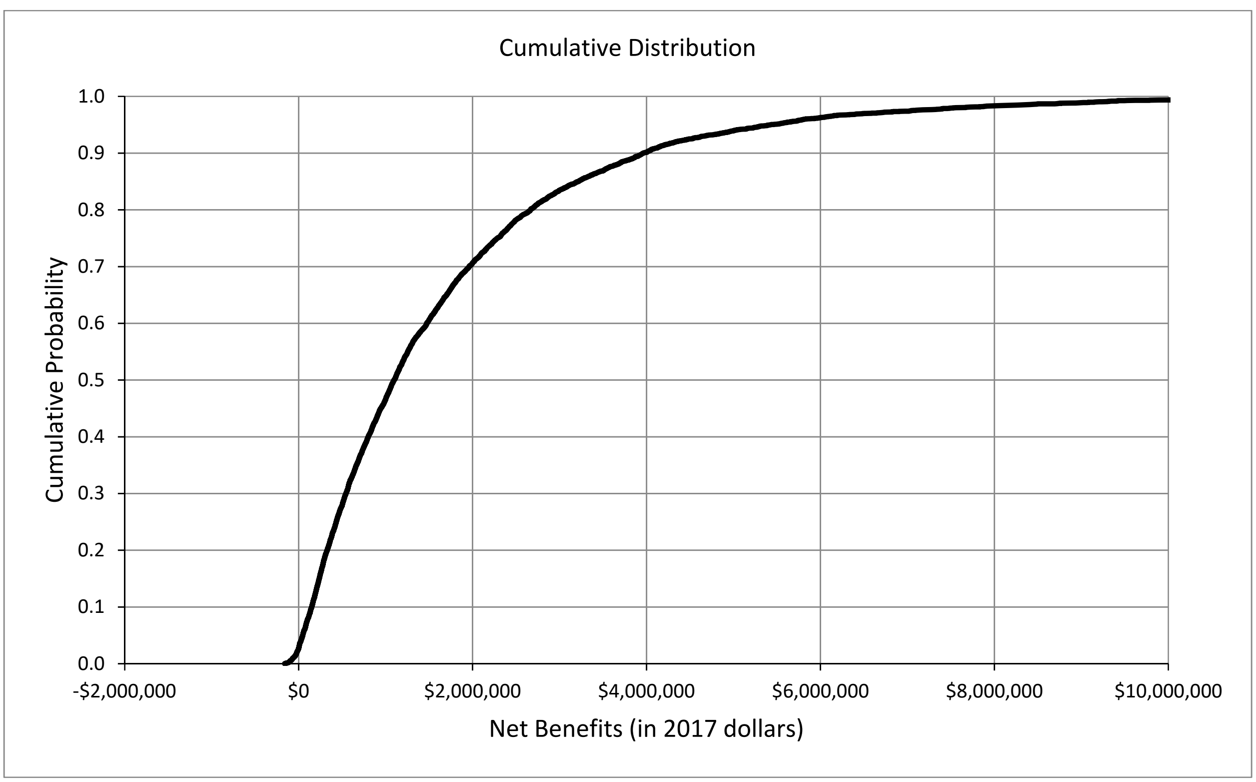

Figure A-24. Cumulative Distribution of RPM Net Benefits

8. Assumptions and Limitations

This analysis depends on a number of assumptions. First, costs are restricted to OUP investments through the CVADA COE. Second, benefits are conceptualized as annual cost savings when comparing the GARI technology to use of trained, experienced law enforcement personnel to carry out the tedious tasks of database management (e.g., storing, searching) and interpreting possible matches. Note that GARI also requires some expert input on the front end for manually indexing each image on a number of features. This cost savings is restricted to differences in the manpower required to conduct the same level of gang tracking and intelligence with and without GARI. The analysis does not include potential benefits from the increased reliability of the GARI system or the enhanced speed of searching and interpretation afforded by the GARI system. The analysis also does not include benefits of the lessons learned from the GARI system that will enhance and improve future designs of next-generation gang graffiti systems. Base case estimates and ranges for the benefit adjustment factor and the number of future GARI installations are speculative and are included primarily to allow for sensitivity and uncertainty analyses spanning a range of possible values.

9. Recommendations for Collecting Additional Information and Analysis

Expert estimates regarding the number of future GARI installations over the next 10 years would be most useful for this analysis. As the tornado diagram indicates, net benefits depend heavily on the number of future installations, since there are cost savings for every year of deployment for every GARI system installed. The greater number of installed-GARI years, the greater the net benefit; in addition, early GARI installations that continue throughout the period have greater influence on net benefits.

A more precise estimate of the cost savings would be possible if more detailed information was collected regarding the manpower savings associated with an installed GARI system. Clearly, the savings will depend on the size of the region, but these may be non-linear. With more information, a more precise estimate of the annualized costs for gang graffiti intelligence gathering could be obtained with more detailed information regarding manpower needs, both with and without the GARI system.

10. References

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Benefit-Cost Analysis of the Social Media Analytics and Reporting Toolkit (SMART)

Developer: Center for Visualization and Data Analytics (CVADA)
Analyst: Jonathan Eyer (CREATE)

1. Summary

Description. The Social Media Analytics and Reporting Toolkit (SMART) is a product developed by the CVADA COE. SMART allows users to map geocoded data from social media communications like Twitter and Instagram, based on key words or phrases. The primary purpose of the technology is to increase situational awareness during and after large events so that security and law enforcement personal can optimally allocate resources, either reducing response times or reducing the staffing costs needed to identify problems.

The valuation is primarily based on the cost savings associated with reduced or optimized staffing that SMART makes possible. There is also a second component of the SMART benefits that relates to the likelihood that SMART changes the overall likelihood of a threat causing damage.

Results. The SMART tool resulted in costs of $320,349 (in 2017 dollars). These costs were related to direct project costs and university cost share. One of the primary benefits of SMART is that it has an intuitive interface which requires little training, so it is unlikely that there will be substantial additional costs associated with deployment of the tool.

The benefits of SMART are associated with reductions in the staffing needed to maintain security at large events. By leveraging user-generated social content to more quickly identify concerns, security and medical personnel can be more efficiently dispatched to address issues in crowds. The benefits of SMART are evaluated under the assumption that identification and response times change linearly with the number of security personnel who are deployed to an event. SMART results in an overall reduction in response times, so its value can be assessed by identifying the costs needed to provide security personnel to reduce the response time by the same amount. Benefits are evaluated under a 10-year time frame, with the assumption that there are 50 events each year at which SMART can be used.

The SMART tool results in total 10-year benefits of approximately $3.5 million (in 2017 dollars). Sensitivity analysis indicates the break-even point for SMART will occur if the tool is used for at least five events per year for each of the next 10 years. Similarly, there is uncertainty about the size of the event at which SMART will be used: The benefits from SMART will be smaller if it is used at small-scale events because less officer time is needed to be offset by the technology. As such, at least 20 officers need to be assigned to each event for SMART to break even. A simulation analysis of all the uncertainties associated with model input parameters indicates the range of 10-year net benefits has a 5^{th} percentile value of \$1.2 million and a 95^{th} percentile value of \$9.1 million. The median value was \$4.5 million

2. Background

Problem context. Social media networks (e.g., Twitter) contain information that relates to crime, risks, emergencies, and other risks that relate to emergency response. If law enforcement and emergency personnel can synthesize this information, risks can be interdicted more effectively, reducing costs or deleterious outcomes. Most of this information comes from disorganized pictures or texts, though, so it is difficult to operationalize the raw information to better allocate resources.

SMART is a tool developed by the CVADA COE that allows law enforcement and emergency management personnel to easily map geocoded social media information. It was developed based on interactions with security personnel to allow rapid representation of security-related terms in social media by operators with minimal geospatial training. SMART has been deployed and utilized by the U.S. Coast Guard and several law enforcement agencies.

3. Baseline

In our baseline, we assume that social media information is not considered in the resource allocation decision. While large organizations have dedicated analyst staff that can analyze information using GIS software, many users of SMART are from small agencies which are unlikely to operationalize the information without a user-friendly tool.

The first component of the valuation relates to expenditure on staffing. In this case, the baseline expenditure is simply the existing amount spent on security and emergency response personnel using their naïve (e.g., not including geospatial information) patrol patterns. For example, if SMART were applied to security at a large boat festival, the baseline expenditure would be the total number of person-hours spent by USCG and police personnel multiplied by the hourly wages of those individuals. The second component relates to the likelihood that a damaging event takes place. In this case, the baseline performance without SMART is the expected damages from preventable events.

Table A-37 shows the baseline parameter assumptions. The number of applicable events is relatively small because SMART is generally presented in the context of Coast Guard-related events, and boating-related large events are infrequent compared to large events that fall under another agency's purview. The parameterizations of the value of officers' time are derived from the assumptions of about one officer per 500 attendees and an eight-hour shift per officer, coupled with BLS statistics on the average hourly wage of a police officer.

Table A-37. Baseline Analysis without SMART

Input Variable	Base
Number of Applicable Annual Events	50
Number of Officers Per Event	200
Value of Officer Time (per 8-hour shift)	$240
Number of Incidents Per Event	6.34
Probability of Major Detectable Event	8.98876E-05
Damage from Major Event	$10,000,000
Baseline Expenditure on Security / Event	$48,000
Baseline Annual Expenditure on Security	$2,400,000
Baseline Expected Annual Damage from Major Event	$44,943.82

4. Cost Analysis

Table A-38 shows the cost of developing SMART. The costs were relatively low, and all costs accrued either directly as COE expenditure or through university cost share. Implementation costs on the part of the users (e.g., training) are not included, but the user-friendly nature of the project suggests that these costs will likely be low compared to the direct costs of building the tool.

Table A-38. Development Cost of SMART (in 2017 Dollars)

Cost Category	Amount
Pre-project costs (COE)	$0
Pre-project costs (other funding)	$0
Project costs (COE)	$187,347
Project costs (university cost share)	$133,002
Oversight cost at the COE	$0
Oversight cost at OUP	$0
Transition development cost	$0
Implementation start-up cost	$0
Implementation cost (User)	$0
Implementation cost (COE)	$0
Implementation cost (Other users)	$0
TOTAL COST	$320,349

5. Benefit Analysis

SMART acts as a force multiplier for law enforcement personnel by reducing the amount of time required to respond to incidents. The benefits of reducing response time can either be modeled as a reduction in expenditure required to keep a baseline response level (e.g., minutes to response) or by decreasing response times while keeping expenditure constant. We choose the former modeling approach because it removes the need to estimate the surplus associated with quicker response times.

The key parameter driving the benefits is how SMART will change response times. The PI of the project indicated that early adopters of the tool experienced 5-10 minute reductions in response times with the tool. The reduction in the number of officers needed to hold response times constant is specified as:

$$Reduction\ in\ Officers = \frac{Reduction\ in\ Response\ Time}{Number\ of\ Officers\ /\ Response\ Time}.$$

The denominator of the equation is the effect of each additional officer on response times, assuming linearity. For example, if there are 200 officers and response times are 30 minutes, then each marginal officer results in a 0.15-minute change in response times.

The staffing benefits of the tool are specified as

$$Staffing\ Expenditure\ Reductions = Reduction\ in\ Officers * Value\ of\ Officer\ Time.$$

The total benefits of SMART are calculated by multiplying the staffing expenditure reductions by the number of applicable events where the tool can be deployed. In the event that SMART will be used for multiple years, future benefits can be discounted into present terms.

While SMART could lower the probability of major event (e.g., shooting) that would cause financial damage or major loss of life, the assumption that agencies will reduce their staffing requirements to hold response times constant removes this impact from the benefits calculation.[21] Similarly, this analysis is unable to extend to search and rescue benefits except to the extent that SMART would lower staffing requirements while holding expected search times constant.

Number of Applicable Events. SMART is currently primarily used by the Coast Guard to provide situational awareness during maritime events, although it has been extended for other crowd management events (e.g., State of the Union address) and ex-post analyses of events. As a baseline, we assume that there are 50 major events per year that are large enough to require a geospatial analysis.

Number of Officers per Event. Following a number of publicly available police staffing guidance documents, we assume a baseline allocation of two officers per 500 attendees.

Value of Officer Time. The BLS reports a mean hourly-wage rate of $30.00 for police officers (Bureau of Labor Statistics, 2017). Each officer is assumed to spend a full eight-hour day working on each event.

[21] The value of SMART could be evaluated by holding expenditure constant and evaluating the change in expected losses due to major events, but the relative lack of data on the frequency of major attacks will result in highly sensitive estimates.

Reduction in Response Time. The PI of the project indicated that preliminary users of SMART reported reductions in response times up to 5-10 minutes (Ebert, 2019).

Table A-39. Annual Benefits of SMART

Input Variable	Base Case Value
Number of Applicable Annual Events	50
Number of Officers per Event	200
Value of Officer Time (per 8-hour shift)	$240
Time to Incident Notice and Response w/o Smart	30
Reduction in Response time w/ Smart	5
Minutes per Officer	0.15
Reduction in Officers Needed	33.33333333
Value of Reduced Officer Time / Event (in millions of 2017 dollars)	$0.01
Baseline Expenditure on Security / Event (in millions of 2017 dollars)	$0.05
Baseline Annual Expenditure on Security (in millions of 2017 dollars)	$2.40
Total Annual Benefits (in millions of 2017 dollars)	$0.4
Discount Factor	0.03
10-Year Discounted Total Benefits (in millions of 2017 dollars)	$3.5
Net Present Value (in millions of 2017 dollars)	$3.2

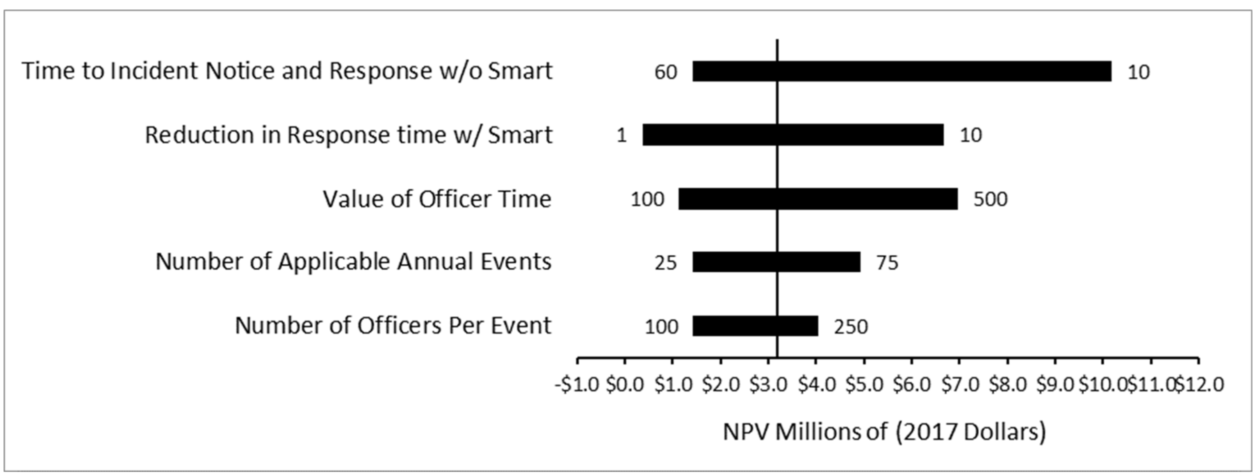
6. Benefit-Cost Analysis – Base Case

Under the baseline parameters, the annual benefit of the SMART tool is approximately $400,000. The parameter values for this analysis are presented in Table A-39. In the base case, SMART reduces response times and the number of required officers by one-sixth. Under the baseline assumption of a 3 percent discount rate, this suggests total 10-year benefits of approximately $3.5 million, easily exceeding the initial $320,000 investment. This suggests a benefit-cost ratio (BCR) of 10.9 and a return on investment (ROI) of 1,000 percent.

7. Sensitivity and Uncertainty Analysis

Break-even Analysis. The value of SMART is sensitive to a number of parameters. There is little guidance about the number of events that could use SMART each year. If limited to major events in which security is provided by the USCG, the number of applicable events could be relatively low. On the other hand, if SMART were deployed widely to federal and local security forces, the impact could be much larger. Holding all other parameters constant, SMART would break even if it were used at five events each year. Similarly, while there is less uncertainty about the number of officers who would be sent to each event, there is still substantial variance in the types of events that might employ SMART. If the tool was used at relatively small events, the cost savings associated with reducing officer staffing would be small. Holding all other parameters constant, SMART will break even as long as there are at least 20 officers assigned to each event.

Sensitivity Analysis. The net benefits associated with SMART are sensitive to the underlying parameter assumptions. Figure A-25 presents a tornado diagram, showing how changes in each underlying parameter affect the NPV of the tool. The key parameters driving the variability in the value of the tool are the reduction rate due to SMART and the amount of time required to detect and respond to incidents without SMART. These parameters determine the percentage reduction in staffing that would result from cost-effective deployment of SMART.



Source: CREATE, using TreePlan/Sensit

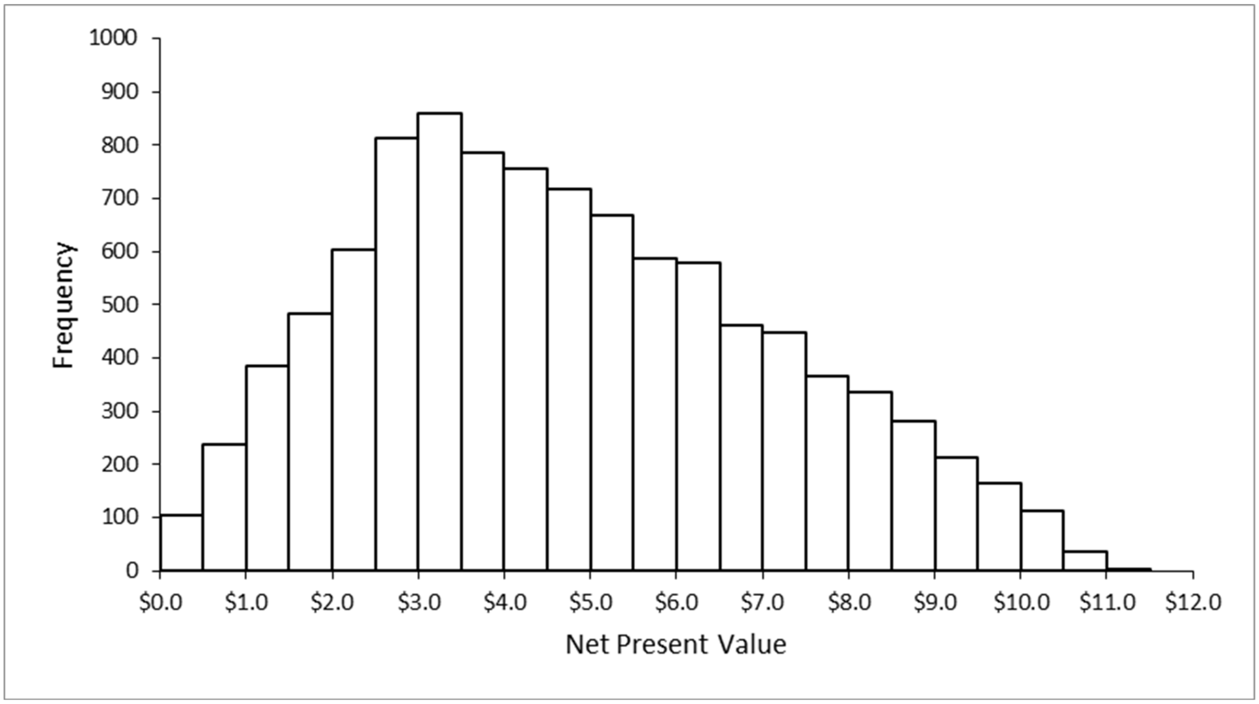
Figure A-25: Tornado Diagram for the NPV of SMART

Uncertainty Analysis. Next, we conduct a formal sensitivity analysis of the value of SMART by varying the values for each parameter and calculating the associated 10-year net present value. In most cases, we assume a triangular distribution. The high, low, and base values are shown in Table A-40. We evaluated the 10-year net present value of the tool under 10,000 simulations of the key parameter values.

Table A-40: Ranges for SMART Analysis

Input Variable	Base Case Value	Low Value	High Value
Number of Applicable Annual Events	50	25	75
Number of Officers per Event	200	100	250
Value of Officer Time (per 8-hour shift)	$240	$100	$500
Number of Incidents per Event	6.34	3	15
Time to Incident Notice and Response w/o Smart	30	10	60
Reduction in Response time w/ Smart	5	1	10
Discount Factor	0.03	0.00001	0.07

Figure A-26 shows the density of the NPV of SMART across the simulations. While the distribution is relatively flat, reflecting the uncertainty in the input parameters, none of the simulations indicate a negative NPV.



Source: CREATE using TREEPlan/Sim VOI

Figure A-26: Net Present Value of SMART for 10 Years (in 2017 Dollars)

Table A-41 shows the summary statistics across 10,000 simulations. The 5th percentile is approximately $1.2 million while the 95th percentile is $9.1 million.

Table A-41: Statistics of SMART NPV Distribution

Mean	$4.8 million
St. Dev.	$2.4 million
5th Percentile	$1.2 million
25th Percentile	$2.9 million
Median	$4.5 million
75th Percentile	$6.4 million
95th Percentile	$9.1 million

8. Assumptions and Limitations

This model has several key assumptions and limitations. The strongest assumption is that security agencies will choose to react to increases in patrol efficiency by reducing staffing. An alternative structure would result in an increase in security and a decrease in the likelihood of damaging events while staffing costs would remain unchanged. Security managers would likely be strategic in their decision about whether to reduce staffing or increase security based on beliefs about the damages associated with failing to identify security threats. Security managers may choose to reduce staffing when damages from missed identifications are low (e.g., drug dealing or trespassing) but increase security when damages from missed identifications are high (e.g., terrorist attack).

There is also substantial uncertainty surrounding the deployment of SMART. While most of the current operators of SMART are USCG-affiliated, the tool could ostensibly be deployed to a wider audience at little additional cost. This would increase the total benefits of SMART relative to the above analysis.

9. Recommendations for Collecting Additional Information & Analysis

The evaluation of the benefits of SMART can be defined more precisely by obtaining more information about several of the parameters. Most importantly, there is ambiguity about how many events to which the tool could be readily applied. More information about the number of large events that are under the purview of the USCG and in which participants have access to social media connections could refine this number. There is also uncertainty about how long it would take officers to identify and find issues in the absence of SMART. While it is unlikely that there will be data on this, consultation with experts could provide improved estimates.

It is also notable that this analysis omitted the possibility that SMART can be used to detect large events, such as shootings or terrorist attacks. The SMART framework could be extended to include situations in which tail risk events are detectable using the SMART technology that are not otherwise detectable (or less detectable) without the tool.

10. References

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