A Value Model for Evaluating Homeland Security Decisions

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One of the most challenging tasks of homeland security policymakers is to allocate their limited resources to reduce terrorism risks cost effectively. To accomplish this task, it is useful to develop a comprehensive set of homeland security objectives, metrics to measure each objective, a utility function, and value tradeoffs relevant for making homeland security investments. Together, these elements form a homeland security value model. This article develops a homeland security value model based on literature reviews, a survey, and experience with building value models. The purposes of the article are to motivate the use of a value model for homeland security decision making and to illustrate its use to assess terrorism risks, assess the benefits of countermeasures, and develop a severity index for terrorism attacks.

KEY WORDS: DHS decisions; identifying objectives; severity index; utility function; value tradeoffs

1. INTRODUCTION

In 2007, Michael Chertoff, then Secretary of the U.S. Department of Homeland Security (DHS), characterized the task of the department as follows:

> We have to identify and prioritize the risks-- understanding the threat, the vulnerability, and the consequences. And then we have to apply our resources in a cost-effective manner . . . .[1]

His successor, Secretary Napolitano, has confirmed this risk management philosophy of the DHS, and many activities are underway to develop appropriate risk assessment and management approaches, models, and tools at the Department. As part of the Department's risk management strategy, the Office of Risk Management and Analysis was created, whose purpose is to "ensure that risk information and analysis are provided to inform a full range of homeland security decisions . . . ."[2]

This risk assessment and management framework includes estimating the risks we face from terrorism and making appropriate risk reduction investments to counter terrorism. As several authors[3,4] have pointed out, this, in turn, requires the estimation of

1. threat (probability of various types and targets of attempts of terrorist attacks) and the threat reduction due to preventive and deterring countermeasures;
2. vulnerability (probability of a successful attack, given an attempt) and the vulnerability reduction due to protective countermeasures;
3. consequences (including lives lost, direct, and indirect economic impacts) given a successful attack and the reduction of consequences due to response and recovery improvements; and
4. costs and other consequences of counterterrorism policies and actions.

Items 1 and 2 can, in principle, be addressed with tools like probabilistic risk analysis, though the practical difficulties are significant.[5] Items 3 and 4 involve describing the possible consequences of terrorist attacks and the costs and side effects of countermeasures in a way that reflects the nation's values

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and concerns. This requires identifying the nation's objectives pertaining to terrorism. It is also important to specify metrics for each objective to describe possible consequences of terrorist actions and of counterterrorism strategies.

A complete set of homeland security objectives is the common foundation about which almost all individuals can agree. Essentially, everyone agrees with objectives such as minimizing the number of fatalities due to terrorism, limiting the damage to infrastructure, minimizing inconvenience to the U.S. public, avoiding limiting any civil liberties, and minimizing costs of terrorism protection. There will naturally be differences about the relative importance of achieving different objectives, but usually not about the objectives themselves. Thus, the objectives tend to unify the nation and the Department by establishing a common value framework.

A model that is constructed from all the relevant objectives, metrics for each of the fundamental objectives, and judgments representing value tradeoffs between objectives, attitudes toward risk, and any synergies in achieving different objectives is called a value model. Once constructed, one component of the value model is a utility function over the strategic objectives that can be used to evaluate alternative actions. As a value model provides a clear understanding of what we want to achieve regarding homeland security, it helps to focus and coordinate all efforts to achieve it. With a value model, the DHS should be able to better invest its $40–$50 billion annual budget. Fortunately, the amount of effort to construct a high quality value model is very small compared to the effort to evaluate alternatives to best achieve the purposes of homeland security. Indeed, using the objectives in the value model, this evaluation should be more consistent, less time consuming, and easier to explain to others.

This article describes how to construct a value model for homeland security. As a practical matter, such a value model would need to be constructed by the DHS staff and endorsed by DHS policymakers, so we will refer to it as a DHS value model. Section 2 introduces the idea of a value model in the terrorism context. Section 3 outlines our methodology and describes a preliminary and illustrative, but conceptually complete, DHS value model developed using this methodology. Specifically, we describe how we identified DHS objectives, organized them, developed metrics for them, and provided an initial prioritization using value tradeoffs. Section 4 discusses uses of such a value model to evaluate both prior-

ities and potential actions of DHS. Section 5 outlines how DHS could build on the illustrative value model developed here to incorporate a complete set of national interests and to assess the necessary value tradeoffs.

2. CONSTRUCTION OF A VALUE MODEL

To evaluate terrorism risks and to assess the effectiveness of actions to counter terrorism, it is now fairly standard within DHS[3,6] to define risk using the following model:

$$R(\text{Terrorist Attack})$$
$$= p(\text{Attempted Attack}) \times q(\text{Success}|\text{Attempt})$$
$$\times [-u(\text{Consequences})], \tag{1}$$

where R is the risk of a terrorist attack, p is the probability of an attempted attack in a given time period (or frequency, if there is a possibility of multiple attacks in the time period), q is the probability that the attempt is successful, and u is a utility function for consequences of a successful attack as described later in this section. If a successful terrorist attack might result in one of several possible consequences, then Equation (1) should be adapted to use the expected utility of the possible consequences. The utility function u is constructed such that $u(x) > u(y)$ if the consequences x are preferred to the consequences y. In the terrorism context, we almost always deal with negative consequences and risks that involve disutilities. To assure that the risk is calculated based on disutilities, we assign a negative sign to u.

The assessment of ps and qs can be done using risk analysis methods.[3,4,7] In practice this is a very difficult task and the appropriate tools are still debated in the risk analysis community.[5]

The assessment and evaluation of consequences is less controversial and this is where the development of a value model is important and useful. It allows us to use Equation (1) to appraise proposed counterterrorism actions. Any such countermeasure, call it C, should have an effect on one or more of p, q, and u (due to its effect on the consequences). For a desirable counterterrorism action, p, q, and/or consequences will likely change so $p_C < p$ (due to preventive actions), $q_C < q$ (due to protective action), and/or $u_C > u$ (due to protective and response and recovery actions). The difference between R_C and R is the benefit of the countermeasures.

2.1. The Concept of a Value Model

A value model is similar to any other model in that it is constructed with logic, judgments, and information. The main difference between a value model and other models is its focus on value judgments instead of on facts and probabilities. Most other models try to describe or predict consequences answering questions like the following: if a specific alternative is chosen or if a specific scenario occurs, what are the possible consequences and their relative likelihoods? A value model tries to answer the question of what is the relative desirability of the various possible consequences that may occur.

A value model is constructed in four steps. First, a complete list of the relevant objectives must be identified and then organized. Second, a metric must be identified for each objective in order to measure the degree to which that objective is achieved by various alternatives. Third, an aggregation rule must be selected to combine achievements on each of the objectives. Fourth, value tradeoffs must be assessed that indicate the amount of achievement on one objective that is equivalent in value to a specified amount of achievement on a second objective. We briefly summarize these steps, which are discussed in more detail elsewhere.[8,9]

2.2. Identifying Objectives

To compile an appropriate list of objectives requires the initial creative step by an individual or individuals to write down anything that they care about or value in a specific decision context. Our decision context of concern is all alternatives appropriate to consider for better protecting the citizens of our nation from terrorism. Each item on this list is termed a value. As values are stated in numerous ways, we want to convert them to a common form. Specifically, we translate each value into a corresponding objective that is specified using a verb and an object. For instance, for the value *safety*, the corresponding objective would be to *ensure safety*. For a value stated as *long security lines at airports*, the corresponding objective might be *minimize waiting time at airport security.*

There is a substantial amount of experience indicating that creating a complete list of objectives for decisions is very difficult. Benjamin Franklin in a 1772 letter to his colleague Joseph Priestley, said this about difficult decisions: "they are difficult, chiefly because while we have them under consideration, all the reasons pro and con are not present to the mind at the same time . . . ."[10]

Recently, experimental work has shown that for several important individual decisions (e.g., selecting a work internship), essentially none of the individuals could identify a complete set of their own objectives and that the average number of objectives identified was less than 50% of those later identified as personally relevant from a complete list provided by the experimenters.[11] Furthermore, the decision-makers subsequently indicated that the relative importance of the objectives that they failed to identify were roughly as important as those that they had identified. To facilitate individuals developing a more complete list of objectives, numerous devices have been shown to stimulate thinking.[12,13] As a high level summary, identifying an appropriate complete list of objectives cannot be done simply by making a list; rather, it requires hard introspective thought about the decision situation in several sessions over a period of time, facilitated by a person familiar with developing objectives.

Once what is considered to be a complete list of objectives is identified, they are organized into four types: strategic objectives, which are the ultimate objectives of an organization that guide all of its decisions; fundamental objectives, which characterize the ultimate intent of any specific decision; means objectives that influence the degree of achievement of other objectives (specifically strategic or fundamental objectives); and process objectives, which concern how the decision is made rather than what decision is made. In this article, our concern is with the strategic objectives of homeland security, so we focus on these and the process and means objectives contributing to the achievement of the strategic objectives.

2.3. Specifying Metrics to Measure Objectives

Identifying a metric is required to measure consequences that indicate performance with respect to each strategic objective. Sometimes, metrics are easy to identify. If the objective is to minimize economic cost, the metric can simply be millions of dollars. However, if the objective is to minimize waiting time at airport security, selecting an appropriate metric requires more thought. Metrics to consider include the average time it takes to get through security, the number of people taking more than 20 minutes to pass through security, the percentage of passengers waiting in line more than 20 minutes before they get to the security check, and the extra time allocated by

passengers to get through security. Different security line arrangements may be better using some of these metrics and worse using others. Hence, value judgments are made in selecting a metric, so careful judgment must be used to choose metrics that measure the real concerns as closely as possible.

2.4. Combining Achievement on Different Objectives

Combining the achievement on different objectives requires an equation that, in essence, allows one to appropriately add up the positive impacts (pros) and subtract the negative impacts (cons) on different objectives to create an overall indicator of the desirability of the combined consequences. Suppose there are two objectives O_1 and O_2 with corresponding metrics $\mathbf{X}_1$ and $\mathbf{X}_2$, and let x_1 and x_2 be specific impacts in terms of $\mathbf{X}_1$ and $\mathbf{X}_2$. An indicator of the desirability or undesirability of any consequence (x_1, x_2) is wanted. Such an indicator is simply a number called the utility of (x_1, x_2) written as $u(x_1, x_2)$. We construct this indicator such that $u(x_1', x_2')$ is greater than $u(x_1'', x_2'')$ if and only if (x_1', x_2') is preferred to (x_1'', x_2''). Furthermore, in situations where there is uncertainty about which consequences (x_1, x_2) might occur, as is almost always the case, it simplifies any analysis if the expectation (i.e., average) of the utilities of the possible consequences logically indicates relative desirability. Fortunately, several sources have provided a logically sound foundation for utility theory, which has such a property.[14–16] This concept has been thoroughly extended to consequences with multiple objectives.[17,18] One possible utility function for the case of two objectives is:

$$u(x_1, x_2) = k_1 u_1(x_1) + k_2 u_2(x_2), \qquad (2)$$

where u_1 and u_2 are single-objective utility functions and the ks are parameters that are calculated from assessed value tradeoffs.

2.5. Value Tradeoffs

The aspect of a value model where there is the greatest potential for disagreements concerns the value tradeoffs. Almost everyone's set of strategic objectives for homeland security would include the following two objectives: minimize loss of life and minimize costs, which might naturally be measured by the number of fatalities and costs in millions of dollars. As some potential alternatives would cost more and potentially result in less life lost and other

alternatives would cost less and potentially result in relatively more life loss, a value tradeoff between these two objectives must be addressed either explicitly or implicitly. In other words, a value judgment must be made about the relative importance of reducing the risks of fatalities due to terrorism and the cost of reducing those risks. For example, is it worth $50 million to reduce the risk of an anthrax attack that would cause 20 fatalities by one chance in 1,000? From such a value judgment, one can calculate how much additional cost is appropriate if it could reduce the number of expected fatalities by one in a terrorist attack. Providing a reasonable judgment to address this issue is one of the most difficult value tradeoffs that we face.

3. CONSTRUCTION OF A DHS VALUE MODEL

The four steps described in Section 2 are used here to construct a homeland security value model. Sequentially, we cover identifying objectives, choosing metrics for each, selecting an aggregation rule to combine achievement on each of the objectives, and specifying the value tradeoffs among the objectives. It is important to point out that our value model is preliminary and illustrative. Section 5 outlines the effort appropriate to construct a value model with legitimacy for DHS.

3.1. Identifying and Organizing DHS Objectives

Several sources were used to develop the initial list of potential homeland security objectives. These included a selective literature review, interviews with individuals knowledgeable about homeland security, a formal questionnaire to individuals working on homeland security problems, and our own experience with homeland security issues and value modeling.

The selective literature review involved searching for indications of objectives in the professional articles and popular press reports that we read about terrorism and counterterrorism activities. When a news article stressed delays for passengers at an airport or concern about recording conversations on telephones, we listed values concerning inconvenience and civil liberties on the objectives list. If a professional article analyzed the risks of suicide bombers in malls, we added objectives concerning public fear and the negative business impacts

to the list of values. An analysis of a proposed requirement that all commercial airlines should include an anti-surface to air missile system on their airplanes[7] included objectives *minimize lifecycle cost of surface-to-missile countermeasures* and *minimize national economic consequences due to a missile attack*, which suggested strategic homeland security objectives of *minimize lifecycle costs of anti-terrorism measures* and *minimize national economic impact of terrorism*.

In discussions with several individuals in DHS and in professions concerned with homeland security, we asked individuals to tell us any objectives that they thought were important to homeland security. We specifically challenged them to think of objectives that might be missed by many others who had not thought as deeply about the issue.

Our most structured activity for identifying objectives was a questionnaire developed and sent to managers and researchers on projects at CREATE, the nation's first DHS University Center of Excellence, at the University of Southern California. The questionnaire, shown in Table I, provided additional lines for responses as required. Collectively, the 12 responses provided 209 objectives, mostly written in the form of a verb and a noun (i.e., object) as requested.

To structure these objectives and others added from our literature search and discussions, we began by placing similar objectives into categories defined by a general higher level objective. Examples included: disrupt terrorist capabilities, improve decision making within DHS, enhance communication, ensure health and safety, minimize social impacts, and protect civil liberties. Within these categories, we could easily combine objectives that were essentially the same but stated differently. Then, following standard procedures,[8,12] we organized the higher level objectives, using cause-effect relationships and hierarchical relationships, into the strategic objectives of homeland security and the means objectives and process objectives that help to achieve the strategic objectives. Fig. 1 indicates the high-level process, means, and strategic objectives and indicates their relationships.

It is useful to elaborate on the highest level strategic objectives in Fig. 1. Viewed from the current time, we want to reduce the current threat by deterring potential terrorist attempts prior to the initiation of an attack and to foil any attack that has been initiated. If an attempt is successful, there are many homeland security objectives under the high-

level objective to reduce consequences of attacks. Obviously, any and all efforts of our government to pursue counterterrorism activities, in addition to influencing the objectives above, have other significant consequences. Regarding these counterterrorism activities, we would naturally like to minimize their costs and the many direct consequences of these actions in terms of objectives that mirror the objectives of terrorist attacks. This is not odd as both are the results of our national principles of life, liberty, and the pursuit of happiness. One of these potential consequences leads us to specify another high-level objective, namely, to protect civil liberties. Over the longer term, we want to minimize future terrorism threats.

3.2. Selecting Metrics to Measure DHS Objectives

A metric is required to indicate the degree to which each of the associated strategic objectives is met. Selecting any metric is a decision that uses judgments to balance how well it indicates performance on the objective, the availability of data and information to evaluate alternatives in terms of the metric, and the ease with which policymakers understand the meaning of different levels of achievement with the metric. In this study we selected the metrics ourselves using our experience with similar value modeling projects.

Table II presents the strategic objectives, along with metrics for all of the lower level objectives in the table. A set of metrics for the lower level objectives is a metric for the related higher level objective. The value tradeoffs for all of the lower level objectives in Table II are discussed later in this section.

The metrics for consequences of terrorist attacks and for consequences of government counterterrorism are mostly obvious choices. For concerns such as illness and injuries, a threshold is needed to define what is meant by the term serious. In these cases, we chose serious to mean that the consequences would prohibit normal life function for at least one year. For metrics concerning fear and disruption of lifestyle, thresholds were also used. Feeling fear was defined to mean at least once weekly for a period of a year and a disrupted lifestyle required altering basic routines such as working, shopping, entertainment, or travel. The hours of inconvenience are spread over numerous individuals. For environmental impact, we consider the impact on what could live in a destroyed area in the future, rather than what was lost by any current action.

Table I. Questionnaire for Identifying DHS Objectives

Your Name:

Please provide a list of all of the objectives and consequence measures that should be important to DHS and the Nation. Please separate these objectives and consequence measures between those that are relevant to the impacts of terrorist events (e.g., fatalities) and those that are relevant to the impacts of countermeasures (e.g., privacy or trade impacts)

List as many objectives and consequence measures as you can. Experience shows that after people have listed all the objectives that they initially think of, they still can identify several more objectives with additional hard thinking.

A useful way to state objectives is with a verb and an noun (e.g. the object of preference).

The following are example objectives (with potential consequence measures in brackets)

    a. minimize deaths from terrorist acts (number of people killed in an attack)
    b. limit business disruptions (aggregate loss of revenue to businesses due to disruption)
    c. avoid inconveniences to US citizens (person-days of unproductive waiting time due to security measures)

Note that there can be several consequence measures for each objective.

Your objectives and consequence measures for evaluating the impacts of terrorist attacks

    1
    2
    3
    4
    5
    6
    7
    8
    9
    10

Your objectives and consequence measures for evaluating the impacts of counterterrorism decisions

    1
    2
    3
    4
    5
    6
    7
    8
    9
    10

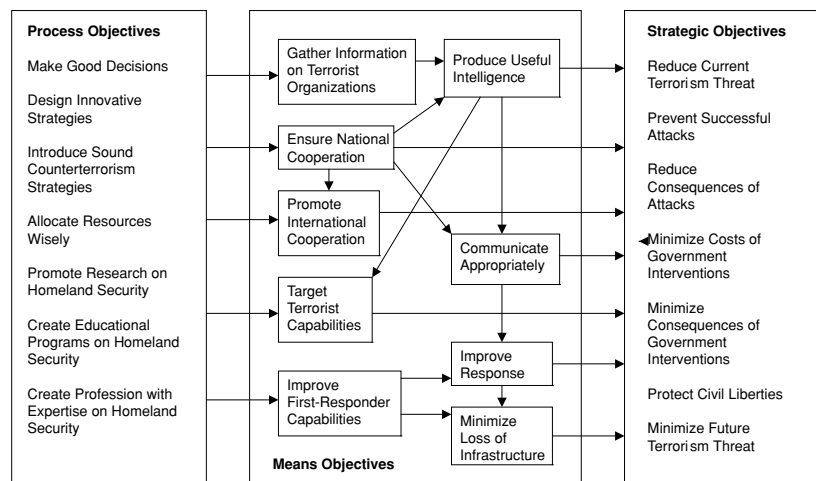**Fig. 1.** Homeland security means-ends objectives network.

Table II. Homeland Security Strategic Objectives

Objectives		Metrics	Unit Value Tradeoff ($ Millions)
Reduce Current Terrorism Threat	p	**See Section 4.1**	
Prevent Successful Attacks	q	**See Section 4.1**	
Reduce Consequences of Attacks			
Minimize Fatalities	X_1	Number of fatalities	6–12
Minimize Morbidity			
illnesses	X_2	number of serious illnesses	0.1–0.5
injuries	X_3	number of serious injuries	0.1–0.5
Minimize Economic Costs			
direct costs			
to individuals	X_4	millions of dollars	1
to businesses	X_5	millions of dollars	1
to society	X_6	millions of dollars	1
indirect costs	X_7	millions of dollars of GDP	1
Minimize Social Impacts			
jobs lost	X_8	number of jobs lost	0–0.2
fear	X_9	number of citizens feeling fear	0.001–0.010
personal disruption of lifestyle	X_{10}	number of citizens with disrupted lifestyles	0.0005–.005
inconvenience	X_{11}	waste of 100,000 hours	1–5
Minimize Environmental Impact	X_{12}	square miles of habitat destroyed	1–10
Minimize Violent Crime	X_{13}	number of criminal participants	0.01–0.05
Minimize Direct Costs of Government			
Interventions	X_{14}	millions of dollars	1
Minimize Consequences of			
Government Interventions			
Minimize Fatalities	X_{15}	number of fatalities	0–10
Minimize Morbidity			
illnesses	X_{16}	number of serious illnesses	0.1–0.5
injuries	X_{17}	number of serious injuries	0.1–0.5
Minimize Economic Costs			
direct costs			
to individuals	X_{18}	millions of dollars	1
to businesses	X_{19}	millions of dollars	1
to society	X_{20}	millions of dollars	1
indirect costs	X_{21}	millions of dollars of GDP	1
Minimize Social Impacts			
jobs lost	X_{22}	number of jobs lost	0.05–0.2
fear	X_{23}	number of citizens feeling fear	0.001–0.01
personal disruption of lifestyle	X_{24}	number of citizens with disrupted lifestyles	0–0005.–005
inconvenience	X_{25}	waste of 100,000 hours	1–5
Minimize Environmental Impact	X_{26}	square miles of habitat destroyed	1–10
Minimize Violent Crime	X_{27}	number of criminal participants	0.01–0.05
Protect Civil Liberties			
Minimize Violations of Privacy	X_{28}	number of incidents	0.001–0.005
Minimize Violations of Civil Rights	X_{29}	number of false arrests or false public accusations	0.005–0.020
Minimize Retaliation Against Innocent People	X_{30}	number of hate crimes against innocent people	0.1–0.2
Minimize Future Terrorism Threat			
Minimize Recruitment of Terrorists	X_{31}	number of new recruits	0.02–0.2
Minimize Economic Support for Terrorism	X_{32}	millions of dollars provided to terrorist organizations	1–10
Minimize Public Support for Terrorism			
in the Moslem world	X_{33}	percent of Moslem world public sympathetic to terrorism	1–10
in the United States	X_{34}	percent of U.S. public sympathetic to terrorism	1–10

3.3. Combining Impacts of Different DHS Objectives

Combining impacts on different objectives requires using a utility function as discussed in Section 2. The important message of this section is that an appropriate DHS utility function should be additive over the several objectives and linear in impacts on each objective.

The 34 lowest level strategic objectives in Table II define in detail the high-level strategic objectives. The measurement of possible consequences of DHS alternatives occurs at this detailed level. Hence, the DHS utility function is defined over the set of lowest level metrics. Notationally for the illustrative DHS utility function, there are 34 strategic objectives $O_1, \ldots, O_{34}$ measured, respectively, by the metrics $\mathbf{X}_1, \ldots, \mathbf{X}_{34}$, where x_i is an impact on $\mathbf{X}_i$, $i = 1, \ldots, 34$, so $(x_1, \ldots, x_{34})$ is a consequence. The appropriate DHS utility function is the linear additive function:

$$u(x_1, \ldots, x_{34}) = -(k_1 x_1 + k_2 x_2 + \cdots + k_{34} x_{34}), \quad (3)$$

where the parameters k_i, $i = 1, \ldots, 34$ are calculated from value judgments about the value trade-offs between objectives as discussed in Section 3.4. For all of the metrics from $\mathbf{X}_1$ to $\mathbf{X}_{34}$, the natural metric used results in a larger consequence being worse than a smaller consequence, which is why a negative sign precedes the consequences corresponding for those metrics in the utility function in Equation (3). This convention is necessary to have a greater utility associated with the preferred consequences. An appropriate measure of disutility, used in calculating risk R in Equation (1), is $-u$.

3.3.1. The Appropriateness of Additivity

Mathematical conditions present the formal logic for a utility function to be of the additive form.[17,18] Here, we offer two logical arguments to support the case that the DHS utility function over strategic objectives should be additive. The first provides the intuitive logic and the second the structural logic.

In nonmathematical terms, the appropriateness of adding the values of achievements on separate objectives follows if one is not also concerned about the achievements on any combinations of objectives. For example, when evaluating investment costs and operational costs of counterterrorism alternatives, this can usually be done by creating a life-cycle cost measure (which is additive in the two terms), without considering how well the alternatives reduce terrorism consequences.

If the overall value of performance depends on achievements on combinations of objectives, the reason for this nonadditivity is often obvious. For example, if one objective is to "increase the availability of a radiological detection device," measured in percent of uptime, and another objective is to "increase the accuracy of the device," measured in the percent of correct identifications of a given radiological source, it is clear that the two objectives are multiplicative, instead of additive. In cases like this, both objectives are means to a more fundamental objective, which might be called the effectiveness of the device. This could be measured by percent of radiological sources correctly identified, which is the product of availability and accuracy.

The structural logic for an additive utility function can be illustrated by using a simple example. Suppose that there are only two strategic objectives pertaining to homeland security: O_1 = minimize fatalities and O_2 = minimize economic damage in the country. Further suppose that these are measured respectively by the metrics $\mathbf{X}_1$ = number of fatalities and $\mathbf{X}_2$ = total cost in millions of dollars caused by terrorism. Now suppose that instead of the additive utility function, the nonadditive utility function:

$$u(x_1, x_2) = k_1 u_1(x_1) + k_2 u_2(x_2) + k_3 u_1(x_1) u_2(x_2), \quad (4)$$

is suggested as a possible utility function. Clearly, the impacts due to fatalities x_1 are incorporated by $k_1 u_1(x_1)$ and the impacts due to the economic cost x_2 are incorporated by $k_2 u_2(x_2)$. If the third factor $k_3 u_1(x_1) u_2(x_2)$ in Equation (4) is included, it should be measuring something different and in addition to fatalities and economic costs attributable to terrorism. However, the first two factors in Equation (4) include all impacts of terrorism that ultimately matter given that the set of the two strategic objectives is complete. Thus, the third term is not necessary and hence inappropriate. If an understanding for the inclusion of this factor turned out to have merit, this would indicate that the set of the original two strategic objectives was not complete. It would then be appropriate to identify what additional strategic objective O_3 was originally missing and captured by this third term. Next, an appropriate metric $\mathbf{X}_3$ for that third objective should be selected with x_3 indicating impacts in terms of that metric. Then, an appropriate utility function would be:

$$u(x_1, x_2, x_3) = k_1 u_1(x_1) + k_2 u_2(x_2) + k_3 u_3(x_3), \quad (5)$$

where u_3 is a utility function that evaluates impacts in terms of objective O_3.

3.3.2. The Appropriateness of Linearity

Three general situations lead to the conclusion that linearity is reasonable for the single-objective utility functions. One situation is when the metric for a strategic objective measures something, and only something, that is of value in itself, as opposed being of value for its implications. An example may help clarify why linearity is reasonable for consequences on strategic objectives.

Consider the deaths that may be caused by a suicide bomber detonating himself in a crowded shopping mall. One may think that it is worth $2 billion to avoid the first death, another $500 million to avoid the second death, and maybe $100 million to avoid the third. The dollar value to avoid additional deaths keeps dropping to the level where each additional death counts the same. Maybe this occurs at around 25 deaths where each additional fatality seems like it should be worth $10 million to avoid. Preferences such as these are certainly not linear in the number of deaths prior to 25. However, such preferences can be reasonable. The reason for these nonlinear preferences has to do with combining the direct and indirect impacts attributable to the deaths caused by terrorists. In this example, assume that these indirect effects are the number of people feeling fear, the number of people who have their freedom to move freely and safely curtailed, and the indirect economic impacts of fewer people visiting shopping malls. For the values described above, the biggest indirect impact would occur with the first death, less with the second, and so forth. It is the enhanced concern that additional terrorist attacks such as this might occur that results in changes of people's behavior and feelings. The difference between 25 and 35 deaths from a suicide bomber in a shopping mall might not induce any additional indirect impacts. However, each of those deaths from 25 to 35 would be critically important to the families and friends of those who died and of course to the individuals themselves.

If we have a complete set of strategic objectives included in a utility function, one objective would concern deaths, another would concern the indirect costs, a third the number of individuals feeling fear, and a fourth the number of individuals whose freedom to move freely and safely was curtailed. Each of the indirect impacts should be captured explicitly by additional objectives, so the first objective concerning deaths should account only for an individual's death and its devastating impact on family and friends. With this understanding, each of the statistical fatalities prior to the 25th fatality should be just as valuable as, but no more valuable than, those fatalities that followed the 25th. As a result, the appropriate utility function for evaluating the number of statistical fatalities should be linear in fatalities.

When the overall consequences of a terrorist attack are captured with a full set of strategic objectives, the calculations could still show that it is worth $2 billion to avoid the first death due to a suicide bomber in a shopping mall. The reasoning would be something like the following: the indirect costs caused would be $1.5 billion, numerous people losing their freedom to move around as they pleased would be assessed to be equivalent in value to $400 million, the fear caused to another large number of individuals would be equivalent in value to $90 million, and the first statistical fatality is worth $10 million to avoid. Overall, each statistical fatality would be valued the same, each person losing freedom to move around would be valued the same, and each individual experiencing fear would be valued the same.

A second situation that leads to linearity is when the possible consequences are described as estimates of expected impact. When expected impacts are used as consequences, linearity is implicitly assumed because, for instance, a consequence of 25 fatalities for sure would be equivalent to a 50–50 chance of either 10 or 40 fatalities because each circumstance has the same expectation, namely, 25 fatalities. For such situations, it would not make sense to build the value model with components that were not linear in consequences.

The third situation where linearity is reasonable is when the same objective with its corresponding metric is relevant to numerous domains. Regarding homeland security activities, the objective of minimizing economic costs applies to numerous federal government activities. Hence, even though the economic costs of terrorism or counterterrorism activities could be large, they are still small compared to the costs of federal government. If an appropriate utility function for federal government costs were created, it may not be linear and may be concave to exhibit risk aversion. However, that utility function should be smooth and cover a range of trillions of dollars. Over any relatively small section of that range, it follows from a mathematical result known as Taylor's formula that a linear function would be an
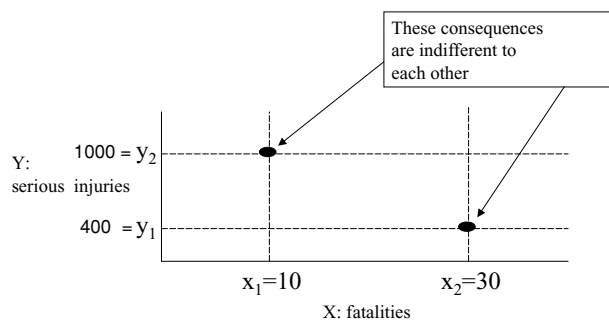
These consequences are indifferent to each other

$Y:$ serious injuries

$1000 = y_2$

$400 = y_1$

$x_1 = 10$ $x_2 = 30$

$X:$ fatalities

Fig. 2. Aid to interpreting value tradeoffs.

excellent approximation. Thus, a linear utility function is reasonable over a range of at least a few hundred billion dollars, which is several times the annual budget of DHS.

3.4. Assessing Value Tradeoffs

Once a homeland security utility function that has the additive linear form is constructed, the final step is to assess value tradeoffs from which the k_i parameters in Equation (3) are calculated. Here, we clarify what is meant by value tradeoffs, discuss the procedures to assess them, and use those procedures to specify first-cut estimates of the parameters.

3.4.1. Understanding Value Tradeoffs

A value tradeoff quantifies the relative value of achievement on two different objectives. It specifies how much achievement on the first objective one is willing to give up to achieve a specified amount on the second objective. In lay terms, it is an even swap of achievement on the first objective for achievement on the second objective. An illustration will be useful.

Consider two of the objectives of homeland security: O_1, minimize fatalities, and O_2, minimize serious injuries. Let us measure these using the metrics **X** for the number of fatalities and **Y** for the number of serious injuries, which will be defined as an injury prohibiting normal life function for one year. Fig. 2 illustrates consequences concerning these two objectives by (x, y), where $(10, 400)$ means 10 fatalities and 400 serious injuries.

In considering the value tradeoff between fatalities and serious injuries, suppose it is determined that from consequence $(30, 400)$, if fatalities could be reduced from 30 to 10, this would be an overall improvement if serious injuries did not increase to as many as 1,000 and would be equally bad if

they increased to exactly 1,000. This would mean that $(30, 400)$ is indifferent to $(10, 1000)$, so the value tradeoff would be 600 serious injuries to avoid 20 fatalities.

Finding pairs of consequences that are indifferent is how value tradeoffs are assessed. And of course, value judgments (i.e., the indifferences) are the basis to specify the value tradeoffs. An assessed indifference pair of consequences has four different but consistent interpretations:

- From (x_1, y_2), an increase in **X** to x_2 is compensated for in terms of value by a decrease in **Y** to y_1.
- From (x_2, y_1), an increase in **Y** to y_2 is compensated for in terms of value by a decrease in **X** to x_1.
- From (x_1, y_1), an increase in **X** to x_2 and an increase in **Y** to y_2 are equally valued (i.e., equally undesirable).
- From (x_2, y_2), a decrease in **X** to x_1 and a decrease in **Y** to y_1 are equally valued (i.e., equally desirable).

As the DHS utility function in Equation (3) is additive and linear, another consistent interpretation of a value tradeoff is to compare the relative value of a unit change on each of the objectives. Since 20 fatalities is deemed equivalent in value to 600 serious injuries, we can say that avoiding one fatality is 30 times as valuable as avoiding one serious injury or that avoiding one fatality is equally as valuable as avoiding 30 serious injuries. Alternatively, we can say that avoiding one fatality would compensate for an increase of 30 serious injuries. When a value tradeoff uses a unit consequence (e.g., one fatality in this case) on one of the metrics, it is referred to as a unit value tradeoff.

3.4.2. Specifying Value Tradeoffs

Value tradeoffs are based on value judgments and should be grounded on sound information and reasoning. In the example above, the meaning of a fatality is clear and the meaning of a serious injury should be unambiguously defined. As a serious injury is defined to have a duration of a year, we imagine that almost everyone would conclude that one fatality is more important (i.e., worse) than one serious injury and perhaps most would say that it is worse than at least 20 serious injuries, although there is no correct answer as this is a value judgment. Also, many people might say that 200 serious injuries are worse

than one fatality. If these value judgments seemed appropriate, they imply that the value tradeoff between fatalities and serious injuries is that one fatality is indifferent to y serious injuries, where y is between 20 and 200.

Information can help us select a reasonable value tradeoff. It would be useful to understand what the quality of life of an individual would be in a year with this serious injury relative to that individual's quality of life without that injury. Useful work on this would include gathering information from individuals who have been seriously injured for a year and professionals who treat and routinely work with such individuals. Suppose it was decided that on average the relative quality of life of the seriously injured individual is 60% compared to the quality of life with no injury. Other information could provide a good estimate of the years of life lost by those who were fatalities. Suppose the data suggested 35 years of life lost on average, but when adjusted for possible degraded quality of life in later years, that about 32 years of quality life were lost with each fatality. Thus, the serious injury is equivalent to a 40% loss of one quality-life year and a fatality is equivalent to 100% loss for 32 quality-life years. With the assumption that all quality-life years are equal, which is probably reasonable given the precision of value judgments and the differences among individuals, this indicates that a serious injury on average results in the loss of 0.4 quality-life years and a fatality results in the loss of 32 quality-life years, which suggests a value tradeoff that 80 serious injuries is equivalently undesirable as one fatality.

As discussed in Section 2.5, any DHS utility function must incorporate the difficult-to-make value tradeoff between the two objectives—minimize loss of life and minimize costs. To make a reasoned and reasonable value judgment about this value tradeoff requires understanding three basic facts. First, the actual value tradeoff being addressed is between very small risks of life loss to many individuals and the costs of reducing these risks. These small risks to many individuals have direct implications for the expected number of lives lost, and since our concern for lives lost is the fundamental reason that we care about the original risks, this tradeoff is better understood by considering the value tradeoff between loss of lives and costs. Second, this value tradeoff cannot be avoided, so it is appropriate to address it explicitly. Third, as there is no way to avoid it, addressing it is not unethical.

To illustrate that the value tradeoff concerns small risks to many individuals and costs, a simple paraphrased story is useful.[19] Suppose that an accident in a coal mine traps one miner, Kirk Eastman. He has enough water and air to survive for a week. A quick appraisal indicates that it would cost $25 million to drill a tunnel and rescue Kirk, an effort that is sure to be successful. The decision is made to proceed. However, just before beginning work on the tunnel, an individual knowledgeable about mine safety raises the following dilemma: "Coal mining is a risky occupation, and accidents all too frequently occur in mines because of a tunnel collapses. If we spend the $25 million to strengthen support systems, we would expect fewer accidents over the next five years and statistics suggest that the lives of four miners would therefore be saved. Should we spend $25 million to save the life of one miner when we could spend the same amount to save four miners?"

Perhaps $25 million should be spent for each purpose, but if only one of them can be funded, many people would choose to rescue Kirk. There is of course no right or wrong answer to this. Rescuing Kirk Eastman would avoid what is referred to as an identifiable fatality, one where it is known exactly whose life is saved or lost. Saving four miners who would have been in accidents that did not occur because of safety investments would avoid four "statistical fatalities." In the former case, everyone would know who, that is, Kirk, was saved, whereas in the latter case this could never be known. Because of this distinction, it may be appropriate to assign a different economic value tradeoff (and most people suggest a smaller one) to saving a statistical life than to saving an identifiable life.

Considering terrorist attacks and counterterrorism decisions, the lives that are saved or lost are statistical fatalities. A program to detect and stop potential terrorist attacks before they occur would lower the risks of life loss by a small amount for large numbers of people. Using data, information, and logical reasoning, it may be possible to estimate the expected number of statistical lives saved, but it would never been known whose lives were saved. Thus, when we consider value tradeoffs between lives lost and economic costs, we are in essence valuing the reduction of small risks to numerous individuals. If a risk to each of 1 million individuals is reduced from three chances in a million of dying in a given year to two chances in a million of dying in that year, the expected number of lives saved is one, which is defined as one statistical life saved.

Regarding most counterterrorism activities, spending more money could reduce specific risks

of loss of life to some individuals. More safety features on aircraft, more security checks, hardening of potential targets of terrorists, and funding more activities to identify and intercept potential terrorists all cost money and, chosen well, would reduce life-threatening risks. Hence, an inherent component of almost all counterterrorism decisions is to make a value tradeoff between the economic costs and loss of life, meaning the loss of statistical lives. Even though many people are uncomfortable with the concept of trading off economic costs against potential fatalities, there is no way to avoid this situation. We could act like it is not necessary or avoid thinking about it, but any actions will imply that a certain value tradeoff was made.

Some people consider it immoral to trade off loss of life versus economic costs. However, most moral theories hold that an action is not immoral when there are no alternatives, so making such a value tradeoff is not immoral. Furthermore, many moral theories argue that refraining from actions that would save lives is immoral. To the extent that analysis can lead to better decisions that will save more lives, it is perhaps immoral not to explicitly address the crucial value tradeoffs between costs and statistical fatalities. Thinking carefully about that value tradeoff and making it explicitly may indeed improve the analysis and save lives.

The federal government has numerous programs that are intended to avoid fatalities. With many of these programs, such as highway safety programs and various health programs, fatalities can be avoided for an investment of much less than $10 million per statistical life saved. Another relevant fact follows from considering where the money comes from that the government uses to avoid public fatalities. It naturally comes from members of the public in the form of various taxes. Analyses have shown that on average individuals and families spend their money in ways that makes their lives safer. In other words, the likelihood of dying in any one year is less if individuals have more disposable income. The analyses of this phenomenon indicate that an additional statistical life is lost for each $8.3–$15.0 million taken from individuals depending on whether it is taken in equal amounts from all families or proportional to a family's income.[20] Collectively, these facts suggest that a reasonable value tradeoff is in the range of $6–$12 million per statistical fatality, because spending more money to avoid statistical fatalities from terrorism would lead to more statistical fatalities from other causes, which are borne by the same people.

3.4.3. Preliminary Set of Value Tradeoffs

The parameters in the homeland security utility function (Equation (3)) indicate the relative importance of a unit of impact on each of the metrics. Being relative, we can arbitrarily set the parameter for a unit of impact on one metric and specify the other parameters with respect to it. As economic costs are essentially measured on a continuous scale, whereas many of the other metrics involve numbers of things, it is convenient to report the unit value tradeoffs relative to economic costs. Specifically, we will use a unit impact of $1 million of direct economic costs to society as our basis for comparison and assign a parameter of 1 to the relative importance of this unit impact.

Table II shows ranges of unit value tradeoffs for the objectives and metrics that we identified for DHS decision making. These unit value tradeoffs specify the economic cost of terrorism countermeasures that are equally valued (i.e., equally less desirable) as a unit consequence of each metric. For example, a value tradeoff of $200,000 for a serious injury means that the equivalent cost of a statistical injury to society is $200,000 or that avoiding one such statistical injury would be worth an investment of $200,000. In Table II, we assigned a range of $100,000 and $500,000 to the unit value tradeoff for a serious injury, defined as an injury serious enough to prohibit normal life function for one year. This range, which is primarily for illustrative purposes, is based on literature surveys of tradeoffs for injuries and illnesses of various severities and the logic relating injuries to statistical fatalities as discussed below.

Let us suppose that $8 million is chosen as the value tradeoff for a statistical life. It is easy to link sets of the value tradeoffs. For example, assume that we have valued 80 serious injuries equivalent to one statistical fatality and one statistical fatality equivalent to an economic cost of $8 million. Then, 80 serious injuries must be equivalent in value to a cost of $8 million, which leads to the unit value tradeoff that $100,000 is equivalent to one serious injury.

This indicates that consistency checks are useful and easy to use. Rather than calculate the value tradeoff between serious injuries and economic costs above, information and logic could have been used to specify it. Suppose that were done and it suggested a cost of $120,000 was equivalent to a serious injury for a year. This is not so different from the calculated $100,000 and it suggests that either assessment is reasonable. Furthermore, it provides a basis, along with the two interrelated value tradeoffs, to develop

a completely consistent set of the three by adjusting some or all of them slightly. For example, with further reflection on the relevant information, and perhaps with the gathering of additional information, it may be decided that $9 million is equivalent to one statistical fatality, one statistical fatality is equivalent to 75 serious injuries, and one serious injury is equivalent to $120,000, which are one consistent set of these value tradeoffs.

Some value tradeoffs are more difficult to assess because there is very little literature addressing them directly. In these cases, we used basic reasoning to provide ranges. Experiencing extended periods of fear is an example. The metric is the number of people experiencing significant episodes of fear, by which we mean a strong emotional reaction at least once a week over a period of a year. This would be a state in which one certainly would have a degraded lifestyle and perhaps have to obtain psychological or psychiatric help. The unit is one person who experiences such significant fear. For illustration we use a range of $1,000–$10,000 of equivalent cost. The $10,000 level would be equivalent to a person who would need substantial psychological treatment, and the $1,000 level would be equivalent to a person who routinely worries about terrorism events, but this does not rise to a condition requiring treatment.

We illustrate the specification of value tradeoffs with two additional examples: disruption of lifestyles and inconveniences, both consequences of terrorist acts. Since terrorist acts are usually conducted in public places to instill fear, some people may choose to reduce their activities in large public places like shopping malls or sports events. This clearly disrupts their lifestyle. How much is it worth to avoid such disruption to an individual for one year? We give a range of $500–$5,000. This is partially based on calibrating the value tradeoff against the "fear" tradeoff, which suggests that, while there is no substitution for fear, there are substitution mechanisms for the disrupted lifestyles, for example, going to smaller venues, online shopping, etc. This leads us to conclude that the value tradeoff for fear is higher than that for disruption. The upper bound of the value tradeoff for disruption is based on consideration of what it would take to compensate one individual for a year of disruption of the kind we are talking about. It seems to us that $5,000 would be a generous compensation.

The value tradeoff for inconveniences was developed quite differently. In this case the tradeoff is for 100,000 hours of wasted time, spread over many people, due, for example, to standing in airport security lines, added time to obtain visas, etc. Our proposed value tradeoff range is $1 million to $5 million per 100,000 hours, which translates into $10–$50 per hour. The lower bound comes from studies of productivity losses during electricity outages (between $3 and $10 per outage hour per person.[21,22] However, during electricity outages, one can still pursue some useful activities especially during daylight hours, suggesting the lower bound of $10/hour/person. The higher number is an estimate based on the assumption that many of the targeted waste hours are by professionals and that they are truly lost productive hours. For example, there is not much else that one can do while waiting in an airport security line.

Many of the metrics for consequences of terrorist attacks, consequences of counterterrorism efforts, and civil liberties indicate the number of individuals who have been impacted in specific ways. For each of these, a threshold level of significant impact, analogous to that discussed for illnesses above, must be chosen to estimate the number of individuals experiencing that impact. To assess the relative value of deterring a potential terrorist attack or foiling an attack in progress, information about the possible consequences of such a successful attack and its likelihood is needed, for which the value can be calculated from the consequences of attacks as illustrated in Section 4.1 below. For the metrics for future terrorism threats, information is needed about how each of these influences the likelihood of attacks.

4. USES OF A HOMELAND SECURITY VALUE MODEL

The DHS value model can be used to improve homeland security decision making in numerous ways. All follow from the same principle: if you better understand what you are trying to achieve and why, it is more likely that you will achieve it. The DHS value model unambiguously outlines what DHS wants to achieve.

4.1. Evaluating Terrorism Risks

The DHS value model (Equation (3)) can be used to evaluate of terrorist risks as defined in Section 2. For this purpose, we need to assess p, q, and the consequences of a successful terrorist attack, specified under the strategic objective *reduce consequences of attacks*. Note

that in this assessment we do not need to consider the consequences under the remaining strategic objectives. However, we have to consider that all assessments of probabilities and consequences are relative to the status quo, i.e., with current countermeasures and interventions in place. To illustrate, recognize that in Table II, O_i, $\mathbf{X}_i$, and x_i, $i = 1, \ldots, 13$, represent the set of 13 lower level strategic objectives under the major strategic objective *reduce consequences of attacks*. Hence, if the consequences of a specific terrorist attack are $x = (x_1, \ldots, x_{13})$ and the utility function is $u(x) = u(x_1, \ldots, x_{13})$, the risk of that terrorist attack as defined in Equation (1) can be represented as:

$$R(\text{Terrorist Attack})$$
$$= p(\text{Attempted Attack}) \times q(\text{Success}|\text{Attempt})$$
$$\times [-u(x_1, \ldots, x_{13})], \tag{6}$$

where $u(x_1, \ldots, x_{13})$ is a part of the DHS utility function (Equation (3)). As mentioned in conjunction with using Equation (1), if a successful terrorist attack might result in one of various possible consequences, then Equation (6) should be adapted to use the expected utility of the possible consequences.

Using Equation (6), it is possible to evaluate the relative risks of different types of terrorist attacks, call them TA_j, $j = 1, \ldots, J$. The consequences of each attack, if successful, can be referred to as x_j, $j = 1, \ldots, J$, where $x_j = (x_{1j}, x_{2j}, \ldots, x_{13j})$. Because of uncertainty, we might want to assess a probability function $p_j(x)$ describing the possible consequences of TA_j, from which an expected utility u_j can be calculated. From Equation (3), the utility of no terrorist attack is 0, so all utilities of terrorist attacks will be less than zero. The absolute magnitude of u_j then indicates the (dis)utility of the terrorist attack TA_j if it successfully occurs and the magnitude of $R(\text{TA}_j)$, which we can write as R_j, indicates the disutility of the attempted terrorist attack TA_j. The relative magnitudes of the u_js indicate the relative significance of successful TA_js, and the relative magnitudes of the R_js indicate the relative importance of additionally protection against terrorist attacks TA_j.

4.2. Evaluating the Benefits of Countermeasures

We define the risk of a specific terrorist attack given that countermeasure C has been implemented as follows:

$$R_C(\text{Terrorist Attack with Countermeasure } C)$$
$$= p_C(\text{Attempted Attack}) \times q_C(\text{Success}|\text{Attempt})$$
$$\times [-u(x_C)], \tag{7}$$

where p_C is the probability of the attempted attack given the countermeasure C, q_C is the probability that the attack is successful given the countermeasure C, x_C is the consequence of such an attack, as defined in Section 4.1, if successful given the countermeasure C, and $R_C(\text{Terrorist Attack})$ is the disutility of that terrorist attack given that countermeasure C has been implemented. In general we would expect $p_C \leq p$, $q_C \leq q$, and $u(x_C) > u(x)$.

The benefit B of a countermeasure to terrorist attack TA can be measured by:

$$B(\text{Countermeasure}) = R(\text{TA}) - R_C(\text{TA}). \tag{8}$$

The decisions necessary to manage terrorism are very complex. Hence, it is not surprising that it is a difficult task to gather all of the information necessary to systematically appraise terrorism management alternatives as outlined here. However, it has been done with some success in several DHS contexts. Examples include assessing the risks of bioterrorism,[23] the risk of surface-to-air missile attacks against commercial aircraft,[7] and evaluating the benefits of the Western Hemisphere Travel Initiative.[24] Most previous studies used relatively simple value models, which employed a small set of objectives and consequence measures (usually $\mathbf{X}_1$–$\mathbf{X}_6$), and value tradeoffs justified by the literature.

Fortunately, the amount of effort to construct a high quality value model is very small compared to the effort to estimate the possible consequences x and x_C necessary to evaluate counterterrorism alternatives of homeland security. Since the value model is applicable across terrorism risks and across countermeasures, it would be a very effective allocation of effort to develop a DHS value model and use it, sometimes with appropriate adaptation for specific risk and benefit assessments. With such use, the evaluation of terrorism management alternatives should be internally more consistent, require less time, and be easier to explain to others.

Terrorist Attack	X_1 = Fatalities $(k_1 = 9)$	X_6 = Direct Costs to Society($mil) $(k_6 = 1)$	SI (Severity Index)	MSI (Magnitude Severity Index)
B: Suicide bomb in public transportation system	15	40	175	2.2
G: Destroy government building with truck bomb	600	1,500	6,900	3.8
D: Dirty bomb in the Los Angeles/Long Beach harbor area	20	50,000	50,180	4.7
N: Small nuclear explosion near population center	40,000	5,000	365,000	5.6

4.3. Developing a Severity Index for Terrorist Consequences

The same objectives, metrics, and value tradeoffs in Table II appropriate to evaluate the threats of possible terrorist attacks provide the basis for creating a severity index for both possible and any actual terrorist attacks. Specifically, an index for the severity SI of a successful terrorist attack resulting in consequence $(x_1, \ldots, x_{13})$ is:

$$SI(x_1, \ldots, x_{13}) = k_1 x_1 + k_2 x_2 + \cdots + k_{13} x_{13}, \quad (9)$$

where the units of the k_is in Equation (6) are deleted to have a magnitude for severity without units. A larger SI indicates a greater severity and, since the magnitude of severity indicated using Equation (9) is linear, a severity calculated as 200 is 10 times as great as one calculated to be 20.

To illustrate how the severity index could be used, suppose a terrorist attack occurred that resulted in 30 fatalities, 200 seriously injured individuals, $20 million in direct costs collectively to individuals and businesses, caused fear to 50,000 citizens, and led to $75 million in indirect economic costs. Furthermore, suppose that the other consequences of terrorist attacks listed in Table II were essentially negligible. Thus, $x_1 = 30$, $x_3 = 200$, $x_4 + x_5 = 20$, $x_7 = 75$, and $x_9 = 50,000$, with the other $x_i = 0$. For this illustration, we will also assume that the relevant unit value tradeoffs are the midpoints of the illustrative ranges in Table II, so $k_1 = 9$, $k_3 = 0.3$, $k_4 = k_5 = 1$, $k_7 = 1$, and $k_9 = 0.0055$. Substituting into Equation (9), the severity index SI for this attack, call it A, is:

$$
\begin{aligned}
SI_A &= 9(30) + 0.3(200) + 1(20) + 1(75) + 0.0055(50,000) \\
&= 270 + 60 + 20 + 75 + 275 \\
&= 700.
\end{aligned}
\quad (10)
$$

From the calculation leading to Equation (10), is easy to see the relative contributions of the different consequences to the overall severity. In this case, fatalities and fear each account for just under 40% of the total severity.

The same concepts and formulation can be used to evaluate the seriousness of possible different types of terrorist attacks in the future, such as a suicide bomber, destroying a government building, a dirty bomb in a harbor, or a small nuclear explosion near a large concentration of people. For these calculations, estimates are needed of what the possible consequences may be. There would naturally be uncertainties about the possible consequences. Since the severity index (Equation (9)) is linear in each of the consequences, the expected severity of a future attack can be calculated by using the expected consequences of each of the metrics that describe that attack in Equation (9).

As an illustration, suppose that the only consequences of the four types of attacks mentioned above are fatalities x_1 and direct economic costs to society x_6. Table III labels the four possible attacks as B, G, D, and N, describes them in terms of their consequences, and calculates their severity index with Equation (9) using midpoint unit value tradeoffs $k_1 = 9$, $k_6 = 1$. As these severities are based on the linear scale, it is correct to interpret that the dirty bomb in a harbor has a severity magnitude of about 10 times the destruction of a government building.

Severity scales for natural catastrophes, such as earthquakes and hurricanes, use a log scale (i.e., magnitude scale) rather than a linear scale as in Equation (9). For example, an earthquake of Richter magnitude 7 has 10 times the destructive potential of an earthquake of Richter magnitude 6. A log scale allows one to include magnitudes of two events, where one event is a billion times larger than the other, on a 1–10 scale. To be on a par with these natural indices, it is easy to take the log of the severity calculated with the SI index to create a magnitude severity index. We could refer to this index as MSI, which is simply calculated as:

$$MSI_A = \log(SI_A) \quad (11)$$

for any terrorist attack A. Applying Equation (11) to the attacks in Table III yields the MSI results shown there. Aside from providing numbers for severity that are in the same ranges as those for natural catastrophes, these numbers are easier to refer to and capture the magnitudes of potential terrorist attacks without being overprecise about differences that are very difficult to estimate. In addition, since DHS is also concerned with natural disasters, appropriate scaling could potentially align the severity indices for successful terrorist attacks and natural disasters.

4.4. Improving the Quality of DHS Decision Processes

As the short-term and long-term effects of using a DHS value model are somewhat different, we discussed the two cases separately.

4.4.1. Short-Term Effects

The DHS value model provides a solid foundation to construct an appropriate value model for any specific decision, such as protecting our borders, installing new security systems at airports, responding to terrorist attacks, or managing a terrorist watch list. For any specific homeland security decision context, one should consider how each objective in the DHS value model might be influenced by potential choices for the specific decision. From this, you essentially follow the process outlined in Section 3. You need to identify all relevant objectives, structure them into both a fundamental objectives hierarchy and a means-ends objectives network, choose metrics for the objectives, and then weight the fundamental objectives. Appropriate fundamental objectives for a specific decision can be logically developed from the strategic objectives of DHS. Appropriate weights for the specific value model can be logically derived from the weights used in the DHS strategic value model.

Once you have identified all the objectives for a specific decision, they can be used for creating alternatives, developing a decision model, indicating what data and information are needed, evaluating alternatives, and for communicating about the decision.

All objectives, but particularly all of the means objectives, can be used to stimulate the creation of alternatives. For each objective, one asks what could be done that might better achieve this objective. Consider a possible terrorist attack that was intended to release a serious pollutant that would harm people if inhaled. Alternatives could be developed that directly influence means objectives such as minimizing pollutant emissions, minimizing pollutant concentra-

tions, or minimizing human exposure to pollutants that could contribute to better achieving the fundamental objective of minimizing illness.

For complex decisions, a decision model is useful to relate each of the alternatives to the consequences that will possibly occur. To guide the development of the model, the means-ends objectives network is helpful. This network breaks down these relationships in a manner consistent with the data and information that must be gathered. Using the example above, information can be collected on where and how much pollutant might be released. Then either an atmospheric model, for air pollutants, or a water flow model, for water pollutants, can usefully relate the emissions to concentrations. Next, a population model can relate concentrations to exposures. And finally a medical model can relate exposures to illnesses. At this stage, the alternatives can be analyzed to indicate how each performs using the utility function.

Obviously, sensitivity analysis can indicate what changes occur in the relative evaluation of alternatives and how significant they are when input information is varied. By viewing different objectives or sets of objectives in the objective function, one can identify the relative pros and cons of each of the alternatives in terms of how well the alternatives meet the various objectives. As it is achieving the objectives that is of concern to people, communicating to the public in terms of the pros and cons of the alternatives is useful.

For some DHS decisions, the formality suggested above is probably not practical or useful. In these cases, it is still critically important to understand the objectives of the decision context and to create innovative alternatives to better achieve them. Thus, even if no model is explicitly used for evaluating alternatives, the quality of the decision-making process can be enhanced by listing of objectives explicitly and using them to create alternatives and to understand their pros and cons.

4.4.2. Long-Term Effects

Three key means objectives in the DHS means-ends objectives network in Fig. 1 contribute to long-term quality decision processes. These are to promote research on homeland security, create educational programs on homeland security, and create a profession with expertise on homeland security. The DHS value model can be used as an outline of the substance of concern for each of these. We want quality research that will help us better understand how

well proposed alternatives will measure up in terms of specified objectives and that will suggest other alternatives that might be even better. We want educational programs to educate a substantial group of individuals who understand the body of knowledge concerning all of the relationships among homeland security objectives and the alternatives that influence the achievement of these, as well as their significance. Some of these individuals will hopefully join a growing group of homeland security professionals who contribute to enlarging our collective knowledge about terrorism and guide coherent effective counterterrorism programs to reduce terrorism as a threat and bring about an enhanced quality of life.

5. CONCLUSIONS

This article makes and supports the following two points:

1. Constructing and using a legitimate value model for homeland security could make a substantial contribution to improving homeland security. Hence, constructing such a value model should be a high priority task. Its existence would guide the thinking, decisions, and actions of homeland security and promote different groups and individuals to work toward accomplishing the same national goals.

2. The knowledge, techniques, and experience necessary to construct a high-quality value model for homeland security currently exist. This article summarizes the knowledge and illustrates the techniques required to construct a preliminary homeland security value model. This demonstrates that a value model for homeland security that meets a high standard of relevance and legitimacy can be constructed and how to do it.

A homeland security value model should be constructed by a project with a diverse group of informed members, including DHS policymakers, managers, stakeholders, and a few experts on value methodology. Their task would be to carefully conduct the procedures described in this article. Specifically, it should identify a complete set of strategic objectives for counterterrorism, specify good metrics for each of these objectives, verify that the additive-linear form of utility function is appropriate or adapt it as necessary, establish a logical set of value tradeoffs, and document the entire effort. Throughout the project,

the team should frequently gather and exchange information with personnel in any other governmental departments, local or national, concerned with homeland security, and frequently consult the public to ensure that its concerns are addressed.

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