Evaluating the effectiveness of the Global Nuclear Detection Architecture using multiple-objective decision analysis

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Evaluating the Effectiveness of the Global Nuclear Detection Architecture Using Multiple-Objective Decision Analysis

an undergraduate’s honors thesis submitted to the

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by

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Executive Summary

The Domestic Nuclear Detection Office was created in 2005 with the purpose of increasing the United States’ detection efforts for radiological and nuclear (RN) threats by terrorists. The office was given the responsibility of developing the Global Nuclear Detection Architecture, a cross-agency strategy for detecting, analyzing, and reporting of RN materials outside of regulatory control. In 2012 the Government Accountability Office expressed concern over the prioritization of GNDA resources as well as the documentation of GNDA progress over time, so the DNDO asked the National Research Council (NRC) for advice on how to develop performance measures and metrics to quantifiably assess the GNDA’s effectiveness. The result of an extensive NRC study was a report titled “Performance Metrics for the Global Nuclear Detection Architecture.” In the report the appointed committee created a notional strategic planning example for evaluating the performance of the GNDA.

The subject of the following report is the creation of a value model that was based off of the NRC’s strategic example and that can be used as an example for evaluating the GNDA’s performance. The report demonstrates that it is feasible to create an adequate performance rating for the GNDA using the techniques of multiple-objective decision analysis.

There were several important tasks associated with the model development as well as model use and analysis. The steps in model development included establishing the goals, objectives, and sub-objectives of the model; developing the metrics used to evaluate the objectives; and creating the value functions necessary to convert the metrics to a common scale. The resulting model had four main goals that were divided into ten objectives and nine sub-objectives. These objectives were measured by twenty-five distinct metrics.

In terms of model use and evaluation, the activities included scoring the metrics, establishing weights, and performing both sensitivity and cost-benefit analysis. The metrics were given notional scores unless publicly accessible data was available. For establishing weights, three different sets of weights were created: (1) equal weights for all measures, (2) weights to based on government spending, and (3) weights based on the adversary’s viewpoint.

Based on these three weight sets and the notional values used, the weight set based on government spending had a higher mean score than the set of equal weights. This shows that, assuming the notional data is reasonable, aspects of nuclear counterterrorism that the government considers to be more important correlate with the aspects that are performing better. However, the score based on the adversary’s stance had the lowest score indicating room for improvement. Analysis techniques were performed for the set of weights based on government spending. A sensitivity analysis example was used to highlight how changing the percent of total weight of a metric has an effect on the overall model value. An example of cost-benefit analysis demonstrated how a proposed increase or decrease in GNDA government spending could be modeled to calculate the change in the model’s overall performance rating.

This report demonstrates that it is possible to evaluate the performance of the Global Nuclear Detection Architecture using multiple-objective decision analysis techniques. The DNDO can adjust the model as necessary, create a standard set of weights, and input the classified data in order to come up with an adequate performance rating of the GNDA.
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1 Introduction

Protecting the nation against radiological and nuclear terrorism is one of the United States Government’s top priorities. Efforts to detect radiological and nuclear (RN) materials have existed for many years. However, in 2005 the Domestic Nuclear Detection Office (DNDO) was established within the Department of Homeland Security (DHS) with the responsibility of improving the nation’s nuclear detection efforts for radiological and nuclear threats. The DNDO was given the responsibility of developing the Global Nuclear Detection Architecture (GNDA), a cross-agency strategy for detecting, analyzing, and reporting of nuclear and radiological materials outside of regulatory control.

Evaluating the effectiveness of the GNDA has proven to be a difficult task. In 2011 the DNDO asked National Research Council (NRC) for advice on how to develop performance measures and metrics to quantifiably assess the GNDA’s effectiveness. The culmination of their findings and recommendations were published in a document titled “Performance Metrics for the Global Nuclear Detection Architecture,” and the abbreviated version was released to the public.

This report details the creation of a value model that is based off the NRC committee’s findings and is used to evaluate the overall effectiveness of the GNDA. The report is broken into five sections, including the introduction. The remaining sections are detailed below:

Section 2: Background information on the Global Nuclear Detection Architecture and the study conducted by the National Research Council

Section 3: Model development and the associated tasks

Section 4: Model use and analysis techniques used to evaluate the model

Section 5: Conclusion and significance of study
2 Background

2.1 The Global Nuclear Detection Architecture

The GNDA is comprised of a “worldwide network of sensors, telecommunications, and personnel, with the supporting information exchanges, programs, and protocols” that contribute to its overall goal of using detection and interdiction capabilities to combat smuggling outside the United States, at the U.S. Border, and inside the border (National Research Council, 2013). The GNDA specifically deals with RN materials out of regulatory control, referring to “materials that are being imported, possessed, stored, transported, developed, or used without authorization by the appropriate regulatory authority, either inadvertently or deliberately” (Hart, 2012).

Because protecting the nation against nuclear terrorism involves a great number of facets, the DNDO has to work closely with Federal, State, local, tribal, international, and private sector partners in order to implement and oversee the GNDA. Beyond just developing the GNDA, the DNDO is charged specifically with the implementation of the domestic portion of the architecture.

In the implementation of the GNDA, the DNDO works closely with several other federal agencies, including

- Department of Energy (DOE) National Nuclear Security Administration (NNSA)
- Director of National Intelligence (DNI)
- Department of Defense (DOD)
- Department of State (DOS)
- Department of Justice, primarily the Federal Bureau of Investigation (FBI)
- Nuclear Regulatory Commission (USNRC)
The DNDO also works with several other agencies within the DHS such as Customs Border Protection (CBP) and the U.S. Coast Guard.

The Global Nuclear Detection Architecture is one part of the larger nuclear counterterrorism (NCT) effort to reduce the risk of nuclear terrorism. The NCT efforts are often described as a spectrum that range from material security all the way to forensics and attribution after an event. This spectrum, as well as where the GNDA’s role fits in, is shown below in Figure 1.

![Nuclear Counterterrorism Spectrum](image)

**Figure 1. Nuclear Counterterrorism Spectrum**

As shown in Figure 1, the scope of the GNDA lies directly between material security (RN materials under regulatory control) and interdiction (the recovery of RN materials to regulatory control). Therefore, the activities of the GNDA do not aim to secure regulated RN materials or return RN materials to regulatory control; they are only concerned with the detection portion of the NCT spectrum.

The Domestic Nuclear Detection Office defines detection as the use of both active and passive technical equipment as well as nontechnical means such as intelligence information to identify RN materials out of regulatory control. The GNDA is preventive in the mission of nuclear counterterrorism because it includes both detecting RN materials before an event occurs.
and also deterring adversaries as a result of the increased possibility of an adversary’s attempt being detected.

2.2 GNDA Structure

In order to increase the probability of detecting an adversary’s attempt to commit an act of radiological or nuclear terrorism on the United States, the GNDA is structured as a multi-layer defense system. One way to view the GNDA components is through its “geographical view” which consists of three main geographical layers: exterior to the U.S., the U.S. border, and inside the U.S. Cross-cutting efforts that span multiple layers and pathways also exist. The definitions of each layer are given from the DHS website:

- “The exterior layer comprises the foreign origin, foreign transit and foreign departure sub-layers. We improve radiological and nuclear material detection abroad through efforts that encourage foreign nations or regions to develop and enhance their nuclear detection architectures.”

- “The transit and border layer (trans-border) is composed of transit to the U.S. from a foreign port of departure or non-port of departure, as well as passing through the U.S. border prior to entering the U.S. interior. This represents the last opportunity to detect radiological or nuclear materials prior to their arrival onto U.S. territory, and initiatives in this layer emphasize maritime domain awareness related to preventive radiological/nuclear detection.”

- “The interior layer of the Global Nuclear Detection Architecture (GNDA) includes all areas within and up to, but not including, the U.S. border. The interior layer focuses on increasing nuclear detection capabilities across the maritime, air, and land pathways and addressing a wide array of potential threats.”
“Cross-cutting efforts focus on programs and capabilities spanning multiple layers and pathways of the Global Nuclear Detection Architecture (GNDA). Efforts undertaken in this layer provide the basis for time-phased deterrence and detection strategies. These elements streamline existing capabilities, improve overall coordination and ultimately seek to enhance radiological and nuclear detection at the federal, state, territorial, tribal and local levels.” Efforts in this area include developing a risk and cost benefit assessment for the architecture as well as performing studies to benefit the overall strategic plan of the GNDA.

A diagram of the three main geographical layers is shown below in Figure 2.

Figure 2. Geographical view of GNDA

2.3 Performance Metrics for the Global Nuclear Detection Architecture

2.3.1 Background and Tasks

Evaluating the performance and improvements of the GNDA’s overall effectiveness has proven to be a challenging task. Currently, the DNDO collects annual self-assessments from each of the GNDA’s partner agencies, and the office is able to come up with a listing of progress from individual programs. However, combining this data in order to measure to measure the overall performance of the GNDA is where the difficulties arise.

In 2011 the DNDO asked National Research Council (NRC) of the National Academy of Sciences for advice on how to develop performance measures and metrics to quantifiably assess the GNDA’s effectiveness. This development would be of great value because it would allow for the GNDA’s progress and improvements to be quantifiably tracked over time, and, by doing so, it can be “used to improve the GNDA strategic plan during future annual review cycles” (National Research Council, 2013). Specifically, the DNDO asked the council to perform two tasks: (1) to assess the feasibility of using performance measures and quantitative metrics for evaluation progress towards meeting the performance goals in the GNDA Strategic Plan, and (2) recommend approaches for evaluating the overall effectiveness of the GNDA. A full statement of these tasks can be found in Appendix II.

The NRC appointed a committee of twelve experts from a variety of related fields to carry out the study. The committee met beginning in May 2012 and several times throughout the next year to review the Global Nuclear Detection Architecture and develop their recommendations. The culmination of their findings and recommendations was a report titled “Performance Metrics for the Global Nuclear Detection Architecture.” While the official report is classified, the abbreviated version was released to the public in December 2013.
2.3.2 Observations, Findings, and Recommendations

The committee discovered significant challenges when addressing the feasibility of developing measures and metrics against the performance goals of the existing strategic plan. The committee found that while it is essentially feasible to create measures to evaluate performance of the GNDA, it was not feasible to create appropriate outcome-based metrics with the current strategic plan. The current goals, objectives, and performance goals of the GNDA Strategic Plan did not directly link to the architecture’s overall mission. Also, these components are primarily output- and process-based.

The committee stated two conditions that had to be met in order to appropriately evaluate the effectiveness of the GNDA. First, a new strategic plan with outcome-based metrics would have to be created, and, secondly, an analysis framework had to be developed to allow of the assessment of outcome-based metrics.

2.3.3 Notional Strategic Planning Example with Metrics

In response to the committee’s findings presented in the previous section, the committee gave a notional strategic planning example with outcome-based metrics in the fourth chapter of the report. In this chapter the committee also gave recommendations for strategic planning on the development of performance metrics. While the committee only gave a couple examples of possible performance measures, the strategic plan that the committee created was structured in a way that allows for the development of appropriate outcome-based metrics.

As noted in the report, a strategic plan must encompass the “vision, mission, and high-level goals and objectives of an organization or program.” The vision statement of an organization lays out the overarching goal and purpose of the organization, while the mission statement describes how the vision statement can be achieved. The goals and their corresponding
objectives must contribute to the mission, and must span the scope of the mission so that every aspect is considered. It is important to not overlook objectives that are difficult to measure. The report states that, “often strategic planning is guided by available data rather than by a logical set of goals and objectives that address the mission.”

For the notional example, the committee considered the broad range of radiological and nuclear terrorism, and then they narrowed the strategic plan to the aspects that were in the scope of the GNDA. The vision and mission statements they created are as follow:

- **Vision:** “For U.S. citizens to live free from the fear of nuclear or radiological terrorism.”
- **Mission:** “Protect the nation from terrorist attacks that use radiological or nuclear (RN) materials.”

From these two statements, they created a series of five goals that supported the mission along with a several objectives for each of these goals. The goals in their strategic plan example were:

- **Goal 1:** Reduce the threat to the nation of radiological or nuclear (RN) attacks by terrorists
- **Goal 2:** Reduce the vulnerability of the nation to RN attacks by terrorists
- **Goal 3:** Reduce the consequences of a successful radiological or nuclear attack on the nation
- **Goal 4:** Reduce the unintended side effects of RN countermeasures
- **Goal 5:** Reduce costs of RN countermeasures

As mentioned, each of these goals had multiple underlying objectives. For example, a couple of the objectives related to Goal 2—Reducing the vulnerability of the nation to RN attacks by terrorists—are to detect RN materials out of regulator control by layers of detection (outside the U.S., at the border of the U.S., and inside the U.S.). A complete list of the goals, their objectives,
and the few metrics that were given in the report is shown in Appendix III. As noted earlier, the only objectives that are within the GNDA scope are those that relate to detection and deterrence. These objectives are highlighted with stars in the appendix.

The notional example that the committee created is not intended to be complete. While the example gives goals and objectives that span the spectrum of protecting the national against nuclear and radiological terrorism, the committee intentionally did not include metrics for every objective. Instead they wanted the DNDO to use the example as a good starting point from which to refine the mission and goals and then come up with a complete set of objectives for each goal.

3 Model Development

Performance measurement and value modeling (a technique of multiple-objective decision analysis), when applied correctly, are useful applications for evaluating the effectiveness and progress for programs or businesses (Parnell, Driscoll, and Henderson, 2011). This section of the report describes the tasks and activities performed to develop a performance-rating model. The model to evaluate the effectiveness of the Global Nuclear Detection Architecture was created using the software Logical Decisions. Logical Decisions is decision-making software that uses multiple-objective decision analysis to evaluate alternatives. The activities and steps required to complete the model were (1) refining the goals, objectives, and sub-objectives; (2) developing the metrics; and (3) assigning value functions for each measure. The first two activities are combined together in the following section.

3.1 Establishing Goals and Objectives and Developing Metrics

In creating the performance model for the GNDA, the first step was to create the overall hierarchical structure. Because the committee came up with a very sensible vision and mission
statement, these were unchanged in the model. The main goals that support the mission were also kept the same, bar one exception: Goal 5—Reduce the cost of RN countermeasures—was removed. The reason this goal was removed is because cost is typically not included in value models. Instead, cost is introduced to compare alternatives using a cost vs. value analysis. This topic is touched on briefly later in the “Cost Analysis” section. The complete overarching structure, composed of the vision, mission, and main goals, is shown below in Figure 3.

Now that the four main goals were established, the objectives were adapted from the list the committee came up with and sub-objectives were created when deemed sensible. For each objective or sub-objective, one or more metrics were developed to measure the GNDA performance.

3.1.1 Goal 1: Reduce the Threat

For Goal 1—Reduce the threat to the nation of RN attacks on the nation—the two objectives presented by the committee were maintained and no sub-objectives were added. The
objectives and metrics for Goal 1 are shown below in Figure 4. For Figure 4 and the following figures used in this section, the main goals are shown in light green while objectives and sub-objectives are in the light blue and orange boxes, respectfully, and the metrics are shown in the darker blue.

Figure 4. Goal 1 Objectives and Metrics

Goal 1: Reduce the threat to the nation of radiological or nuclear (RN) attacks by terrorists

Objective 1.1: Deter terrorists’ RN attacks by demonstrating high likelihood of failure

Objective 1.2: Identify terrorist plans for radiological or nuclear attacks

Metric 1: Probability of deterrence by denial

Metric 2: Probability of identifying terrorists plans via intelligence efforts

The metrics associated with Goal 1 are (1) the probability of deterrence by denial, and (2) the probability of identifying terrorist plans via intelligence efforts. While these metrics are outcome-based, they will not be easy to measure. An entire sub-section of the report is based on the quantification and measurement of deterrence. Because of the complexity, the deterrence by denial for this model would be the calculated using the Probabilistic Effectiveness Methodology (PEM). PEM is a “simulation tool with a holistic approach for nuclear smuggling” (Cuéllar et al., 2011). Similarly, the second metric, the probability of identifying terrorist plans via intelligence efforts would be assessed by the Intelligence Community.
3.1.2 Goal 2: Reduce the Vulnerability

While the structure for Goal 1 is pretty straightforward, Goal 2—Reduce the vulnerability of the nation to RN attacks by terrorists—is more complex and involves more components. The main objectives of Goal 2 that were outlined in the report were broken down into detection efforts by geographical layers, and they remained unchanged for this model. These objectives are shown below in Figure 5.

Figure 5. Goal 2 Objectives

Goal 2: Reduce the vulnerability of the nation to RN attacks by terrorists

- Objective 2.1: Detect RN materials out of regulatory control outside of the U.S.
- Objective 2.2: Detect RN materials out of regulatory control at the border of the U.S.
- Objective 2.3: Detect RN materials out of regulatory control inside the U.S.

Each of these objectives has several sub-objectives that were created. First Objective 2.1 and the detection of RN materials outside of the United States will be addresses.

As described earlier in section 2.2, sub-layers of the exterior layer of the architecture include foreign origin, foreign transit, and foreign departure. For the purpose of this model, foreign origin was considered to be in the scope of material security, which does not fit into the specific scope of the GNDA. Transit of RN materials from one foreign country to another was also not considered because the ultimate focus of the architecture is on not allowing materials inside the United States where they can be used for an attack; this also helps simplify the model
greatly. Therefore, foreign departure, which overlaps with the U.S. border layer, was the main focus of this objective. The components of Objective 2.1 are shown below in Figure 6.

Figure 6. Objective 2.1 Sub-Objectives and Metrics

The objective was divided into two sub-objectives: Detect RN materials out of regulatory control (1) at foreign ports of departure (PODs), and (2) in route to the United States. For the first sub-objective concerning foreign PODs, the metrics created were the probability of detecting U.S. bound RN materials and foreign seaports and foreign airports. It is important to note that the metrics only include *U.S. bound* RN materials out of regulatory control. Since the purpose of the GNDA is to protect specifically the United States from RN attacks by terrorists, the transportation of RN materials from one country to another is not considered in the model. The main focus of the nation’s nuclear counterterrorism efforts is to keep the materials out of the nation, regardless of where the attempt to bring in these materials comes from. Thus, focusing only on the transport from foreign departure to the United States simplifies the model and makes it more outcome-oriented.
As mentioned, the exterior layer of the GNDA overlaps with the U.S. border layer. The reason for this overlap is because materials can be transported from Canada or Mexico to the United States by land through the U.S. border; the departure from the foreign country and entry into the United States happens almost simultaneously. To eliminate redundancy, only foreign seaports and airports are considered under Objective 2.1, and U.S. border crossings are considered under Objective 2.2.

The second sub-objective for Objective 2.1 is the detection of RN materials in route to the United States. Specifically, this sub-objective focuses on efforts of the U.S. Coast Guard in its role of maritime security. The metric used is the percentage of vessels in the U.S. coastal region searched by the coast guard. This metric relies on the assumption that if the Coast Guard searches a vessel, it will detect any unregulated RN materials present.

The focus of Objective 2.2 is the detection of RN materials at the United States borders. As in the notional example provided by the committee, the objective is split up into detection efforts at ports of entry (POEs) and between ports of entry. The metrics related to this first sub-objective, the detection of RN materials at U.S. ports of entry, are shown on below in Figure 7.
This sub-objective is divided into five different metrics based on types of POEs. The five metrics are the probability of detecting incoming RN materials at major U.S. seaports, minor U.S. seaports, primary U.S. airports, vehicle border crossings, and rail border crossings. The reason seaports were divided into major and minor seaports because large variations exist in the RN detection equipment deployed at the 22 seaports with greatest volume of imports and the remaining U.S. seaports (Department of Homeland Security, Office of Inspector General [OIG], 2013).

The second sub-objective for Objective 2.2 focuses on the detection of incoming RN materials between POEs. The two metrics that measure this sub-objective breakdown the measurement into RN materials transported via land and via water. Namely, the metrics are the probability of detecting RN materials transported across the U.S. border via land between POEs and the probability of detection of RN materials entering the country via the 95,000 miles of
shoreline that exist between seaports. The components related to the second sub-objective, to detect RN materials between ports of entry, are shown below in Figure 8.

The third and final objective of Goal 2 is to detect RN materials out of regulatory control inside the United States border. This objective encompasses all efforts of detecting unregulated RN material once it successfully enters the country or it is taken from a secure facility within the United States. Referring to the geographical layers shown previously in Figure 2, the interior layer of detection includes U.S. origin, the regional U.S., target vicinity, and the actual target. As mentioned earlier in the paper, material security shares an interface with detection, but it is not within the scope of the GNDA. Thus, this model does not include U.S. origin of RN materials.

The first sub-objective under Objective 2.3 models the U.S. regional sub-layer of the GNDA structure. The U.S. regional layer is represented as the transport of RN materials across the country; this encompasses the actions a terrorist can take to transport the materials from the one location within the country to the target vicinity. The sub-objective is divided into five metrics that measure the probability of detection by modes of transportation, specifically, train,
truck, inland waterways, primary airports, and non-primary airports. Primary airports are defined as having 10,000 or more passenger borders each year while non-primary airports have fewer than 10,000 (Federal Aviation Administration, 2012). Sub-Objective 2.3.1 and its metrics are shown below in Figure 9.

Figure 9. Objective 2.3 Sub-Objectives and Metrics (1)

The second sub-objective of Objective 2.3, and the final portion of Goal 2, models aspects related to detecting RN materials within target vicinity and at the target. These two sub-layers are modeled together because the target and target vicinity blur together due to the vast area of destruction and/or disruption of radiological and nuclear weapons. The targets that a terrorist may choose to attack are divided into urban areas and critical infrastructure. Critical infrastructure is defined by the Department of Homeland Security as, “the assets, systems, and networks, whether physical or virtual, so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof” [INSERT SOURCE]
Such infrastructure targets range anywhere from government facilities to public drinking water systems. Figure 10 below shows the metrics related to Sub-Objective 2.3.2.

**Figure 10. Objective 2.3 Sub-Objectives and Metrics (2)**

3.1.3 **Goal 3: Reduce the Consequences**

The third goal of the model is to reduce the consequences of a successful radiological or nuclear attack on the nation. The two objectives presented by the committee in the notional example—diverting RN attacks to lower-consequence targets and providing early warning of RN attacks—were kept the same, but sub-objectives were added to the first objective. These sub-objectives break down the term targets into urban areas and critical infrastructure, as done in the previous section. The components related to the measurement of Goal 3 are shown below in Figure 11.
The metric developed to measure the ability of the GNDA to divert RN attacks to lower-consequence cities is based off spending on the Urban Areas Security Initiative (UASI). The UASI program is part of the Homeland Security Grant Program, and the funds allocated by the program “address the unique planning, organization, equipment, training, and exercise needs of high-threat, high-density urban areas, and assists them in building an enhanced and sustainable capacity to prevent, protect against, mitigate, respond to, and recover from acts of terrorism” (Department of Homeland Security, Homeland Security Grand Program [HSGP], 2013). In 2013 UASI allocated over 350 million dollars to 25 high-threat, high-density urban areas. The specific metric used is the percent of the United States population covered by the UASI. This metric relies on the assumptions that the money allocated to each of these cities was used efficiently in regards to detection measures, and also that the funds were used on radiological and nuclear detection efforts instead of on other efforts such as bioterrorism countermeasures. This metric
also ignores other aspects that the funds can be used for such as in response and recovery from an attack.

The metric to measure for diverting RN attacks to lower-consequence critical infrastructure is the percentage of critical infrastructure targets protected by RN detection equipment. The third and final metric for Goal 3 measures the ability of the GNDA to provide early warning of RN attacks, and the metric is the detection alert time. This metric is based on a constructed scale of when RN materials out of regulatory control are detected. The scale is broken up into five sections ranging from detecting RN terrorism plans in advance, to detecting in time at the U.S. border, to the worst scenario of detecting after an event occurs.

3.1.4 Goal 4: Reduce the Unintended Side Effects

The final goal of the model is to reduce the unintended side effects of RN countermeasures. The same three objectives the committee created in the notional strategic plan are used in the model. These objectives and their metrics are shown below in Figure 12.

Figure 12. Goal 4 Objectives and Metrics
The first objective—minimize impacts on privacy and civil liberties—is measured by the number of complaints from civil liberty groups with zero being the ideal number. The second objective—minimize impacts on flow of commerce and the economy—is measured using a constructed scale as a performance rating. The scale ranges from 1 to 5 with a score of 5 being no impact and 1 being an extreme impact on the flow of commerce and the economy.

The final objective related to unintended side effects of the GNDA is to avoid transfer of RN risks to other nations. This is an interesting objective that almost counters progress of the other objectives; if the GNDA is performing very well and it is difficult for terrorists to attack the United States, terrorists may divert their attacks to other nations. Thus, while the other objectives have high performance values, this objective would be given a lower score. Therefore, the metric used to measure this objective is the number of countries spending money on global nuclear detection efforts. The more countries that are spending money on NCT, the lower the probability of diverting RN attacks to other nations. Also, it will be harder for terrorists acquire and transport RN materials, thus reducing the probability of RN attacks in general.

3. 1. 5 Summary of Model Structure

The model created to evaluate the performance of the Global Nuclear Detection Architecture is fairly complex. There are twenty-five different metrics used to measure series of ten objectives and nine sub-objectives. All of these objectives support one of four main goals, which contribute to the mission and vision of the Global Nuclear Detection Architecture. The entire model structure can be seen in Appendix IV.
3.2 Assigning Value Functions

Value functions are the part of the model that assigns a metric’s score a specific value. They are used to measure “returns to scale over the range of the value measure” (Parnell et al., 2011). Value metrics have varying units, so the use of value functions allows for scores to be converted to a standard unit.

Value functions can be either continuous or discrete. The majority of measures in the model were given continuous value functions. Specifically in relation to the metrics associated with Goal 2, reducing the vulnerability to the nation, the measures were given continuous value functions with increasing returns to scale. For an example, the value function that was created within Logical Decisions for Metric 9—probability of detecting RN materials at vehicle border crossings—is shown below in Figure 13.

Figure 13. Continuous Value Function for Metric 9
On the x-axis of the graph is the scale of the value measure, which in this case is the probability of detection for RN materials at U.S. vehicle border crossings. This probability ranges from 0 to 1. On the y-axis is the standard unit of value scaled from 0 to 100. Since this function is convex with increasing returns to scale, as the probability of detection increases, the resulting value increases exponentially. This shape was chosen because if RN materials were only correctly identified at border crossings half of the time, it would not be of much value in the protection of the United States. It is only when an attempt is detected a large majority of the time that the detection efforts are very valuable.

As shown in the lower part of Figure 13, the selected point for the function has a level of .6 and a value of .25. This means that if the U.S. vehicle border crossings are successful in detecting unregulated RN materials 60% of the time, the return to scale will be 25 (out of a possible 100) in the value model.

The only discrete value functions used in the model were for the two measures with constructed scales. These were Metric 22—detection alert times—and Metric 24—a performance rating on level of impact to commerce and the economy. The value function for Metric 24 is shown below in Figure 14.
In this value function, the measure is given a standard value score of 100 if the GNDA is rated as having no impact on commerce and the economy, a value score of 60 if it as rated as having minimal impact, and so on and so forth.

4 Model Use and Analysis

After the structure of the model was complete and it was created in the Logical Decisions software, the metrics could be scored and analysis was performed on the model. The specific activities associated with this portion of the project were (1) scoring the metrics, (2) assigning weights to the metrics, and (3) evaluating the results. Both sensitivity analysis and cost-benefit analysis were performed.

4.1 Scoring the Metrics

Two alternatives were evaluated using the model: the ideal performance for the GNDA and the baseline, or current, level of performance. Each alternative was given a notional score for each metric to assess the GNDA’s performance. For the ideal alternative, the best possible value for each metric was chosen. However, it is important to note that this value, while the ideal
value, was not always feasible. For example, it would be ideal to have every single country spending money on global nuclear detection efforts, but this is neither possible nor practical with for many third-world countries.

Because much of the data related to RN detection efforts is not publicly available, notional values were given to many of the metrics in the baseline alternative. However, the metrics were researched thoroughly so that reasonable notional values were given when possible. This list of metrics and their associated used in the model are given below in Table 1. This table also shows if the values used are notional and, if they are not, the source that the data comes from.

Table 1. Baseline Metric Values with Sources

<table>
<thead>
<tr>
<th>#</th>
<th>Metric</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Prob. of deterrence by denial</td>
<td>0.90</td>
<td>Notional</td>
</tr>
<tr>
<td>2</td>
<td>Prob. of identifying terrorists plans for RN attacks</td>
<td>0.90</td>
<td>Notional</td>
</tr>
<tr>
<td>3</td>
<td>Prob. of detecting US bound RN materials at foreign seaports</td>
<td>0.05</td>
<td>Bloomberg Article</td>
</tr>
<tr>
<td>4</td>
<td>Prob. of detecting US bound RN materials at foreign airports</td>
<td>0.90</td>
<td>Notional</td>
</tr>
<tr>
<td>5</td>
<td>Percentage of vessels in US coastal region that are searched</td>
<td>10%</td>
<td>Notional</td>
</tr>
<tr>
<td>6</td>
<td>Prob. of detecting RN materials at major US seaports</td>
<td>0.97</td>
<td>DHS OIG</td>
</tr>
<tr>
<td>7</td>
<td>Prob. of detecting RN materials at minor US seaports</td>
<td>0.85</td>
<td>Notional</td>
</tr>
<tr>
<td>8</td>
<td>Prob. of detecting inbound RN materials at primary US airports</td>
<td>0.95</td>
<td>Notional</td>
</tr>
<tr>
<td>9</td>
<td>Prob. of detecting RN materials at vehicle border crossings</td>
<td>0.93</td>
<td>Bakir, N.O. (Report)</td>
</tr>
<tr>
<td>10</td>
<td>Prob. of detecting RN materials at US rail border crossings</td>
<td>0.80</td>
<td>Notional</td>
</tr>
<tr>
<td>11</td>
<td>Prob. of detecting RN materials transported via land between points of entry</td>
<td>0.10</td>
<td>Notional</td>
</tr>
<tr>
<td>12</td>
<td>Prob. of detecting RN materials at coastal region between seaports</td>
<td>0.10</td>
<td>Notional</td>
</tr>
<tr>
<td>13</td>
<td>Prob. of detecting RN materials being transported within US via truck</td>
<td>0.05</td>
<td>Notional</td>
</tr>
<tr>
<td>14</td>
<td>Prob. of detecting RN materials being transported within US via train</td>
<td>0.20</td>
<td>Notional</td>
</tr>
<tr>
<td>15</td>
<td>Prob. of detecting RN materials being transported within US via inland waterways</td>
<td>0.05</td>
<td>Notional</td>
</tr>
<tr>
<td>16</td>
<td>Prob. of detecting RN materials being transported within US via primary airports</td>
<td>0.95</td>
<td>Notional</td>
</tr>
<tr>
<td>17</td>
<td>Prob. of detecting transport within US via non-primary airports</td>
<td>0.20</td>
<td>Notional</td>
</tr>
<tr>
<td>18</td>
<td>Prob. of detection of RN materials around major urban areas</td>
<td>0.90</td>
<td>Notional</td>
</tr>
<tr>
<td>19</td>
<td>Prob. of detection of RN materials around critical infrastructure</td>
<td>0.90</td>
<td>Notional</td>
</tr>
<tr>
<td>20</td>
<td>Percent of population covered by Urban Areas Security Initiative</td>
<td>37%</td>
<td>UASI/Population</td>
</tr>
<tr>
<td>21</td>
<td>Percentage of critical infrastructure targets protected</td>
<td>90%</td>
<td>Notional</td>
</tr>
<tr>
<td>22</td>
<td>Detection alert times</td>
<td>DIT at US border</td>
<td>Notional</td>
</tr>
<tr>
<td>23</td>
<td>Number of complaints from civil liberty groups</td>
<td>0</td>
<td>No complaints cited</td>
</tr>
<tr>
<td>24</td>
<td>Performance rating on level of impact (Constructed scale)</td>
<td>5-No Impact</td>
<td>Notional</td>
</tr>
<tr>
<td>25</td>
<td>Number of countries spending money for global nuclear detection efforts</td>
<td>40</td>
<td>Notional</td>
</tr>
</tbody>
</table>

For the baseline alternative, the metrics were also given a confidence interval to account for uncertainty common to most measurements. Since the confidence ranges typically could not be
accurately predicted using publicized data, most of the confidence intervals are featured as a triangular distribution to simplify the model. The triangular distributions each feature a notional minimum and maximum value with the midpoint being the value score noted in Table 1. However, for the constructed scales the uncertainty is measured as a probability breakdown between two or more of the possible scale outcomes. The metrics and their associated scores and confidence intervals are shown below in Table 2.

Table 2. Baseline Metric Values with Ranges

<table>
<thead>
<tr>
<th>#</th>
<th>Metric</th>
<th>Value</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Prob. of deterrence by denial</td>
<td>0.90</td>
<td>.80 - .95</td>
</tr>
<tr>
<td>2</td>
<td>Prob. of identifying terrorists plans for RN attacks</td>
<td>0.90</td>
<td>.80 - .95</td>
</tr>
<tr>
<td>3</td>
<td>Prob. of detecting US bound RN materials at foreign seaports</td>
<td>0.05</td>
<td>.04 - .08</td>
</tr>
<tr>
<td>4</td>
<td>Prob. of detecting US bound RN materials at foreign airports</td>
<td>0.90</td>
<td>.85 - .95</td>
</tr>
<tr>
<td>5</td>
<td>Percentage of vessels in US coastal region that are searched</td>
<td>10%</td>
<td>5% - 20%</td>
</tr>
<tr>
<td>6</td>
<td>Prob. of detecting RN materials at major US seaports</td>
<td>0.97</td>
<td>.95 - 1.00</td>
</tr>
<tr>
<td>7</td>
<td>Prob. of detecting RN materials at minor US seaports</td>
<td>0.85</td>
<td>.70 - .90</td>
</tr>
<tr>
<td>8</td>
<td>Prob. of detecting inbound RN materials at primary US airports</td>
<td>0.90</td>
<td>.80 - .95</td>
</tr>
<tr>
<td>9</td>
<td>Prob. of detecting RN materials at vehicle border crossings</td>
<td>0.93</td>
<td>.80 - 1.00</td>
</tr>
<tr>
<td>10</td>
<td>Prob. of detecting RN materials at US rail border crossings</td>
<td>0.80</td>
<td>.70 - .90</td>
</tr>
<tr>
<td>11</td>
<td>Prob. of detecting RN materials transported via land between points of entry</td>
<td>0.10</td>
<td>.05 - .15</td>
</tr>
<tr>
<td>12</td>
<td>Prob. of detecting inbound RN materials at coastal region between seaports</td>
<td>0.10</td>
<td>.05 - .20</td>
</tr>
<tr>
<td>13</td>
<td>Prob. of detecting RN materials being transported within US via truck</td>
<td>0.05</td>
<td>.05 - .10</td>
</tr>
<tr>
<td>14</td>
<td>Prob. of detecting RN materials being transported within US via train</td>
<td>0.20</td>
<td>.10 - .30</td>
</tr>
<tr>
<td>15</td>
<td>Prob. of detecting RN materials being transported within US via inland waterways</td>
<td>0.05</td>
<td>.05 - .10</td>
</tr>
<tr>
<td>16</td>
<td>Prob. of detecting RN materials being transported within US via primary airports</td>
<td>0.95</td>
<td>.90 - 1.00</td>
</tr>
<tr>
<td>17</td>
<td>Prob. of detecting transport within US via non-primary airports</td>
<td>0.20</td>
<td>.10 - .30</td>
</tr>
<tr>
<td>18</td>
<td>Prob. of detection of RN materials around major urban areas</td>
<td>0.90</td>
<td>.85 - .95</td>
</tr>
<tr>
<td>19</td>
<td>Prob. of detection of RN materials around critical infrastructure</td>
<td>0.90</td>
<td>.80 - .95</td>
</tr>
<tr>
<td>20</td>
<td>Percent of population covered by Urban Areas Security Initiative</td>
<td>37%</td>
<td>35% - 40%</td>
</tr>
<tr>
<td>21</td>
<td>Percentage of critical infrastructure targets protected</td>
<td>90%</td>
<td>80% - 95%</td>
</tr>
<tr>
<td>22</td>
<td>Detection alert times</td>
<td>DIT at US border</td>
<td>*</td>
</tr>
<tr>
<td>23</td>
<td>Number of complaints from civil liberty groups</td>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>24</td>
<td>Performance rating on level of impact (Constructed scale)</td>
<td>5-No Impact</td>
<td>5 (90%), 4 (10%)</td>
</tr>
<tr>
<td>25</td>
<td>Number of countries spending money for global nuclear detection efforts</td>
<td>40</td>
<td>35-60</td>
</tr>
</tbody>
</table>

*Range: Detect in Time Outside U.S (10%), Detect in Time at U.S. Border (90%), Detect in Time Inside U.S. (10%)

The data shown in these two tables along with additional information regarding the value scores and the full sources can be found in Appendix V.
4.2 Establishing the Weights

Measure weights are a significant aspect in value modeling; weights allow the user of the model to establish what metrics are more important to the stakeholders and then factor this into the overall score of alternatives. For appropriate swing weights to be used, the weights need to reflect both the importance of the value measure and the level of variation that exists in the range of the measure. More weight should be given to the metrics that are important to the stakeholders and have a large range from minimal acceptable to ideal. To assess the performance value of the GNDA, three different sets of weights were used: equal weights, weights based on spending, and weights based on the adversary’s viewpoint.

4.2.1 Weight Set 1: Equal Weights

The first set of weights considered is that of equal weights for all twenty-five metrics. This means that each metric is assigned .04% of the weight of the entire model. The results output from Logical Decisions using equal weights are shown below in Figure 15.

Figure 15. Evaluation of Alternatives Using Equal Weights

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideal</td>
<td>100</td>
</tr>
<tr>
<td>Baseline</td>
<td>50</td>
</tr>
</tbody>
</table>

The model output displays the overall value of the ideal and baseline alternatives into value component graphs (stacked bar graphs) based on the performance of each goal. The ideal alternative has an overall score of 100 as expected, while the baseline alternative has a value of
50 given the use of equal weights. The uncertainties of each measure are also shown for the baseline alternative. The value uncertainty summary for the baseline is shown in Figure 16.

Figure 16. Value Uncertainty Summary for Baseline Using Equal Weights

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Median</th>
<th>Min.</th>
<th>5%P</th>
<th>95%P</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>50</td>
<td>1</td>
<td>51</td>
<td>48</td>
<td>49</td>
<td>52</td>
<td>53</td>
</tr>
<tr>
<td>Ideal</td>
<td>100</td>
<td>No uncertainties</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This value shows that while the mean score is 50, the median overall score for the model is 51 while the minimum and maximum possible scores based on uncertainties are 48 and 53, respectively.

4.2.2 Weight Set 2: Weights Based on Government Spending

The second set of metrics was established to reflect the level of importance of the metrics to the DNDO and national government. The weights were created based on the United States’ viewpoint of what were the most important aspects in regards to nuclear counterterrorism. To assess the priorities of the DNDO, the weights were based on government spending in terms of nuclear counterterrorism measures. However, finding the breakdown of spending related to various measures was a complicated task. Because the DNDO does not have a centralized budget, spending towards a specific measure could span efforts from several different government agencies. Also, only a very general budget breakdown of each agency’s spending is publicly available. Nevertheless, weights were established to reflect spending as perceived from available budgets and individual research on metrics. Each measure was given a value of 10, 50 or 100. For metrics not associated with spending efforts, such as number of complaints from civil liberty groups, weights were just based on perceived importance. The breakdown of the second set of weights is shown below in Table 3.
Table 3. Weights Based on Government Spending

<table>
<thead>
<tr>
<th>Based on Spending</th>
<th>$5</th>
<th>$5</th>
<th>$5</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 identifying terrorists' plans</td>
<td>5</td>
<td>U.S Coastal Region</td>
<td>4</td>
</tr>
<tr>
<td>3 Foreign seaports</td>
<td>7</td>
<td>U.S minor seaports</td>
<td>11</td>
</tr>
<tr>
<td>6 U.S. major seaports</td>
<td>10</td>
<td>US rail border crossings</td>
<td>12</td>
</tr>
<tr>
<td>8 Inbound at U.S primary airports</td>
<td>18/20</td>
<td>Urban Area Security</td>
<td>13</td>
</tr>
<tr>
<td>9 U.S. Land Border Crossings</td>
<td>19/22</td>
<td>Critical infrastructure</td>
<td>14</td>
</tr>
<tr>
<td>16 Transport through US primary airports</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Based on Perceived Importance</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Deterrence by denial</td>
<td></td>
<td></td>
<td>24 Complaints by Civil Liberties Groups</td>
</tr>
<tr>
<td>23 Detection alert times</td>
<td></td>
<td></td>
<td>25 impact on commerce/economy</td>
</tr>
<tr>
<td>26 Number of countries spending</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Value:</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

These weights were input into the Logical Decisions, and the model output can be seen below in Figure 17.

Figure 17. Evaluation of Alternatives Based on Government’s Viewpoint

Based on this set of weights, the overall rating for the baseline performance is 62. This is a 24% increase from the performance rating based on equal weights. This significant increase (assuming the notional values have some accuracy to them) shows that the aspects of nuclear counterterrorism that the government considers to be more important correlate with the aspects that are performing better. It can be inferred that the government spending has led to an increased performance in measures that are considered to be of more importance.
Figure 18 below shows the value uncertainty summary for the baseline as measured by the weights based on government spending. As seen in the figure, the overall performance rating for the baseline can range from 59 to 65 with the mean score being 62, as mentioned earlier.

Figure 18. Value Uncertainty Summary Using Government’s Viewpoint Weights

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Median</th>
<th>Min.</th>
<th>5%P</th>
<th>95%P</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>62</td>
<td>1</td>
<td>62</td>
<td>59</td>
<td>60</td>
<td>64</td>
<td>65</td>
</tr>
<tr>
<td>Ideal</td>
<td>100</td>
<td>No uncertainties</td>
<td>59</td>
<td>60</td>
<td>64</td>
<td>65</td>
<td></td>
</tr>
</tbody>
</table>

4.2.3 Weight Set 3: Weights Based on Adversary’s Viewpoint

The third and final set of weights used to evaluate this model was based on the adversary’s viewpoint. The measures were given a value of 10, 50, or 100 based on their possible perception on ability to avoid detection. Because the metrics related to Goal 2 are scored on probability of detection at different layers in the GNDA, the highest weights were given to the path of least resistance to the attacker. This relies on the assumption that the attacker will take the path of the lowest probability of detection when planning an attack on the nation. The weights given to each metric are shown below in Table 4.
Table 4. Weights Based on Adversary’s Viewpoint

<table>
<thead>
<tr>
<th>#</th>
<th>Metric</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Prob. of deterrence by denial</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>Prob. of identifying terrorists plans for RN attacks</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>Prob. of detecting US bound RN materials at foreign seaports</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>Prob. of detecting US bound RN materials at foreign airports</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>Percentage of vessels in US coastal region that are searched</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>Prob. of detecting RN materials at major US seaports</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
<td>Prob. of detecting RN materials at minor US seaports</td>
<td>50</td>
</tr>
<tr>
<td>8</td>
<td>Prob. of detecting inbound RN materials at primary US airports</td>
<td>10</td>
</tr>
<tr>
<td>9</td>
<td>Prob. of detecting RN materials at vehicle border crossings</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>Prob. of detecting RN materials at US rail border crossings</td>
<td>50</td>
</tr>
<tr>
<td>11</td>
<td>Prob. of detecting RN materials transported via land between points of entry</td>
<td>100</td>
</tr>
<tr>
<td>12</td>
<td>Prob. of detecting inbound RN materials at coastal region between seaports</td>
<td>100</td>
</tr>
<tr>
<td>13</td>
<td>Prob. of detecting RN materials being transported within US via truck</td>
<td>100</td>
</tr>
<tr>
<td>14</td>
<td>Prob. of detecting RN materials being transported within US via train</td>
<td>10</td>
</tr>
<tr>
<td>15</td>
<td>Prob. of detecting RN materials being transported within US via inland waterways</td>
<td>50</td>
</tr>
<tr>
<td>16</td>
<td>Prob. of detecting RN materials being transported within US via primary airports</td>
<td>10</td>
</tr>
<tr>
<td>17</td>
<td>Prob. of detecting transport within US via non-primary airports</td>
<td>50</td>
</tr>
<tr>
<td>18</td>
<td>Prob. of detection of RN materials around major urban areas</td>
<td>50</td>
</tr>
<tr>
<td>19</td>
<td>Prob. of detection of RN materials around critical infrastructure</td>
<td>50</td>
</tr>
<tr>
<td>20</td>
<td>Percent of population covered by Urban Areas Security Initiative</td>
<td>50</td>
</tr>
<tr>
<td>21</td>
<td>Percentage of critical infrastructure targets protected</td>
<td>50</td>
</tr>
<tr>
<td>22</td>
<td>Detection alert times</td>
<td>100</td>
</tr>
<tr>
<td>23</td>
<td>Number of complaints from civil liberty groups</td>
<td>10</td>
</tr>
<tr>
<td>24</td>
<td>Performance rating on level of impact (Constructed scale )</td>
<td>10</td>
</tr>
<tr>
<td>25</td>
<td>Number of countries spending money for global nuclear detection efforts</td>
<td>50</td>
</tr>
</tbody>
</table>

The output of Logical Decisions using these weights and the uncertainty summary are shown below in Figure 19 and Figure 20.

Figure 19. Evaluation of Alternatives Using Adversary Weights
Using weights based on the adversary’s viewpoint decreased the mean baseline performance rating to 36. This is to be expected since higher weight was given to the metrics related to probability of detection that had a lower score. Based on the uncertainties, the minimum possible rating score using the inputs specified in the report is a 33 while the maximum score is a 38.

4.3 Evaluating the Model

4.3.1 Sensitivity Analysis

When using value modeling to decide between candidate solutions, it is important to conduct sensitivity analysis to evaluate the robustness of the analysis. Sensitivity analysis of weights is conducted to see if “a change in an assumption changes the preferred solution” (Parnell et al., 2011). Because the model in this report only compares the current system to the ideal outcome, the use of sensitivity analysis to compare alternatives is not applicable. However, sensitivity analysis can be performed to show how change in weights will affect the overall performance rating of the baseline.

For an example, Metric 6, the probability of detecting RN materials at major U.S. seaports, is considered using the results from the second set of weights that was based on government spending. The sensitivity graph for the measure that was created by the Logical Decisions is shown below in Figure 21.
On the y-axis of this graph is the overall model performance rating based on the given set of weights. On the x-axis is the percent of total weight that this measure makes up. The vertical line to the right of the y-axis shows where the measure currently is. Based on this set of weights, Metric 6 is currently set to 7% of the total weight of the model. The green line shows how the total value of the model increases or decreases based on how the percent of total weight for this metric is changed. If Metric 6 was given no weight in the model, the mode’s overall performance rating would drop to 59. However, if the government thought that probability of detection at seaports was the most important aspect in all of nuclear counterterrorism and set its weight to 50% of the total weight, the performance of the model would increase to approximately 75 (estimated from graph).
Sensitivity analysis is not only limited to evaluating the weight assigned to a specific measure; it can also be applied an overarching section of the model that is composed of multiple metrics, such as one of the four goals in this model.

4.3.2 Cost-Benefit Analysis

Cost-benefit analysis is a valuable technique typically used to evaluate the cost vs. value tradeoff for a series of alternatives. Because only one alternative, the baseline, was evaluated in this model, cost-benefit analysis can instead be used to show how decreases or increases in spending in specific GNDA areas will likely affect the overall score of the model. To provide an example for this analysis, Metric 10, detecting an attempt to bring RN materials into the U.S. at rail border crossings, is considered. Since 2001 well over 1,000 Radiation Portal Monitors (RPMs) have been deployed at border crossings around the nation. Each portal monitor costs roughly $450,000 (Schneidmiller, 2009).

For the example, suppose the Customs Border Patrol deploys 50 additional RPMs at rail border crossings, making the total cost of the project around $22.5 million. The current probability of detecting RN material at rail border crossings for the baseline model is at .80. Suppose these additional monitors are projected to bring the total probability for Metric 10 up to .90. By inputting this new metric value into the model, the overall GNDA performance rating (using the second set of weights) increases from 62 to 63. This analysis can be repeated for other spending alternatives to see how they affect the model output. This analysis should then be applied to evaluate how future resources can be allocated so that the potential GNDA performance rating is maximized.
5 Conclusion

5.1 Model Significance

Evaluating the effectiveness of the Global Nuclear Detection Architecture is an important task that will allow for the progress and development of the architecture to be tracked over time. The evaluation will allow for a better prioritization of GNDA resources, resulting in more efficient allocation of funds and the potential to improve the performance at a quicker rate. Even though the effectiveness rating in this report cannot be taken as true due to the use of notional data, the report provides a good example of how to assess the GNDA performance.

5.2 Future Development

The DNDO can use this model to input the classified data and come up with an applicable performance rating for the GNDA. The DNDO should adapt the model to adjust the metrics where it sees necessary, and it should decide on the set of weights deemed most appropriate for the GNDA evaluation. As suggested in the report by the NRC, the DNDO should also create an Analysis Framework to assist in the model’s evaluation. The framework will need to incorporate the development of additional models, similar to the PEM model mentioned earlier, that evaluate the performance of specific metrics within the GNDA model.
REFERENCES


APPENDIX I

List of Commonly Used Acronyms

• DNDO: Domestic Nuclear Detection Office
• GNDA: Global Nuclear Detection Architecture
• NCT: Nuclear Counterterrorism
• NRC: National Research Council
• RPM: Radiation Portal Monitor
• UASI: Urban Areas Security Initiative
APPENDIX II
Statement of Task

An ad hoc committee will conduct a study and prepare a report to the Domestic Nuclear Detection Office (DNDO) on quantitative approaches for evaluating the effectiveness of the Global Nuclear Detection Architecture, specifically in the context of the following two tasks:

**Task 1:** Assess the feasibility of using performance measures and quantitative metrics for evaluating progress toward meeting the performance goals in the Global Nuclear Detection Architecture Strategic Plan

The committee should assess the feasibility of using performance measures and quantitative metrics for evaluating progress in meeting these performance goals. This assessment should consider the following factors:

- Definition of performance measures for each of the performance goals in the Strategic Plan.
- Definition of quantifiable performance metrics for each performance measure including, as appropriate, efficiency, output, and outcome-oriented performance measures.
- Identification of data to be used to quantify these performance metrics.
- Identification of methodologies to be used to collect and analyze these data.
- Specification of performance target values for assessing the effectiveness of each performance measure.

If the use of performance measures and quantitative metrics is determined to be feasible, the committee should, to the extent practical, recommend specific performance measures, metrics, and the other supporting information described in the list above for consideration by the Domestic Nuclear Detection Office.

If the use of performance measures and metrics is determined to be infeasible, the committee should recommend alternative evaluation approaches.

**Task 2:** Recommend approaches for evaluating the overall effectiveness of the Global Nuclear Detection Architecture
The committee should specifically recommend

- Approaches for developing an overall analysis framework to assess the effectiveness of the Global Nuclear Detection Architecture in terms of its ability to detect, deny, confuse, and/or deter adversaries.

- Approaches for exercising this analysis framework using combinations of modeling/simulation, red teaming, and/or related methods to assess the cost effectiveness of and tradeoffs in Global Nuclear Detection Architecture components.

In executing these tasks the committee should examine efforts by other organizations to develop risk-informed metrics and analysis approaches for complex technological systems.

This project is sponsored by the U.S. Department of Homeland Security's Domestic Nuclear Detection Office.
APPENDIX III

Notional Strategic Plan with Metrics

Note: Objectives within the scope of the GNDA are highlighted by stars.

Vision: For U.S. citizens to live free from the fear of nuclear or radiological terrorism
Mission: Protect the nation against terrorist attacks that use nuclear and radiological (RN) materials

Goal 1: Reduce the threat to the nation of radiological or nuclear (RN) attacks by terrorists.
   Objective: Secure RN materials in place.
     ★ Objective: Deter terrorists’ RN attacks by demonstrating high likelihood of failure.
     Metric: Effectiveness of deterrence by denial
     Objective: Deter terrorists’ RN attacks by demonstrating the capability for attribution and intent of retribution.
     ★ Objective: Identify terrorist plans for radiological or nuclear attacks.

Goal 2: Reduce the vulnerability of the nation to RN attacks by terrorists.
     ★ Objective: Detect RN materials out of regulatory control by layers of detection:
       outside of the United States,
       at the border of the United States, and
       Metric: Probability of detecting an attempt to bring RN materials into the United States at ports of entry (POEs)
       Metric: Probability of detecting an attempt to bring RN materials into the United States between POEs
       inside of the United States
       Objective: Disrupt terrorist attacks that use RN materials after detection
       Objective: Return RN materials to regulatory control
       Objective: Protect targets from RN attacks

Goal 3: Reduce the consequences of a successful radiological or nuclear attack on the nation
     ★ Objective: Divert RN attacks to lower-consequence targets
     ★ Objective: Provide early warning of RN attacks
       Metric: Detection alert times
       Objective: Respond and recover
       Objective: Decontaminate

Goal 4: Reduce unintended side effects of RN countermeasures
     ★ Objective: Minimize impacts on privacy and civil liberties
     ★ Objective: Minimize impacts on the flow of commerce and the economy
     ★ Objective: Avoid transfer of RN risks to other nations

Goal 5: Reduce costs of RN countermeasures
     ★ Objective: Reduce research and development costs
     ★ Objective: Reduce capital costs
     ★ Objective: Reduce operations and maintenance costs
     Metric: Total life-cycle cost
APPENDIX IV
Entire Model Structure

Vision: “For U.S. citizens to live free from the fear of nuclear or radiological terrorism.”

Mission: “Protect the nation from terrorist attacks that use radiological or nuclear (RN) materials.”

Goal 1: Reduce the threat to the nation of radiological or nuclear (RN) attacks by terrorists.

- Objective 1.1: Deter terrorists’ RN attacks by demonstrating the high likelihood of failure
  - Metric 1: Probability of deterrence by denial
- Objective 1.2: Identify terrorist plans for radiological or nuclear attacks
  - Metric 2: Probability of identifying terrorists’ plans via intelligence efforts

Goal 2: Reduce the vulnerability of the nation to RN attacks by terrorists.

- Objective 2.1: Detect RN materials out of regulatory control outside of the United States
  - Sub-Objective 2.1.1: Detect RN materials out of regulatory control at foreign ports of departure (PODs)
    - Metric 3: Probability of detecting U.S. bound RN materials at foreign seaports
    - Metric 4: Probability of detecting U.S. bound RN materials at foreign airports
  - Sub-Objective 2.1.2: Detect RN materials out of regulatory control in route to the U.S.
    - Metric 5: Percentage of vessels in the U.S. coastal region that are searched
- Objective 2.2: Detect RN materials out of regulatory control at the border of the United States
  - Sub-Objective 2.2.1: Detect RN materials at U.S. ports of entry (POEs)
    - Metric 6: Probability of detecting an attempt to bring RN materials into the U.S. at major U.S. seaports
    - Metric 7: Probability of detecting an attempt to bring RN materials into the U.S. at minor U.S. seaports
- Metric 8: Probability of detecting an attempt to bring RN materials into the U.S. at primary U.S. airports
- Metric 9: Probability of detecting an attempt to bring RN materials into the U.S. at vehicle border crossings
- Metric 10: Probability of detecting an attempt to bring RN materials into the U.S. at rail border crossings
  - Sub-Objective 2.2.2: Detect RN materials between U.S. ports of entry (POEs)
    - Metric 11: Probability of detecting an attempt to bring RN materials into the U.S. via land between ports of entry
    - Metric 12: Probability of detecting an attempt to bring RN materials into the U.S. via coastal region between seaports
- Objective 2.3: Detect RN materials out of regulatory control inside of the United States
  - Sub-Objective 2.3.1: Detect RN materials being transported inside the U.S.
    - Metric 13: Probability of detecting materials transported within the U.S. via train
    - Metric 14: Probability of detecting materials transported within the U.S. via highway system
    - Metric 15: Probability of detecting materials transported within the U.S. via inland waterways
    - Metric 16: Probability of detecting materials transported within the U.S. via primary airports
    - Metric 17: Probability of detecting materials transported within the U.S. via non-primary airports
  - Sub-Objective 2.3.2: Detect RN materials within target vicinity inside the U.S.
    - Metric 18: Probability of detecting RN materials around major urban areas
    - Metric 19: Probability of detecting RN materials around critical infrastructure

Goal 3: Reduce the consequences of a successful radiological or nuclear attack on the nation.

- Objective 3.1: Divert RN attacks to lower-consequence targets
Sub-Objective 3.1.1: Divert RN attacks to lower-consequence cities
  ▪ Metric 20: Percent of U.S. population covered by Urban Areas Security Initiative
Sub-Objective 3.1.2: Divert RN attacks to lower-consequence critical infrastructure
  ▪ Metric 21: Percent of critical infrastructure targets protected

Objective 3.2: Provide early warning of RN attacks
  ▪ Metric 22: Detection alert times

Goal 4: Reduce the unintended side effects of RN countermeasures

Objective 4.1: Minimize impacts on privacy and civil liberties
  ▪ Metric 23: Number of complaints from civil liberty groups
Objective 4.2: Minimize impacts on flow of commerce and the economy
  ▪ Metric 24: Performance rating on level of impact to commerce and the economy
Objective 4.3: Avoid transfer of RN risks to other nations
  ▪ Metric 25: Number of countries spending money on global nuclear detection efforts
# APPENDIX V

Baseline Metric Scores with Sources and Additional Notes

<table>
<thead>
<tr>
<th>#</th>
<th>Metric</th>
<th>Value</th>
<th>Range</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Prob. of deterrence by denial</td>
<td>0.90</td>
<td>.80-.95</td>
<td>N</td>
</tr>
<tr>
<td>2</td>
<td>Prob. of identifying terrorists plans for RN attacks</td>
<td>0.90</td>
<td>.80-.95</td>
<td>N</td>
</tr>
<tr>
<td>3</td>
<td>Prob. of detecting US bound RN materials at foreign seaports</td>
<td>0.05</td>
<td>.04-.08</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Prob. of detecting US bound RN materials at foreign airports</td>
<td>0.90</td>
<td>.85-.95</td>
<td>N</td>
</tr>
<tr>
<td>5</td>
<td>Percentage of vessels in US coastal region that are searched</td>
<td>10%</td>
<td>5%-20%</td>
<td>N</td>
</tr>
<tr>
<td>6</td>
<td>Prob. of detecting RN materials at major US seaports</td>
<td>0.97</td>
<td>.95-1.00</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Prob. of detecting RN materials at minor US seaports</td>
<td>0.85</td>
<td>.70-.90</td>
<td>N</td>
</tr>
<tr>
<td>8</td>
<td>Prob. of detecting inbound RN materials at primary US airports</td>
<td>0.90</td>
<td>.80-.95</td>
<td>N</td>
</tr>
<tr>
<td>9</td>
<td>Prob. of detecting RN materials at vehicle border crossings</td>
<td>0.93</td>
<td>.80-1.00</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>Prob. of detecting RN materials at US rail border crossings</td>
<td>0.80</td>
<td>.70-.90</td>
<td>N</td>
</tr>
<tr>
<td>11</td>
<td>Prob.of detecting RN materials transported via land between points of entry</td>
<td>0.10</td>
<td>.05-.15</td>
<td>N</td>
</tr>
<tr>
<td>12</td>
<td>Prob. of detecting inbound RN materials at coastal region between seaports</td>
<td>0.10</td>
<td>.05-.20</td>
<td>N</td>
</tr>
<tr>
<td>13</td>
<td>Prob. of detecting RN materials being transported within US via truck</td>
<td>0.05</td>
<td>.05-.10</td>
<td>N</td>
</tr>
<tr>
<td>14</td>
<td>Prob. of detecting RN materials being transported within US via train</td>
<td>0.20</td>
<td>.10-.30</td>
<td>N</td>
</tr>
<tr>
<td>15</td>
<td>Prob. of detecting RN materials being transported within US via inland waterways</td>
<td>0.05</td>
<td>.05-.10</td>
<td>N</td>
</tr>
<tr>
<td>16</td>
<td>Prob. of detecting RN materials being transported within US via primary airports</td>
<td>0.95</td>
<td>.90-1.00</td>
<td>N</td>
</tr>
<tr>
<td>17</td>
<td>Prob. of detecting transport within US via non-primary airports</td>
<td>0.20</td>
<td>.10-.30</td>
<td>N</td>
</tr>
<tr>
<td>18</td>
<td>Prob. of detection of RN materials around major urban areas</td>
<td>0.90</td>
<td>.85-.95</td>
<td>N</td>
</tr>
<tr>
<td>19</td>
<td>Prob. of detection of RN materials around critical infrastructure</td>
<td>0.90</td>
<td>.80-.95</td>
<td>N</td>
</tr>
<tr>
<td>20</td>
<td>Percent of population covered by Urban Areas Security Initiative</td>
<td>37%</td>
<td>35%-40%</td>
<td>4</td>
</tr>
<tr>
<td>21</td>
<td>Percentage of critical infrastructure targets protected</td>
<td>90%</td>
<td>80%-95%</td>
<td>N</td>
</tr>
<tr>
<td>22</td>
<td>Detection alert times</td>
<td>DIT at US border</td>
<td>*</td>
<td>N</td>
</tr>
<tr>
<td>23</td>
<td>Number of complaints from civil liberty groups</td>
<td>0</td>
<td>None</td>
<td>5</td>
</tr>
<tr>
<td>24</td>
<td>Performance rating on level of impact (Constructed scale)</td>
<td>5-No Impact</td>
<td>5 (90%), 4 (10%)</td>
<td>N</td>
</tr>
<tr>
<td>25</td>
<td>Number of countries spending money for global nuclear detection efforts</td>
<td>40</td>
<td>35-60</td>
<td>N</td>
</tr>
</tbody>
</table>

For the “Notes” column, the letter ‘N’ indicates that the metric was given a notional value. However, the sources or details for the remaining metrics are listed below


a. Relies on assumption that RPMs at the northern U.S. border are performing at the same success rate

4. Percent value calculated by totaling the estimated population of the twenty-five cities covered by the Urban Area Security Initiative in 2013 and dividing this number by the total United States population
   a. Source of twenty-five UASI funded cities:

5. No complaints could be found from numerous Google searches.