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Prioritizing Countries by Concern Regarding Access to Weapons of Mass Destruction Materials

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Abstract

This article presents a global prioritization methodology that evaluates the relative risks of non-state actor acquisition of materials that could be used in chemical, biological, radiological, nuclear and high explosive Weapons of Mass Destruction (WMD) from the country's relevant infrastructure. Prioritization is based on three domains: 1. Assessing relative scale of materials in each country, 2. The country's corresponding security posture, and 3. The presence of threat actors. The output is a list of countries prioritized from greatest risk to least. Rather than providing an overall 1 to N ranking, however, the results are placed into tiers based upon their natural groupings within the three domains. The countries in the highest tiers are flagged as potential US national security concern; those scoring in the middle and at the bottom are flagged as posing lower US national security concern. A systematic approach assesses each country by leveraging many disciplines, such as risk and decision analysis, as well as expert judgement. A quantitative value model based on Multi-Attribute Value Theory (MAVT) organizes the objectives scoring criteria into a value tree using lessons learned from previous studies, published literature, and expert judgement. The article presents the prioritization categories and corresponding value model scoring criteria to include measurement type, weight, range, and value preference. Country names and data are notional in order to share the details on the underlying methodology and model without identification of actual security risks. A deliberative process addresses factors external to the model and scrutinizes inputs, methodology, model, and results.

Keywords: Prioritization model; WMD materials; Security posture; Threat presence Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525 SAND2021-3697 J.

Introduction

Sandia National Laboratories' Global Risk and Decision Analysis (GRADA) team has been providing risk management, decision analysis support, and tools specifically to support prioritization activities focusing on the prevention of the development of and the response to Weapons of Mass Destruction (WMD) and other non-conventional weapons since 2003. This work supports the US's cooperative threat reduction efforts, which focuses on "reducing threats posed by states of concern and terrorist organizations seeking to acquire weapons of mass destruction material, equipment, and expertise. The programs focus on critical states around the world where proliferators seek to acquire WMD and terrorists threaten U.S. interests".

The GRADA team includes subject matter experts across numerous technical domains, among them, physical security, international security, regulatory frameworks, public health, physics, chemistry, biology, risk analysts, decision analysts, computer scientists, system engineers, statisticians, and modeling and simulation. Over the last 15 years, the team's work has expanded from specifically focusing on where exploitable materials exist to more than a dozen analysis products addressing topics such as dual-use equipment, evolving expertise, the movement of materials and equipment, the changing dynamics of insider threats, and assessing the security posture maturity level of a country or facility. Several analysis products (methodologies, models, and final results) have been reviewed by the National Academies of Science or through robust external peer reviews.

The core of these methodologies used in these analysis products draws from Multi-Attribute Value Theory (MAVT), which guides the development of the multiple objective decision analysis frameworks; the framework organizes a defined problem space (e.g. risks of acquisition of biological materials) into a hierarchy of factors and the lowest level factors are quantified by measurable scoring criteria [2]. MAVT uses the values and preferences of the decision maker, which improves the overall acceptance of the results by the stakeholders. These values and preferences are often the result of many discussions and ideally based on a consensus of stakeholders. There are unique models developed for each defined problem space, but each of these models leverages the same underlying methodology and systems analysis principles. Each model relies on the creation of value functions to explicitly analyze each criterion. The creation of each unique value model consists of four components: defining the attributes used to measure the criteria, defining value functions for each attribute based upon the preference toward the objectives, assessing the weights of each criteria, and defining an algorithm for combining all the attribute scores into a single score reflecting the final relative value [3].

This paper focuses on the country prioritization model considering the problem: "there is an ongoing concern regarding a threat actor's (threat actors include terrorists, criminals, and potential radicalized individuals) acquisition of materials that could be used in the

development of a biological weapons from a country's existing biological infrastructure." As such this paper will provide a methodology and model supporting answering the following question:

What is a country's relative risk of a threat group's acquisition of dual-use biological materials (pathogens, equipment, or even expertise)?

The following sections provide the overall framework that forms the basis of the underlying methodology as well as the actual model used in defining the relative prioritization. Because of subject sensitivity, country names are not listed, and the data and all the model parameters are synthetic. The actual model considers the relative risk of almost 200 countries. This example is limited to 20 countries to demonstrate the efficacy of the approach. The methodology applied to develop the model, the process used to elicit information from stakeholders, the weighting process used, the development of the value functions, and the final math formulation will be presented. The descriptions of the value functions may be generalized due to the nature of the model but will be sufficient for insight into the way each measure is scored. In addition, the deliberative approach [4] applied in every step of the methodology will be discussed. This paper includes the notional results, observations and key insights, limitations, and other possible improvements to the approach beyond MAVT.

Framework Overview

The framework implements an analytic-deliberative process [5]. Figure 1 shows the overall methodology.

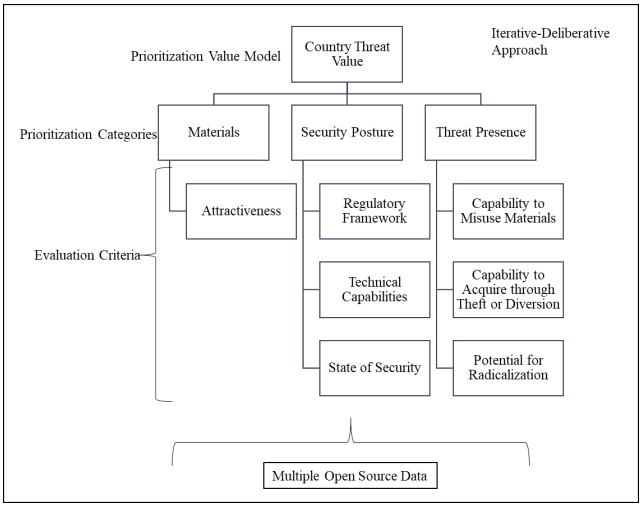

Figure 1: Overall methodology.

The overall objective of this methodology is to prioritize countries by the potential for a non-state actor to exploit resources of the country in the development of a WMD.

The first step is to outline the factors or criteria that support the prioritization, as seen in Figure 1; these factors or criteria are broken into three major topics: The presence of resources (or materials) that could be exploited in the development of a WMD, the security of these resources (security posture), and the presence of a threat aiming to exploit these resources in the development of a WMD. These three topics mirror the general concepts surrounding security vulnerability assessments where assets, threats targeting those assets, and security vulnerabilities that would allow that threat to achieve its goal regarding those assets are defined [6]. Under each topic, detailed criteria are defined leveraging expert opinion and existing models; these criteria support defining the overall value of a country under each topic. For example, the criteria that define the security posture of a country include the regulatory frameworks regarding security of resources of interest, the technical capabilities regarding security, and the state of security of those resources; these three factors combine to create a single value reflecting the country's security posture.

For each of these criteria, data is collected from a variety of open sources. Table 1 provides a partial list of publicly available data sources used for this model. Some data is collected as proxy since exact data is not available and some data is collected as background to support outlining measurements via constructed ordinal interval scales. Comparing the available data to the criteria and leveraging the diverse expertise of the team, value functions to normalize raw data in a manner reflective of its relationship to the criteria are developed. These value functions, along with the data sources, are reviewed and discussed with external reviewers and stakeholders prior to formal analysis. Each country is evaluated for each evaluation criterion of each prioritization category. The results provide a preliminary prioritization for each country. The final prioritization step is a deliberative process between analyst, SMEs, stakeholders, and decision makers. With the final prioritization, decision makers have an analytically based tiering to help inform how to adjust policies and allocate resources.

Sample list of public data sources
Corruption perception (transparency.org)
Country corruption index (transparency.org)
Country inflation rates (tradingeconomics.com)
Country regulatory policies (oecd.org)
Country safety index (globalsafetyindex.com)
Country unemployment rate (en.wikipedia.org)
DHS Report on community-level indicators of radicalization
Economic freedom index (heritage.org)
Fragile states index (fundforpeace.org/fsi)
Global health security index (NTI)
Global terrorism index (globalterrorismindex.org)
Income inequality ranking (GINI) (en.wikipedia.org)
Nuclear threat initiative (NTI) Nuclear Security Index
Political stability index (en.wikipedia.org)
Political terror scale (politicalterrorscale.org)
Recent outbreaks (ProMedMail.org)
Recent relevant research publication (SCOPUS.org)
Unemployment rate of the educated population (databank.worldbank.org)

Table 1: Public data sources

Methodology

The National Research Council defines a deliberative process as "any formal or informal process for communication and collective consideration of issues. Participants in deliberation discuss, ponder, exchange observations and views, reflect upon information and judgments concerning matters of mutual interest and attempt to persuade each other" [7]. The Deliberative Method has been used in similar studies such as Lundberg and Willis [8] to compare risk from multiple hazards. In a comparable manner, an iterative-deliberative method is applied to this framework to select countries, develop criteria and value model, assign weights, evaluate the country, and then complete final review and adjudication of prioritization. The deliberative method is implemented in five steps [9] modifying the context to: country ranking (prioritization) vs. risk ranking:

- Determine the countries to be prioritized
- Identify the criteria to consider (includes the value tree)
- Evaluate each country in terms of the criteria used to score each country
- Select stakeholders and analysts and perform initial prioritization
- Describe the issues identified and the resulting country prioritization

Country evaluation prioritization

The country prioritization model provides a global overview assessing the threat toward a country's infrastructure. The specific focus here is theft or diversion of material that could be utilized in the development of a biological weapon. The model does not include, for example, geo-political or specific stakeholder priorities that may also be considered when making programmatic decisions.

Through the deliberative process, the model considers three critical categories to determine the individual country's overall prioritization (see Figure 1):

Materials: The relative level of resources in a country that could be used in the development of a WMD and the utility (or attractiveness) of those materials to a threat group;

Security Posture: State of security, technical capabilities, and regulatory framework of the country regarding the materials; and

Threat Presence: Intent and capabilities of non-state actors who operate and freely move within the country.

Each prioritization category is evaluated and quantified by measurable ordinal scoring criteria or by the specific raw data (e.g. counts). Each criterion x, the ordinal scale or raw data, is transformed into an interval scale, v(x), through the deliberative process. The result is unique value functions, normalized to a standard scale 0-1, where one is the highest possible criterion value and zero reflects its absence in the country (see Table 2).

Criteria, Definition, Description, Global Weights, and Value Functions		
1. Materials: Attractiveness (Constructed Direct)		Global weight
Attractiveness of the defined materials to a threat actor based upon the potential impact of their misuse, characterized by the presence, type, quantity, state and form of WMD materials		0.5
Level	Description	Value function
1	Not feasible for use in the development of a WMD	0
2	Minimal feasibility for use in the development of a WMD	0.01
3	Feasibility for use in the development of a WMD, processing or other work required	0.1
4	Useful in the development of a WMD	1
2. Security posture: Regulatory framework (constructed direct)		Global weight
The maturity of regulatory framework that impacts the overall security of the materials		0.06
Level	Description	Value function
1	Siloed: Frameworks may exist, but are isolated and fragmented	0
2	Transition: Frameworks being improved to support more effective risk management	0.25
3	Managed: Frameworks are robust and enforcement feasible	0.5
4	Transformed: Frameworks are robust, enforcement exists, and included in outreach initiatives	0.75
5	Advantaged: Frameworks are optimized, balanced, maintained, and include continual improvement	1
3. Security posture: Technical capability (constructed direct)		Global Weight
The maturity of technical capability that impacts the overall security of the materials		0.06
Level	Description	Value Function
1	Initial: No security culture, limited, unpredictable, and poorly controlled technology	0
2	Managed: Basic security awareness and generalized security processes	0.25
3	Defined: Basic steps to implement a security culture and the abilities to implement standard security measures	0.5
4	Predictable: Advanced steps to support a security culture and the	0.75

	abilities to implement robust security measures	
5	Optimizing: Mature security culture exists, the abilities to implement robust security measures and continual improvement	1
4. Security posture: State of security (constructed direct)		Global weight
The maturity of state of security that impacts the overall security of the materials		0.13
Level	Description	Value function
1	Non-Existent: No security measures identified; deterrence may exist but is limited	0
2	Managed: Threats/risks identified, but security measures are compliance based and ad hoc	0.33
3	Defined: Threats/risks identified, and security measures are robust, structured, and follow best practices	0.66
4	Optimizing: Threats/risks identified, and security measures are robust, structured, follow best practices, and includes robust management level support	1
5. Threat presence: Capability to misuse materials (constructed direct)		Global weight
The capabilities of terrorist with intent regarding the development of a WMD		0.08
Level	Description	Value function
1	Capability level description is not provided.	0
2		0.2
3		0.5
4		1
6. Threat presence: Capability to acquire through theft or diversion (constructed direct)		Global weight
The capabilities of both terrorists and criminals with intent to acquire materials which could be used to support the development of a WMD		0.1
Level	Description	Value function
1	Capability level description is not provided.	0
2		0.33
3		0.67
4		1
7. Threat presence: Country criminal index (constructed proxy for the potential for radicalization)		Global weight
The capabilities of both terrorists and criminals with intent to acquire materials which could be used to support the development of a WMD		0.08
Level	Description	Value function
1	Capability level description is not provided.	1
2		0.2
3		0.05
4		0

Table 2: Constructed Scales and Value Functions for the Global WMD Prioritization Value Tree (the Global Weight is the Product of the Evaluation Measure's Weight and the Value

Using the deliberative process, each criterion weight is assigned based upon the subject matter expert's preference of the criterion's swing of importance in assessing the parent prioritization category [10]. Research shows that additive models are the most extensively used model in multi-criteria decision analysis [11] with the condition of preferential independence among the criteria. Additionally, many weighting methods are built on the assumption of the use of an additive value function. The final prioritization value for Materials, Security Posture, and Threat Presence are combined using the math model in the equation below.

$$v(\boldsymbol{x}) = \sum_{i=1}^{n} w_i v_i(x_i) \quad (1)$$

Mathematically, the total country score would be calculated by aggregating the weight (wm) times the criterion v(xm), where n is the total number of criteria being considered, wi is the weight of the ith criteria, vi(xi) is the ith value function, and x is the vector of all criteria values and weights wi must sum to 1.

$$\sum_{i=1}^{n} w_i = 1 \quad (2)$$

Prioritization value model (Tree): Given the need to prioritize countries and the data sources, an approach that is similar to other methods used to prioritize critical assets is applied as a part of the iterative-deliberate process [12]. For example, RAND identifies five models which use the objectives' hierarchy of factors which is referred to here as the value model (value tree) and is more affiliated with MAVT [13].

Through data analysis and consultation with decision makers, criteria to address each of the prioritization categories, Materials, Security Posture, and Threat Presence, are developed. The deliberative process and research, together with subject matter expert consultations, determines the scheme for how these categories should be combining for the overall prioritization.

Presence of materials: The presence of specific materials (or resources) in a country can be used to define the potential of that country being targeted or exploited by a threat group. Materials are typically associated with a site that is working with, producing, or using the material as part of normal operations; such sites might include a pharmaceutical production company, a research reactor, a veterinary diagnostic laboratory, a hospital, etc. The prioritization process collects information on the available materials in evaluation of the materials' value in development of a WMD and site level meta

data to help provide context regarding the country's security posture and inform discussions on engagement options.

The materials at a site or those generalized across a country are given a score x, based upon their Attractiveness in WMD development - the attractiveness may not be the same for all sites within a country, but for a country level analysis the attractiveness of each individual site is not considered, but rather the attractiveness of the collection of sites within the country. The score is based upon the type of material, the quantity (where relevant), and the physical state of the material as well as its feasibility for use (see Table 2).

Security posture: The Security Posture (Figure 1) of a country (focused toward the specific materials) is based on measures that reflect its level of maturity in a series of security elements. The use of a maturity model to reflect the Security Posture helps promote and track improvements over time. The three primary means used to measure a country's Security Posture maturity is divided into three criteria as shown in Figure 1: Regulatory Framework-having regulatory frameworks that support and enforce the security of materials; Technical Capabilities-having robust technical capabilities within a country to promote and maintain security; and State of Security-having robust security measures designed to support protection of materials from theft or diversion.

These criteria are derived from the IAEA's definition of nuclear security: "Nuclear Security includes the assembly of characteristics, attitudes and behavior of individuals, organizations and institutions which serves to support and enhance nuclear security" [14] and the CDC's defined end-state for the GHSA biosafety and biosecurity action package, defined as: "Implementation of a comprehensive, sustainable and legally embedded national oversight program for biosafety and biosecurity, including the safe and secure use, storage, disposal, and containment of pathogens found in laboratories and a minimal number of holdings across the country, including research, diagnostic and biotechnology facilities. A cadre of biological risk management experts possesses the skillset to train others within their respective institutions. Strengthened, sustainable biological risk management best practices are in place using common educational materials" [15].

The maturity of regulatory frameworks to support and enforce security is based on the RSA Archer Maturity Model [16], where the levels of maturity are defined in five evolving stages:

- Siloed – Regulatory frameworks may exist to manage risks associated with materials but are isolated and fragmented;
- Transition – Regulatory frameworks are being improved to support more effective risk management of the materials and scopes expanded;
- Managed – Regulatory frameworks are robust enough to be effective at supporting risk management of materials, enforcement feasible;
- Transform – Initiative underway to help industries, government facilities, research and development programs, and universities implement policies to support risk management, enforcement exists; and,
- Advantaged – Regulatory frameworks and management policies are optimized and balanced to ensure business and risk priorities are maintained, communication and continual improvement processes exist.

Proxy data was used to determine a country's level of regulatory maturity to score the Regulatory Framework criteria. This proxy data describes the level of implementation of such regulatory measures as UN Resolution 1540; regulations on transportation and importation of dangerous goods that specifically include the defined materials; national control lists for the materials that define the security roles and responsibilities in the event of purchase, use, storage, disposal, or resale of the defined materials; and, finally, the existence and funding of agencies to enforce these regulations.

The maturity of a country's Technical Capabilities to promote and maintain the security of the materials is defined by the following five maturity levels, these definitions are based upon discussions with subject experts on creating security cultures and reviewing the Carnegie Mellon People Capability Maturity Model (P-CMM) [17]:

- Initial – There is no indication of any security culture to include technical capabilities regarding security directed toward the specific materials within the country; capabilities of those within the country are limited, unpredictable, and poorly controlled.
- Managed – Persons within some industries, government programs, research and development programs, and universities programs are aware of security; capabilities of those within the country follow some generalized security processes.
- Defined – Persons within some industries, government programs, research and development programs, and universities programs have taken some steps to implement a security culture (culture doesn't really exist yet, but there are individuals, organizations, groups, programs, etc., working to create a culture); capabilities of those within the country align with the abilities to implement standard security measures.
- Predictable – The industries, government programs, research and development programs, and universities programs are actively working to create and support a security culture (culture exists in pockets and there are active efforts to broaden this culture to all relevant programs); capabilities of those within the country align with the abilities to implement robust security measures.
- Optimizing – There is an active security culture within industries, government programs, research and development programs, and university programs in the country; capabilities of those within the country align with the abilities to implement robust security measures and work with the facility to ensure proper risk management and continual improvement.

Factors that influence the maturity level of Technical Capabilities in a country include existence and robustness of any active training and outreach programs that focus on risk management with specific emphasis on security and a demonstrated level of security expertise. The score for Technical Capabilities is based on subject matter expertise that uses background data and expert knowledge and experience.

The level of the State of Security, which is designed to protect materials from theft or diversion, is defined by four maturity levels. These maturity levels are similar to cyber security maturity models [18] but focus on security measures that consider all pillars of security and the level risk management (see Figure 2).

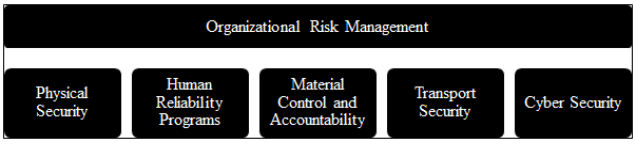

Figure 2: Security pillars for the state of security criterion

The Four Levels of Maturity for the State of Security are:

Non-Existent: There is no security measures identified which provides detection, delay, or response to security incidents. Measures to provide deterrence may exist but are limited.

Managed: Threats and security risks have been identified for the site, measures are often compliance based and ad hoc (e.g. Implemented security measures include only perimeter fencing and CCTV).

Defined: Threats and security risks have been identified and a management strategy implemented. The processes are robust and follow standards and best practices to include implementation of structured concepts of security to include the elements of deter, detect, delay, and respond. These have been implemented across all relevant pillars but some gaps in management oversight may exist.

Optimizing: In addition to the measures defined in level three, level four includes robust management level policies and support. Processes are reviewed and continual improvement supported.

A country's maturity regarding implementation of security measures to protect against theft or diversion of the defined materials is based upon site level vulnerability assessments when available. These assessments provide specific details on a site's level of maturity and are conducted by various subject matter experts. Additional experts review these reports to define the site's level of maturity by scoring the maturity level at 1-4. This data is aggregated across all sites assessed for a country using a simple average to define a country's overall security status. For countries where site assessments do not exist, SMEs review any ad hoc assessments to include safety assessments and leverage their personal knowledge of the country to provide a country's security status score. The score is then adjusted as necessary by SMEs taking in to account additional proxy data that shows the country's ability to support and maintain its infrastructure (e.g. power, water, roadways, etc.). This adjusted score reflects a country's ability to support and maintain normal infrastructure onto its ability to support and maintain a security infrastructure.

Threat presence: The intent and capabilities of non-state actors who operate and can freely move within the country is scored with the following criteria (presented as the evaluation criteria from Figure 1).

Capability to misuse materials–the technical skills known of threat groups to misuse materials and support the development of a WMD;

Capability to acquire material through theft or diversion–technical skills of threat groups to acquire materials; and

Potential for radicalization-potential for an individual with access to those materials to be radicalized by a threat group.

SMEs consider the role of the threat profile (presence) in evaluating the relative threat toward a country's infrastructure, specifically focusing on theft of materials that could be utilized in a WMD.

SME judgements are used to assess the capabilities to use materials in the development of a WMD and the capability to acquire material through theft or diversion for threats that operate and freely move within the country using the ordinal scale criteria shown in Table 2. As with all the other criteria, an interval measure v(x) developed by the SMEs creates the value functions. Note: The ordinal scale's description is not provided in Table 2.

The assessment of the potential to radicalize those with access is based upon a separate model designed to define a country's coercion or radicalization index (CCI). The CCI is used as a proxy for potential to radicalize and is based on a multi-objective decision analysis framework that leverages heavily from the 2012 DHS Community-Level Indicators of Radicalization report and developed in partnership with Sandia, the Radicalization Center of the UK, and the START Institute at the University of Maryland. The goal of this model is to reflect, at a country level, factors that may influence an individual's or community's willingness to become radicalized or coerced into supporting non-state actor causes, including criminal and foreign terrorist organizations. The CCI reflects two potential elements of threat: The first is the potential for individuals with access to materials of concern to be willing and able to acquire these materials in support of non-state actors (e.g. insider threat); and second, the potential for non-state actors to operate and move freely within these countries.

The CCI is based upon a weighted average of externally defined indices and updated as new indices become available. The factors used in this model reflect the social and economic stresses within the country, the current terrorist and crime levels, and the marginalizing of populations. SMEs in radicalization studies use the CCI to score the potential for radicalization for each country. The current indices included in the model are shown in Table 2 and specifically called out here:

- Corruption perception index (reflecting the current level of corruption in the country's government);
- Unemployment rate of the educated population;
- Income inequality rank (GINI Index);
- Political terror scale (reflecting the current terrorist threat within the country); and,
- Fragile state index (reflecting the stability of the country).

Each index is converted to a value between zero and one, one reflecting the worst possible scenario. The value functions are linear, that is, they do not alter the original numerical relationship of the original index value. The final score is a weighted product of all the indices and not included in this paper. Subject matter experts from the various partner institutions defined the weights. The final value falls between zero and one, with one being a country that has the greatest potential for radicalization.

Efficacy country prioritization model for strategic planning and measuring impact

As mentioned previously, country prioritization is designed to support programmatic decision making by providing an overview of the relative threat toward a country's infrastructure, specifically focusing on theft of materials that could be utilized in a WMD. As noted, these models do not include all factors that would need to be considered but support a technical basis for decisions.

Using this type of analysis, the results highlight groupings of countries that share common issues. These can reflect a large presence of materials, a lack of security, the presence of a threat, or any combination of the three. The final assessment is designed to highlight countries where the presence of materials and their security posture are not in balance to account for the current threat present. As such, countries with the greatest imbalance will be grouped into the highest tier and considered a priority for implementation of support measures. Support measures, typically, are those designed to either increase a country's security posture or designed to reduce the presence of materials.

Countries with a smaller presence of materials, no current threat actors or lack of security would be in a lower tier and would reflect a lower urgency for engagement. However, as threat actor's move and a country's infrastructure changes, this might warrant a need for engagement. By working with a country to increase its security posture, the country will remain in balance baring any threat or material changes. Countries where the level of security is in balance or more robust than needed, based on either the material currently present or the existing threat would not directly benefit from engagement activities designed to enhance their security posture; however, they may benefit from other forms of partner engagements.

Specific strategies for a country's engagement can be defined by looking at the sub-objectives of this analysis and the raw data. For example, for a country that is in the highest tier, this type of analysis can identify the specific entities responsible for import, transport, storage, use, resale, or disposal of the defined material, allowing engagements to be targeted directly. Likewise, specifically considering the security posture, the sub-objectives and each individual maturity model highlights specific gaps. Knowledge of these gaps can be used to formalize a plan for engagement that has been defined to move the security posture to the next level of maturity. By formalizing an engagement plan, metrics (both internal and external) can be defined.

As several factors used to define a country's relative threat are dynamic, this type of analysis should be repeated to capture changes over time. These changes will reflect the impact of engagement activities, to include those formalized by the end users of these tools as well as others and capture any changes in the presence of materials or threat actors. In the following section, the parameters of the model, scoring data, results and visualizations will be demonstrated through an example assessment. All data is notional.

Model application

In this section, an application of the model is presented, and results analyzed. The section includes all input data and various visualizations. Additionally, the additive preference structure is modified by showing a model variant where materials and security posture are additive and threat presence is multiplicative.

Problem formulation: U.S. Department of State's Office of Cooperative Threat Reduction is interested in knowing which countries pose the greatest proliferation risk based countries with threat actors that have or seek to acquire WMD material, equipment, and expertise. A prioritization model is useful to help inform programmatic decisions on where to invest funds and target efforts to counter threats in the vulnerable at-risk countries.

Input and output data by country: In this notional application, the names of countries are referred to as c1, c2, etc. The scored criteria for each country are shown in Table 3, Table 4 and Table 5. Also included in Table 3 are the global weights, local weights, and value tree to allow the reader to see the elements that make up the model along with the scoring data.

Country threat value			
	Materials	Security posture	Threat presence
local weights	0.5	0.25	0.25

	Attractiveness	Regulatory frameworks	Technical capabilities	State of security	Capability to misuse materials	Capability to acquire through theft or diversion	Potential for radicalization
local weights	1	0.25	0.25	0.5	0.3	0.4	0.3
global weights	0.5	0.06	0.06	0.13	0.08	0.1	0.08
Country							
C1	2	1	1	3	4	4	1
C2	4	5	5	4	4	4	4
C3	3	5	3	2	4	4	2
C4	3	2	4	4	1	2	4
C5	3	2	2	2	3	3	4
C6	4	5	4	4	3	1	4
C7	3	3	1	1	1	4	1
C8	2	1	4	2	4	2	2
C9	1	1	2	1	2	1	3
C10	1	2	2	1	2	3	3
C11	3	1	4	3	2	2	3
C12	4	4	5	4	2	4	4
C13	1	2	1	2	1	1	4
C14	1	2	2	1	2	1	2
C15	2	2	2	3	1	2	1
C16	2	1	3	4	2	3	4
C17	1	5	1	3	1	3	1
C18	3	2	3	3	1	3	4
C19	3	2	4	4	2	2	3
C20	3	5	5	4	4	4	5

Table 3: Input data for each criterion per country

Country threat value							
	Materials	Security posture			Threat presence		
	Attractiveness	Regulatory frameworks	Technical capabilities	State of security	Capability to misuse materials	Capability to acquire through theft or diversion	Potential for radicalization
Country value, v(x)							

C1	0.01	0	0	0.66	1	1	1
C2	1	1	1	1	1	1	0.25
C3	0.1	1	0.5	0.33	1	1	0.75
C4	0.1	0.25	0.75	1	0	0.33	0.25
C5	0.1	0.25	0.25	0.33	0.5	0.67	0.25
C6	1	1	0.75	1	0.5	0	0.25
C7	0.1	0.5	0	0	0	1	1
C8	0.01	0	0.75	0.33	1	0.33	0.75
C9	0	0	0.25	0	0.2	0	0.5
C10	0	0.25	0.25	0	0.2	0.67	0.5
C11	0.1	0	0.75	0.66	0.2	0.33	0.5
C12	1	0.75	1	1	0.2	1	0.25
C13	0	0.25	0	0.33	0	0	0.25
C14	0	0.25	0.25	0	0.2	0	0.75
C15	0.01	0.25	0.25	0.66	0	0.33	1
C16	0.01	0	0.5	1	0.2	0.67	0.25
C17	0	1	0	0.66	0	0.67	1
C18	0.1	0.25	0.5	0.66	0	0.67	0.25
C19	0.1	0.25	0.75	1	0.2	0.33	0.5
C20	0.1	1	1	1	1	1	0

Table 4: Value scores v(x) per country for each criterion

Country threat value							
	Materials	Security posture			Threat presence		
	Attractiveness	Regulatory frameworks	Technical capabilities	State of security	Capability to misuse materials	Capability to acquire through theft or diversion	Potential for radicalization
Country weighted value, w(x)v(x)							
C1	0.005	0	0	0.083	0.075	0.1	0.075
C2	0.5	0.063	0.063	0.125	0.075	0.1	0.019
C3	0.05	0.063	0.031	0.041	0.075	0.1	0.056
C4	0.05	0.016	0.047	0.125	0	0.033	0.019
C5	0.05	0.016	0.016	0.041	0.038	0.067	0.019
C6	0.5	0.063	0.047	0.125	0.038	0	0.019
C7	0.05	0.031	0	0	0	0.1	0.075
C8	0.005	0	0.047	0.041	0.075	0.033	0.056
C9	0	0	0.016	0	0.015	0	0.038
C10	0	0.016	0.016	0	0.015	0.067	0.038
C11	0.05	0	0.047	0.083	0.015	0.033	0.038
C12	0.5	0.047	0.063	0.125	0.015	0.1	0.019
C13	0	0.016	0	0.041	0	0	0.019
C14	0	0.016	0.016	0	0.015	0	0.056
C15	0.005	0.016	0.016	0.083	0	0.033	0.075
C16	0.005	0	0.031	0.125	0.015	0.067	0.019
C17	0	0.063	0	0.083	0	0.067	0.075
C18	0.05	0.016	0.031	0.083	0	0.067	0.019
C19	0.05	0.016	0.047	0.125	0.015	0.033	0.038
C20	0.05	0.063	0.063	0.125	0.075	0.1	0

Table 5: Weighted value scores per country

Results and Discussion

In Figure 3, the threat value is normalized (0,1). Countries C2, C12, and C6 are clearly the highest priority and countries C10, C14, and C9 are the least in priority in terms of likelihood that threat actors have or seek to acquire WMD material, equipment, and expertise. These results should be useful to assist all cooperative threat reduction efforts by stakeholders such as the U.S. government in focusing resources.

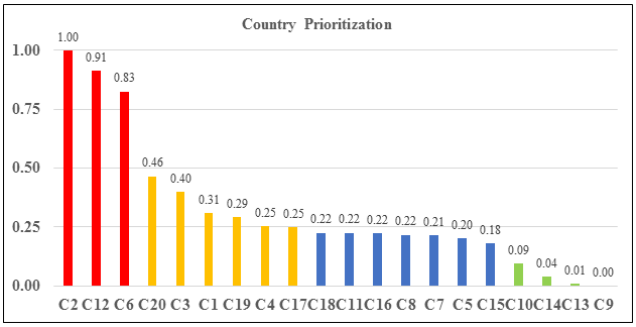

Figure 3: Country Prioritization Considering All Seven Criteria in Additive Preference Form.

The country prioritization value model has seven criteria and 32,000 possible combinations of scores (4,5,5,4,4,4,5). The model assumes a complete additive structure. However, it could be argued that if there is zero threat presence then the country is not a likely source of WMD materials, equipment and expertise.

In Figure 4, shows results where materials and security posture are additive, and threat presence is multiplicative.

Figure 4 demonstrates the model's sensitivity to Threat Presence as the results are dramatically different. Instead of multiplying by Threat Presence, Figure 5 shows a two-dimensional plot where the normalized materials and security posture scores are additively combined and then plotted with respect to each country's Threat Presence normalized score. As in the case of Figure 3, countries C6, C12, and C2 are in the top right quadrant and represent the greatest concern. Since threat presence is dynamic and may change at any

time, the additive structure and the results in Figures 3 and 5 are a better rationale for informing resource decisions than Figure 4.

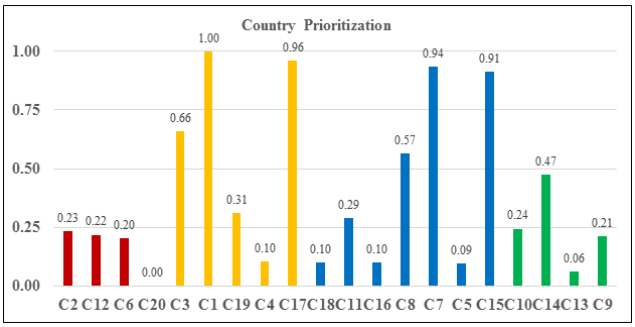

Figure 4: Materials and Security Posture are additive, and Threat Presence is Multiplicative

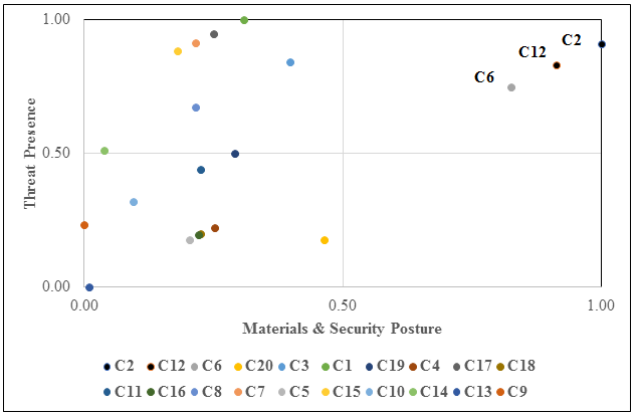

Figure 5: Material & Security Posture (Additive) v. Threat Presence

Model sensitivity analysis

To understand the impact of weights in the model on the results, a simulation was created, and each criteria weight varied by +/- 10 percent. Next, each criteria's contribution to variance in the results was investigated. Clearly attractiveness and state of security criteria have the most dominant effect on country threat value. Attractiveness accounts for 61.2% of the variance in threat value whereas technical capabilities and regulatory frameworks have a small effect on country threat value. If a decision maker wants to simplify the model, technical capabilities and regulatory frameworks could be removed with little impact on prioritization. However, decision makers change over time and this model's parameters reflect the values and preferences of the decision makers.

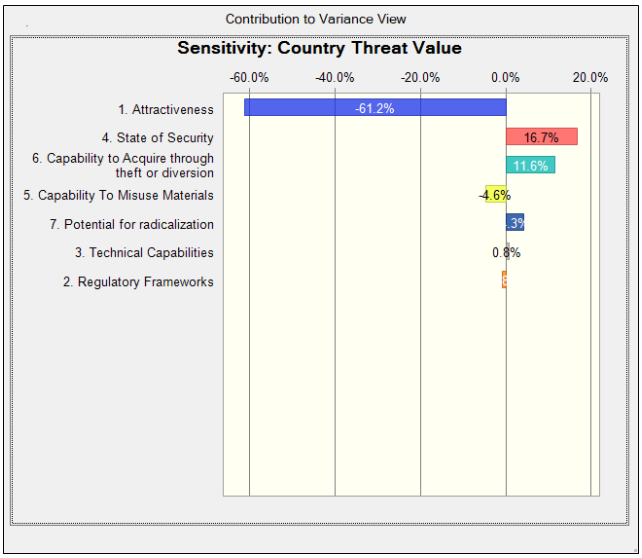

Figure 6: Country threat prioritization sensitivity analysis

Conclusion

To prioritize countries regarding access to WMD materials, a systemic and systematic methodology that allows for a relative comparison of countries and a prioritization tool has been developed. MAVT was used to ensure the values and preferences of the stakeholders and decision makers were encoded in the value model (Figure 1). Criteria and value functions in Table 2 were established from numerous data sources in Table 1. An iterative-deliberative process was utilized throughout the development of the model and the overall methodology. This research and resulting methodology have been used to inform resource allocation decisions within the US Department of state's office of cooperative threat reduction.

- This methodology does have certain limitations, as follows:
- The criteria are defined by using raw data (when possible) or using constructed ordinal scales to score countries. These scales are converted to values using defined values functions and combine using a weighted average.
- The model's precision is limited in that, when applied to a larger set of countries–say 193–ranking priorities from 1 to 193 is not practical. The best this model can do is tier countries into categories (see Figures 2 and 3).
- The model is limited in its sensitivity to attractiveness is a country with no attractive material has no value in this model regardless of their threat or security posture. It can be argued that attractiveness drives most of the prioritization.
- The model does not currently address uncertainty in scoring assessments for each criterion. This is due to the primary use of proxy data and the challenges of reflecting uncertainty in proxies coupled with the issues mentioned previously regarding reflecting priorities between 1 to 193.

Future work to overcome limitations in the current model includes development of more interval and ratio scale measures for criteria. These types of measures will provide more discrimination to better differentiate among countries. In addition, interval and ratio level measures allows for scoring ranges which would allow the model to be stochastic with distributions of scores that represent the uncertainty

in the assessments. Future versions of the model should identify more criteria for the attractiveness criterion to reduce model sensitivity.

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