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Using Probabilistic Terrorism Risk Modeling for Regulatory Benefit-Cost Analysis: Application to the Western Hemisphere Travel Initiative in the Land Environment

Henry H. Willis¹,* and Tom LaTourrette²

This article presents a framework for using probabilistic terrorism risk modeling in regulatory analysis. We demonstrate the framework with an example application involving a regulation under consideration, the Western Hemisphere Travel Initiative for the Land Environment (WHTI-L). First, we estimate annualized loss from terrorist attacks with the Risk Management Solutions (RMS) Probabilistic Terrorism Model. We then estimate the critical risk reduction, which is the risk-reducing effectiveness of WHTI-L needed for its benefit, in terms of reduced terrorism loss in the United States, to exceed its cost. Our analysis indicates that the critical risk reduction depends strongly not only on uncertainties in the terrorism risk level, but also on uncertainty in the cost of regulation and how casualties are monetized. For a terrorism risk level based on the RMS standard risk estimate, the baseline regulatory cost estimate for WHTI-L, and a range of casualty cost estimates based on the willingness-to-pay approach, our estimate for the expected annualized loss from terrorism ranges from $2.7 billion to $5.2 billion. For this range in annualized loss, the critical risk reduction for WHTI-L ranges from 7% to 13%. Basing results on a lower risk level that results in halving the annualized terrorism loss would double the critical risk reduction (14–26%), and basing the results on a higher risk level that results in a doubling of the annualized terrorism loss would cut the critical risk reduction in half (3.5–6.6%). Ideally, decisions about terrorism security regulations and policies would be informed by true benefit-cost analyses in which the estimated benefits are compared to costs. Such analyses for terrorism security efforts face substantial impediments stemming from the great uncertainty in the terrorist threat and the very low recurrence interval for large attacks. Several approaches can be used to estimate how a terrorism security program or regulation reduces the distribution of risks it is intended to manage. But, continued research to develop additional tools and data is necessary to support application of these approaches. These include refinement of models and simulations, engagement of subject matter experts, implementation of program evaluation, and estimating the costs of casualties from terrorism events.

KEY WORDS: Benefit-cost analysis; homeland security; probabilistic risk analysis; terrorism

1. INTRODUCTION

The White House Office of Management and Budget (OMB) directs agencies to use benefit-cost analyses to justify proposed regulations during the regulatory review process (OMB, 2003). This presents a challenge to the Department of Homeland Security (DHS) because applying benefit-cost analysis to efforts to combat terrorism raises difficult questions, including:

1. How, where, and when will terrorists attack?
2. How vulnerable are targets to attack?
3. What are the consequences of terrorist attack?
4. How do regulations reduce terrorism risk?

Estimating the costs of a regulatory action is a relatively straightforward process. However, estimating the benefits of terrorism security regulations requires answering these difficult questions.

Estimates of terrorism risk and risk reduction must account for significant uncertainty. In particular, estimates must judge how likely attacks will be and also how effective countermeasures will be at reducing terrorism risks (Willis et al., 2005). Usually, precise estimates are not available for either of these factors. In lieu of reliable ways to estimate benefits, break-even analysis is an approach that can be used to better understand the conditions under which a regulatory action is justified on the basis of a benefit-cost analysis.

This article describes a framework for using probabilistic risk modeling to conduct break-even analyses of a regulatory action motivated by terrorism security, demonstrates an application of the framework on the regulatory analysis of a currently proposed regulation (the Western Hemisphere Travel Initiative for the Land Environment, WHTI-L), and discusses how this type of analysis can be further integrated into the regulatory review process at the Department of Homeland Security.

2. USING RISK MODELING IN REGULATORY BENEFIT-COST ANALYSIS

Applications of risk analysis to terrorism security have used many different methods and approaches. Examples of methods that have been applied include agent-based models (N-ABLE, 2006; Tsvetovat & Carley, 2002), game theory (Kunreuther, 2005; Bier et al., 2005), economic input-output models (Haimes et al., 2005; Gordon et al., 2006), probabilistic risk analysis (Rosoff & von Winterfeldt, 2006; ASME, 2007), operations research approaches drawing upon queuing theory and decision analysis (Martonosi et al., 2005; Wein et al., 2006), and probabilistic models developed and used in the insurance industry (Willis et al., 2005; Willis, 2007; Carroll et al., 2005; Doherty et al., 2005).

One way to characterize these approaches is whether they assess the risk of a specific scenario or to specific facilities or alternatively whether they address the overall risk derived from the outcomes of numerous individual scenarios, each weighted by the probability that that scenario will occur. We refer to this latter approach as probabilistic risk modeling. All of the examples referenced above, with the exception of probabilistic models used by the insurance industry, are generally used to assess risks of specific scenarios.

In terms of characterizing the benefits of terrorism security, probabilistic risk modeling has two advantages over the individual scenario avoidance approach. First, by incorporating a wide range of potential attack scenarios, the overall risk provides a more comprehensive picture of the terrorist threat that includes both more likely but lower consequence attack scenarios as well as low probability, catastrophic attack scenarios. Second, by including the relative likelihood of many different modes of attacks on many different targets, this approach is capable of reflecting the effect that security can have on changes in terrorists’ preferences for attack and the resulting changes in terrorism risk. Such analysis is accomplished by calculating and comparing multiple assessments, each representing scenarios with different assumptions about terrorist intentions and capabilities, target vulnerabilities, and even attack consequences. Some terrorism security efforts focus on particular weapon types or protect specific target types, and their net effect may be to cause potential terrorists to shift their focus to scenarios with less security and hence a higher probability of success. In such cases, measuring benefits by focusing on specific scenarios avoided would not account for the possibility that the risk has been transferred but not reduced.

2.1. The RMS Probabilistic Terrorism Model

One model that incorporates the probabilistic risk modeling approach is the Risk Management Solutions (RMS) Probabilistic Terrorism Model. This model is one of a class of models that have been developed to help the insurance and reinsurance industries assess exposure that firms bear to terrorism risk in their policy portfolios.3

The RMS model generates a probabilistic estimate of the overall terrorism risk from loss estimates for dozens of types of potential attacks against several thousand potential targets of terrorism across the United States. For each attack mode-target pair (constituting an individual scenario) the model accounts for the probability that a successful attack will occur and the consequences of the attack.

Individual scenario probabilities in the RMS model are derived in terms of the probability that a

3 Risk Management Solutions is a provider of products and services for the quantification and management of catastrophic risks and a sponsor of the RAND Center for Terrorism Risk Management Policy. Other firms that have developed terrorism risk models include AIR and EQECAT.
2.2 Break-even Benefit-Cost Framework Using Probabilistic Risk Modeling

Within the context of benefit-cost analysis, a regulation is efficient if the incremental cost of implementing the regulation is exceeded by the incremental benefit generated by the regulation. We model the incremental benefit of a terrorism security regulation as the reduction in terrorism risk due to the regulation. When risk reduction is expressed in terms of the annualized loss avoided, the incremental benefit is the difference between the annualized loss from terrorism without and with the regulation in place. Thus, benefits exceed costs when

\[ L_b - L_n \geq C_r, \]

where \( L \) is the annualized loss from terrorism, the subscripts \( b \) and \( n \) indicate conditions without the regulation (baseline) and with the regulation (new), respectively, and \( C_r \) is the annualized cost of the regulation.4

The effect of a new terrorism security regulation is to change the risk, and in so doing change the annualized loss from \( L_b \) to \( L_n \). A regulation may change terrorism risk by changing the probability of attack, the consequences, or both. It is generally difficult to ascribe the influence of a terrorism security effort exclusively to reducing probability or exclusively to reducing consequences because of the dynamic nature of terrorist adaptation (Jackson et al., 2005). A terrorism security measure could deter potential terrorists or protect potential targets so that the probability of attack would decrease. Alternatively, terrorists could adapt by shifting to different attack modes or target types that would change not only the probability of successful attack, but also the expected consequences of attack. Since terrorism risk reflects both probability and consequence, using risk reduction as the measure of benefit in a benefit-cost analysis captures both effects.

To make the focus on risk reduction more explicit, we define a risk reduction factor, \( R \), as:

\[ R = (L_b - L_n) / L_b. \]

\( R \) is a dimensionless parameter characterizing the risk-reducing effectiveness of a proposed regulation. For a positive risk reduction (i.e., \( L_n \leq L_b \)), \( R \) ranges from 0 (no risk reduction) to 1 (complete mitigation of risk).

Combining Equation (1) with Equation (2) gives

\[ R \geq C_r / L_b. \]

When inequality (3) holds, the benefit of a terrorism security regulation exceeds the cost. The point at which the risk reduction just equals \( C_r / L_b \) is the

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4 Regulations could result in net savings, in which case \( C_r \) would be negative.
minimum risk reduction for which the regulation is justified, and we define the critical risk reduction, $R_c$, as:

$$R_c = C_r / L_b.$$  (4)

This relationship leads to three interesting cases when the risk reduction is positive. First, when $C_r > L_b$, $R_c$ exceeds 1, which violates the bounds on $R$. In this case the regulation is not justified on a benefit-cost basis because its cost is more than the expected losses being avoided. Second, when $C_r \leq 0$ the regulation is justified as long as $L_b > 0$, indicating that a risk-reduction investment that has no cost or results in a net savings is always justified. Finally, when $L_b = 0$, $R_c$ is undefined. Here, because the potential risk is zero, the regulation is only justified if the regulation results in a net savings.

### 3. APPLICATION OF PROBABILISTIC TERRORISM MODELING TO BREAK-EVEN BENEFIT-COST ANALYSIS OF WHTI-L

Current regulations permit U.S. citizens and non-immigrant aliens from Canada, Bermuda, and Mexico to enter the United States from certain Western Hemisphere countries without presenting a passport. The Intelligence Reform and Terrorism Prevention Act of 2004 requires that the Secretary of Homeland Security develop a plan for reliably evaluating the identity and citizenship of people entering the United States. In response, Customs and Border Protection (CBP), jointly with the Department of State, is promulgating a regulation specifying documentation requirements for people entering the United States via land borders from countries in the Western Hemisphere. Briefly, the proposed regulation would require all U.S. citizens to possess a traditional passport book, a newly proposed passport card, or a CBP-trusted traveler card to enter the United States from Canada, Mexico, or the Caribbean (Chertoff & Fore, 2007). In the following section we use a probabilistic terrorism risk modeling approach in a break-even analysis using WHTI-L as an example application. Analyses were conducted for different assumptions about the level of terrorism threat and consequences and using different methods for valuing morbidity and mortality consequences. Using these cost and terrorism loss estimates, we estimate the critical risk reduction ($R_c$) necessary for WHTI-L to be efficient using Equation (4).

### 3.1. Costs of WHTI-L Regulation

Direct costs for WHTI-L were provided by Industrial Economics Incorporated (IEc, 2007). These cost estimates comprise two components: welfare losses to travelers resulting from the increased cost of access and the anticipated government implementation expenditures. Welfare losses represent the cost of purchasing the necessary travel documents for those travelers choosing not to purchase the necessary travel documents. Government implementation costs include the costs to install and operate passport card technology at land points of entry, including an increase in secondary inspections resulting from implementation of the regulation. IEc, Inc. examined a number of different cases reflecting different documentation requirements being considered, different estimates of the future rate of cross-border travel, and the rate at which future expenditures are discounted. These costs (Table I) represent the annualized costs for a 10-year planning horizon. Among the configurations under consideration, current plans appear to favor Alternative 3 and an exemption for children under 16 (U.S. Department of Homeland Security, 2007). We therefore define this (using the 3% discount rate) as the baseline cost estimate.

### 3.2. Terrorism Losses

As noted above, the benefit of terrorism security regulations in terms of benefit-cost analysis is avoided terrorism losses. To quantitatively compare benefits to costs, both need to be expressed in common units, which are typically monetary. To the extent possible, therefore, benefit-cost analysis requires monetization of relevant benefits.

Estimates of the expected annualized loss from terrorist attacks in the United States were derived from the RMS Probabilistic Terrorism Model. The RMS model estimates terrorism losses in terms of property damage and casualties. Model results for the standard risk estimate are shown in Table II. Property damage in the RMS model is monetized by using insurance records and other metrics of property value to convert damage to buildings and contents to monetary values. The RMS model performs this conversion internally by means of nationwide databases of property characteristics and values. Monetization of casualties is more challenging because there are different ways to estimate the monetary values for
Using Probabilistic Terrorism Risk Modeling for Regulatory Benefit-Cost Analysis

Table I. Estimated Total Direct Costs ($ Million) for WHTI-L

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Discount Rate:</td>
<td>3%</td>
<td>7%</td>
</tr>
<tr>
<td>No children exemption</td>
<td>$320</td>
<td>$340</td>
</tr>
<tr>
<td>Decreasing cross-border travel rate</td>
<td>$380</td>
<td>$400</td>
</tr>
<tr>
<td>Steady-state cross-border travel rate</td>
<td>$490</td>
<td>$510</td>
</tr>
<tr>
<td>Increasing cross-border travel rate</td>
<td>$270</td>
<td>$290</td>
</tr>
<tr>
<td>Children Under 14 Exempt</td>
<td>$330</td>
<td>$340</td>
</tr>
<tr>
<td>Decreasing cross-border travel rate</td>
<td>$390</td>
<td>$400</td>
</tr>
<tr>
<td>Steady-state cross-border travel rate</td>
<td>$260</td>
<td>$280</td>
</tr>
<tr>
<td>Increasing cross-border travel rate</td>
<td>$320</td>
<td>$330</td>
</tr>
<tr>
<td>Children under 16 exempt</td>
<td>$370</td>
<td>$380</td>
</tr>
</tbody>
</table>

Source: IEc (2007).

Table II. Expected Value of Standard Risk Estimate from the RMS Model

<table>
<thead>
<tr>
<th>Loss Category</th>
<th>Annualized Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. casualties—medical only or minor</td>
<td>7,120</td>
</tr>
<tr>
<td>No. casualties—temporary total</td>
<td>710</td>
</tr>
<tr>
<td>No. casualties—permanent partial—minor</td>
<td>270</td>
</tr>
<tr>
<td>No. casualties—permanent partial—major</td>
<td>170</td>
</tr>
<tr>
<td>No. casualties—permanent total</td>
<td>80</td>
</tr>
<tr>
<td>No. casualties—fatal</td>
<td>450</td>
</tr>
<tr>
<td>Total casualties</td>
<td>8,800</td>
</tr>
<tr>
<td>Building</td>
<td>$395,000,000</td>
</tr>
<tr>
<td>Contents</td>
<td>$231,000,000</td>
</tr>
<tr>
<td>Business interruption</td>
<td>$675,000,000</td>
</tr>
<tr>
<td>Total property</td>
<td>$1,305,000,000</td>
</tr>
</tbody>
</table>

Notes: Standard risk estimate is the expected (average) annual loss using the standard threat outlook. Losses are annualized over a 10-year planning horizon (see text). Property losses rounded to the nearest million $. Casualty estimates rounded to the nearest 10.

Casualties and none perfectly capture the theoretical scope of costs that should be included (Tolley et al., 1994). The next section discusses different ways that casualty costs are estimated and presents the values used in our analysis.

3.2.1. Monetization of Casualties

Monetary estimates of the costs of casualties vary over a considerable range (e.g., Viscusi & Aldy, 2003) and it is therefore useful to examine the effect of using different estimates of these costs. We estimated the costs of injuries using three methods: estimates of medical and productivity costs (cost of injury), willingness-to-pay estimates derived from the wage-rate literature (willingness to pay), and comparisons of utilities for different health states (quality of life). To gauge the importance of assumptions about the value of morbidity effects to the analysis, we also conducted one case considering only losses from fatalities and excluding morbidity losses. Further details of calculations for each morbidity valuation approach are provided below.

A complication in comparing casualty monetization methods is that different valuation studies use different injury classification systems. A majority of expected casualties estimated from the RMS model are injuries or deaths resulting from physical trauma. Examples of attack modes that cause such consequences include bombs, sabotage attacks, and conflagration. Because of this, the most relevant readily available casualty cost estimates are those associated with trauma injuries from automobile crashes. We therefore use cost estimates for healthcare, productivity, and quality of life that have been derived for injuries classified according to the maximum abbreviated injury scale (MAIS; Association for the Advancement of Automotive Medicine, 2005).

The MAIS is also convenient for our purposes because the injury categories correspond well to those in the RMS model. The MAIS categorizes injuries into
Table III. Comparison of RMS and MAIS Casualty Categories

<table>
<thead>
<tr>
<th>RMS Casualty Category</th>
<th>MAIS Injury Severity Category</th>
<th>Conditions That Would Fall into the Various Categories in Both the MAIS and RMS Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical only or minor</td>
<td>1: Minor injury</td>
<td>Abrasion, laceration, strains, sprains, contusions: can be treated and released.</td>
</tr>
<tr>
<td>Temporary total</td>
<td>2: Moderate injury</td>
<td>Simple broken bone, loss of consciousness, serious strains and sprains: requires follow-up and several weeks or months to heal, but will heal completely.</td>
</tr>
<tr>
<td>Permanent partial—minor</td>
<td>3: Serious injury</td>
<td>Complicated fracture, serious joint injury, concussion, minor crush injury: requires substantial follow-up and some minor disability will result.</td>
</tr>
<tr>
<td>Permanent total</td>
<td>5: Critical injury</td>
<td>Spinal cord syndrome, crush syndrome with kidney failure, massive head injury: extended hospitalization, significant long-term disability.</td>
</tr>
<tr>
<td>Death</td>
<td>6: Immediately fatal</td>
<td></td>
</tr>
</tbody>
</table>

Note: Examples of injuries provided by Sullivan (2007).

six levels of severity ranging from minor to fatal. Table III provides examples of injuries associated with each category and how we associated the MAIS categories to the RMS workers’ compensation casualty categories.

In terms of the types of injuries that put people in the respective injury classes, there is a great deal of similarity between the MAIS and the RMS scale. One difference is that the MAIS is most concerned with triage and allocation of on-scene medical resources, while the RMS scale tries to account for the long-term prognosis. This difference manifests itself in two ways that have opposing effects. On the one hand, some proportion of people with serious injuries will not go back to work even if they are not completely medically disabled, in which case the same injury would score higher on the RMS scale than on the MAIS. On the other hand, many injuries with life-threatening trauma could potentially have total or near-total recovery, in which case the same injury would score lower on the RMS scale than on the MAIS. Taken together, these effects work to cancel each other, diminishing differences in the two classification systems.

3.2.1.1. Cost of injury estimates. The easiest morbidity and mortality costs to measure are the direct costs incurred for treatment of injury. Adding these costs to estimates of lost labor productivity and effects of lost productivity of others in the household provides a measure of the financial consequences of morbidity and mortality consequences, sometimes referred to as the cost of injury. This method does not account for reduction in one’s quality of life (i.e., pain and suffering), which has been shown to be a far greater component of the loss than medical or lost productivity costs (Tolley et al., 1994). Cost of injury estimates therefore represent lower bounds for the purposes of benefit-cost analyses.

Estimates of medical costs and productivity losses were derived from a survey of costs of casualties resulting from vehicle crashes. The National Highway Traffic Safety Administration (NHTSA) estimated the costs of healthcare and productivity losses for vehicle crash casualties classified according to the MAIS (Blincoe et al., 2002). Cost of injury estimates used in our analysis are shown in Table IV.

3.2.1.2. Willingness-to-pay estimates. A common method to derive estimates of willingness to pay to avoid injuries is to analyze relationships between hourly wages and occupational fatality and injury risks. In theory, workers demand higher wages for...
incurring exposure to such risks, and any risk-related wage premium represents a revealed valuation of injuries. Viscusi and Aldy (2003) reviewed 40 studies presenting willingness-to-pay estimates of injury risk premiums derived from wage differential analyses. These studies examine nonfatal job risks in terms of the overall injury rate, the rate of injuries severe enough to result in a lost workday, and the rate of total lost workdays. In contrast to the cost of injury and quality of life based cost estimates, the willingness-to-pay-based injury cost estimates do not distinguish costs for injuries of different severities. Across these studies the value of injury ranged from approximately $20,000 to $70,000 (2000 US$).

We used the high end of this range and assigned this value for all nonfatal injury categories from the RMS model. We excluded injuries in the lowest severity category because they are very minor and are not expected to be representative of the types of injuries that are associated with the estimated wage premiums. Despite using the high end of the range of injury values, the distribution of types of workplace injuries is probably biased toward less severe injuries relative to the injury distribution that would result from a terrorist attack. Hence, these willingness-to-pay estimates likely underestimate the value of injuries resulting from a terrorist attack. Resulting injury costs, reported in 2005 US$, are listed in Table IV.

For fatal injuries, we use estimates of willingness to pay to avoid fatal injuries, which is commonly referred to as the value of a statistical life (VSL). We use VSL estimates of $3 million and $6 million, which reflect assumptions typically used by the U.S. Department of Transportation and U.S. Environmental Protection Agency, respectively (Institute of Medicine, 2006).

### Table IV. Casualty Cost Estimates

<table>
<thead>
<tr>
<th>RMS Category</th>
<th>MAIS Category</th>
<th>Cost of Injury</th>
<th>Willingness to Pay ($3M VSL)</th>
<th>Quality of Life ($3M VSL)</th>
<th>Willingness to Pay ($6M VSL)</th>
<th>Quality of Life ($6M VSL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical only</td>
<td>MAIS 1</td>
<td>$7,000</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Temporary total</td>
<td>MAIS 2</td>
<td>$70,000</td>
<td>$79,000</td>
<td>$330,000</td>
<td>$79,000</td>
<td>$660,000</td>
</tr>
<tr>
<td>Permanent partial—minor</td>
<td>MAIS 3</td>
<td>$202,000</td>
<td>$79,000</td>
<td>$480,000</td>
<td>$79,000</td>
<td>$960,000</td>
</tr>
<tr>
<td>Permanent partial—major</td>
<td>MAIS 4</td>
<td>$383,000</td>
<td>$79,000</td>
<td>$210,000</td>
<td>$79,000</td>
<td>$420,000</td>
</tr>
<tr>
<td>Permanent total</td>
<td>MAIS 5</td>
<td>$1,222,000</td>
<td>$79,000</td>
<td>$2,430,000</td>
<td>$79,000</td>
<td>$4,860,000</td>
</tr>
<tr>
<td>Fatal</td>
<td>MAIS 6</td>
<td>$1,086,000</td>
<td>$3,000,000</td>
<td>$6,000,000</td>
<td>$6,000,000</td>
<td></td>
</tr>
</tbody>
</table>

Notes: All values are reported in 2005 US$ using the consumer price index. VSL = value of a statistical life. Casualty costs are rounded to the nearest $1,000.

Sources: 1Blincoe et al. (2002), 2Viscusi and Aldy (2003), 3Graham et al. (1997).

### Table V. Preference Weights for Different Injuries

<table>
<thead>
<tr>
<th>Injury Level</th>
<th>Best Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIS 2</td>
<td>0.89</td>
</tr>
<tr>
<td>MAIS 3</td>
<td>0.84</td>
</tr>
<tr>
<td>MAIS 4</td>
<td>0.93</td>
</tr>
<tr>
<td>MAIS 5</td>
<td>0.19</td>
</tr>
<tr>
<td>Fatality</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: Graham et al. (1997).

#### 3.2.1.3. Quality of life estimates

The value of injuries can also be estimated by eliciting peoples’ preferences for different health states and comparing these preferences to estimates for the VSL. Graham et al. (1997) published preference weights for injuries corresponding to the MAIS injury severity categories. These values were derived from estimates of the utility of different health states following injuries from motor vehicle accidents using the Functional Capacity Index. In deriving these preference weights, Graham et al. adjusted the values to account for the proportion of injuries in different MAIS categories that have nonpersistent health effects based on the work of Segui-Gomez (1996). The resulting preference weights are shown in Table V. The preference weight values do not vary monotonically because of variance in the proportion of nonpersistent injuries by MAIS category. In particular, estimates that a large proportion of MAIS 4 injuries are nonpersistent results in a relatively high preference weight for this injury.

Preference weights reflect the relative utility of the quality of life associated with decreased health states compared to perfect health. By convention, perfect health is valued at 1.0, death at 0, and preference rates can be negative.
category and reduces the relative significance of these injuries.

We used the preference weights in Table V to convert injuries to equivalent fatalities and then calculated the monetary value of all casualties for our two monetary estimates of the VSL, $3 million and $6 million. Like Graham et al. (1997), we excluded injuries associated with MAIS 1 because they are very minor and measurement of preference weights for very minor injuries is very unreliable. The resulting estimates for the monetary value of different injury levels are listed in Table IV.

3.2.1.4. Discounting losses from terrorism. The RMS model calculates a current assessment of expected annual losses for the next year. IEc used a 10-year planning horizon to compute the annualized regulatory cost estimates. To enable comparison to these costs we annualized terrorism loss estimates assuming the same 10-year planning horizon and discounted annual terrorism losses according to OMB guidance (OMB, 1992, 2003) on discounting inflation-adjusted costs and benefits (i.e., stated in real as opposed to nominal dollars) to reflect the social rate of time preference (3%) and the before-tax rate of return to private capital in the U.S. economy (7%). We assumed that the inflation-adjusted, undiscounted loss from terrorism in each year of the 10-year planning horizon used by IEc from 2005 through 2014 is equal to the RMS estimate of annual terrorism loss for 2006.6 Thus when incorporating discounting, the annualized lost estimate for terrorism for the 10-year planning horizon is equal to the estimate of annual losses for 2006 regardless of the discount rate.7

Note that this approach assumes that the level of terrorism risk does not change as a result of changes in the intent or capability of terrorists, the concentration of people or property value around targets of terrorism, or the value of property changing at a different rate than the discount rate used. In general, the more one perceives that terrorism risk will increase in the future because of these factors, the greater the annualized terrorism loss and the lower the required risk reduction to make a regulation’s benefit exceed its cost. Though we conducted a sensitivity analysis around these factors, it is not reported in the results because we have little basis on which to predict the trends in terrorism risk over the next 10 years.

3.3. Results

Using Equation (4) we can compute the critical risk reduction, or the amount of risk reduction above which the benefit of the WHTI-L regulation exceeds the cost, as a function of annualized terrorism loss. Fig. 1 shows the general results for the baseline regulatory cost. In the area above the curve, the benefit exceeds the cost and the regulation is efficient on a benefit-cost basis. Below the curve, the cost exceeds the benefit and the regulation is not efficient. The critical risk reduction decreases with increasing annualized terrorism loss because the fractional decrease in annualized loss required to offset the regulation cost decreases with increasing loss magnitude. This means that the minimum required risk-reducing effectiveness of WHTI-L depends inversely on estimates of the annualized terrorism loss. Fig. 1 shows that for an annualized loss of $6 billion, a risk reduction of about 6% is sufficient to offset the WHTI-L costs. An annualized loss of $0.5 billion requires a risk reduction of approximately 70%.

To explore the risk-reducing effectiveness required under different conditions, we present results for different assumptions about regulatory costs and benefits. In examining benefits, we explore the effect of two uncertainties in the baseline terrorism loss on the critical risk reduction: estimates of the terrorism risk level and casualty valuation in the intent or capability of terrorists, the concentration of people or property value around targets of terrorism, or the value of property changing at a different rate than the discount rate used. In general, the more one perceives that terrorism risk will increase in the future because of these factors, the greater the annualized terrorism loss and the lower the required risk reduction to make a regulation’s benefit exceed its cost. Though we conducted a sensitivity analysis around these factors, it is not reported in the results because we have little basis on which to predict the trends in terrorism risk over the next 10 years.

3.3.1. Effect of Regulation Cost

Fig. 2 shows the effect on the critical risk reduction of the uncertainty related to the regulatory cost of WHTI-L. The cost estimates illustrated in Fig. 2 range from $270 million to $520 million per year. This range reflects differences in the costs of the different versions of WHTI-L being considered as well as uncertainty in the future cross-border travel rate and discount rate (Table I). These results indicate that the uncertainty in the cost of the regulation translates to

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6 Regulatory costs and terrorism risk estimates are based on modeled estimates for the entire planning horizon even though in principle these values are known for 2005 and 2006. This decision was made because the planning horizon is intended to capture the costs and benefits from the 10 years following implementation of the regulation. The base year of the 10-year planning was established as 2005 based on when work began on the regulatory analysis.

7 This result is obtained by calculating the net present value of losses stated in real dollars across the 10-year period assuming real discount rates of 3% and 7% and subsequently calculating the annualized losses, again using real discount rates of 3% and 7%.
3.3.2. Effect of Terrorism Risk Level

The terrorism risk level reflects the probability of attack, or the threat, and the consequences of attacks. The RMS model expresses uncertainty in terrorism threat using “threat outlooks,” which represent perceptions about terrorist intentions and capabilities. The default terrorism risk estimates from the RMS model assume a “standard” threat outlook based on current perceptions of the intent and capabilities of the global Jihadist terrorist threat. Uncertainty in consequence estimates can arise through variations in the hazard distribution (e.g., blast pressure transmission), vulnerability (e.g., the extent of

Fig. 1. Critical risk reduction as a function of expected annualized terrorism loss.

Fig. 2. Effect of uncertainty in regulation cost on critical risk reduction.
building damage), as well as uncertainties in model parameters and data.

The overall uncertainty in the risk level resulting from uncertainties in threat and consequences is difficult to characterize. We have examined the effect of uncertainty in the terrorism risk level by calculating the critical risk reduction for terrorism risk levels ranging from half to twice that of the standard risk estimate from the RMS model. The total range in critical risk reduction is a factor of four and ranges from 6.6% to 26% for the case shown in Fig. 3. Though the uncertainty about terrorism threat may be even greater than this range, the range presented demonstrates the sensitivity of conclusions drawn from break-even analysis to estimates of terrorism risk. In particular, the curvature of the risk-reduction curve in Fig. 3 dictates that conclusions are more likely to change if risk is underestimated than if it is overestimated.

### 3.3.3. Effect of Casualty Costs

The effect of casualty costs on the critical risk reduction is illustrated in Fig. 4. The cost of injury approach gives the lowest annualized loss ($2.1 billion) and therefore requires the greatest percentage risk reduction in order for the reduction in annualized loss to exceed the WHTI-L cost (17%). As noted above, the cost of injury approach is generally considered to greatly underestimate the value of casualties, and so must be considered a lower bound on annual loss and hence an upper bound on the critical risk reduction. Conversely, the casualty cost estimate for the quality of life approach anchored to a $6 million VSL leads to the highest annualized loss ($5.2 billion) and therefore the lowest critical risk reduction (7%).

The fatalities only, willingness-to-pay, and quality of life results are quite sensitive to the fatality cost (VSL) chosen. Fatalities represent a relatively large fraction of the casualty distribution (Table II) and are the most expensive casualty type in any of these cost sets (Table IV). As a result, fatality costs account for from 20% to nearly 70% of the total baseline terrorism loss in our analysis. Note that the injury costs in the willingness-to-pay cost sets are so low relative to the fatality costs that the resulting risk reductions are very similar to the cases in which casualty costs are included for fatalities only.

Taken together, the uncertainties in the terrorism risk level and casualty costs translate into a wide range in the necessary risk-reduction effectiveness of WHTI-L (Table VI). For the low-risk-level estimate and the cost of injury casualty costs, the annualized loss is $1.0 billion and the critical risk reduction is 35%. At the other extreme, the high-risk-level estimate combined with the casualty costs based on the quality of life approach anchored to a $6M VSL results in an annualized loss of $10 billion, requiring a risk reduction of 3.5%.

### 3.4. Important Assumptions

We make four important assumptions in this analysis. In each case, we view them as reasonable first-order assumptions to understand the nature of the
benefit-cost ratio for this regulation. However, the conclusions of the analysis rest significantly on these assumptions so they deserve note and possibly further investigation.

First, we assume that the benefits of this regulation are solely related to reduction in terrorism risk. Other potential benefits could be considered, such as efficiencies in the border crossing process or co-benefits of reductions in smuggling or other transnational illicit activities. The nature and magnitude of such benefits are difficult to estimate but may warrant further investigation. To the extent that such benefits exist but are not quantified, the break-even analysis will overstate necessary risk reductions.

Second, the estimates of WHTI-L costs by IEc account only for lost opportunity cost (measured in terms of a reduction in consumer surplus) associated with obtaining the necessary travel documents to continue traveling by land in the Western Hemisphere and loss of access to Western Hemisphere countries for travelers who choose not to obtain acceptable documentation. This may not fully capture other costs that WHTI-L could impose, such as subsequent reductions in commerce with Canada and Mexico stemming from the impediments posed by the greater cross-border travel documentation requirements.

Third, the estimates from the RMS model are likely underestimates of terrorism loss because they only reflect the direct, insurable costs of terrorism. They do not include any indirect losses that would result from continued change in consumption patterns or preferences or that would result from propagating consequences of interdependent infrastructure systems (Greenberg et al., 2006). To our knowledge, no reliable estimates of the indirect losses stemming from large terrorist attacks exist, so we are not able to estimate the effect of not including these losses. As mentioned above, the model also excludes nonworker casualty losses and losses associated with government buildings and employees. Though some of these effects are likely small compared to the other uncertainties associated with terrorism risk, it would be constructive to compare these results to others based on analysis using different approaches to modeling the overall risk of terrorism.

Finally, the willingness-to-pay and quality of life injury and fatality valuation estimates used in this study are derived from studies of workplace and automobile casualties. These types of events are qualitatively different than terrorists attacks, which are perceived to be less controllable, more poorly understood, and capable of potentially affecting thousands of people in a single incident rather than a few at a time. Psychometric studies of risk perception suggest that risks are perceived to be greater and less acceptable when associated with these types of characteristics (Fischhoff et al., 1981). Thus, the values used to estimate injuries may be underestimates of those.
Table VI. Expected Annualized Loss and Critical Risk Reduction for Different Conditions

<table>
<thead>
<tr>
<th></th>
<th>Expected Annualized Loss ($B)</th>
<th>Critical Risk Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low Risk</td>
<td>Standard Risk</td>
</tr>
<tr>
<td>Cost of injury</td>
<td>1.0</td>
<td>2.1</td>
</tr>
<tr>
<td>Willingness to pay ($3M VSL)</td>
<td>1.4</td>
<td>2.7</td>
</tr>
<tr>
<td>Quality of life ($3M VSL)</td>
<td>1.6</td>
<td>3.2</td>
</tr>
<tr>
<td>Willingness to pay ($6M VSL)</td>
<td>2.0</td>
<td>4.1</td>
</tr>
<tr>
<td>Quality of life ($6M VSL)</td>
<td>2.6</td>
<td>5.2</td>
</tr>
</tbody>
</table>

Note: Results are for baseline regulation cost.

associated with injuries from terrorist events. Future studies of willingness to pay to avoid terrorism risks could improve the estimates of value of casualties.

4. DISCUSSION

While a break-even analysis is useful for understanding uncertainties or perspectives related to the costs and benefits of a proposed terrorism security regulation, it does not directly inform decisions about whether a particular regulation is justified on a benefit-cost basis. For such an analysis to be prescriptive, regulators must also have a means to estimate the extent to which a regulation would actually reduce terrorism risk. Developing approaches to estimate risk reduction provides a way to connect terrorism risk assessment to terrorism risk management and thus improve the effectiveness of homeland security policies and resource allocation. Going forward DHS will need to address three challenges: (1) developing approaches for estimating benefits, (2) understanding how risk reduction affects the distribution of risk, and (3) developing estimates of the cost of casualties from terrorism.

4.1. Approaches to Estimating Benefits

As this study reveals, it is impossible to develop a rational risk management plan without understanding the benefits of measures that are proposed or estimated. The unfortunate reality facing DHS policymakers is that estimating the benefits of homeland security policies is inherently difficult because of the very poorly characterized terrorism risk level and the very low expected frequency of large attacks. Further, benefits are particularly difficult to characterize and quantify for overarching security measures not tied to specific target types or attack modes, such as border security efforts, because of the vast number of scenario pathways that such efforts impact. Because of these aspects, the impacts of homeland security regulations and policies are very difficult to recognize and may take a long time to become apparent. While this area of research has become more active in recent years, it is still quite immature (CREATE, 2006). In general, three types of approaches are used: program evaluation and assessment, modeling and simulation, and expert judgment.

Program evaluation and assessment is the only one of the three approaches that can provide empirical evidence of risk reduction. The steps of program evaluation and assessment include establishing goals, defining metrics and measures, assessing performance, and analyzing and improving policy based on findings. Examples of such assessment of regulations include studies of the Terrorism Risk Insurance Act (e.g., Doherty et al., 2005), the 9/11 Victims’ Compensation Fund (Dixon & Stern, 2004), and gun violence prevention programs (Tita et al., 2003). As DHS considers promulgating regulations and implementing new programs, incorporating evaluation into the planning will enable future assessment of program effectiveness.

Modeling and simulation allow a prospective analysis of what benefits alternative regulatory strategies might yield. Each of the approaches to modeling and simulation discussed in Section 2 provides a unique perspective and requires limiting assumptions. Thus, use of modeling and simulation to assess effectiveness of regulations can benefit from approaches that use combinations of models together.

Finally, expert judgment is often used when neither empirical data nor appropriate models adequately describe the performance of a policy or regulation. In general, expert judgment may be called upon when outcomes are difficult to quantify, either
because they are not tangible or they span multiple objectives that are difficult to express in common metrics. Expert judgment may also be used when outcomes are difficult to attribute to specific regulatory actions, either because of the complexity of causal relationships or lags in time between implementation and measurement (e.g., Morgan & Henrion, 1990). Expert judgment has already been used by DHS to assess the effectiveness of grant applications and can be a continued tool to supplement assessment and modeling and simulation.

In continued consideration of the benefits of its initiatives, DHS regulators can draw upon these three approaches to better understand whether a proposed regulation is normatively justified. However, application of any of these methods requires continued research to provide the required tools and supporting data.

4.2. Understanding How Risk Reduction Affects the Distribution of Risk

The results in Section 3 are based on the expected value measures of terrorism risk. However, a significant proportion of terrorism risk estimates are associated with unlikely events that have catastrophic consequences if they were to occur. Basing risk management of events solely on the expected value of distribution of consequences like this can be misleading (Haimes, 2004). For example, there may exist opportunities to reduce the maximum consequences of a risk, that is, cap the maximum losses. If the probability associated with consequences above the established cap is sufficiently small, the reduction in overall risk provided by such an option may be too small for the benefit to exceed the expected cost. Nevertheless, it may be justifiable to take such an action if the consequences being averted are irreversible and/or catastrophic. To address this issue, it is necessary to understand not just the expected risk reduction associated with policies or programs, but also how they are expected to change the distribution of risk. There are several approaches that could be used to incorporate the distribution of risk into decision making. Examples from other risk management contexts include application of expected utility analysis, setting risk tolerances to avoid maximum risk or exposure levels, and adoption of engineering design standards such as safety factors or return-period-based load factors.

4.3. Estimating the Costs of Casualties

A challenge to any benefit-cost approach to assessing the impacts of homeland security regulations and policies is the issue of monetizing casualties for estimating terrorism losses. While there is a general agreement that willingness to pay is the appropriate conceptual approach for making such estimates, there is uncertainty and debate about how to best collect such data and about the quality of existing estimates. As illustrated in our analysis, nonfatal casualties are a nonnegligible part of the consequences of an attack and casualty cost estimates vary considerably. Hence, the method used to value nonfatal casualties can have a substantial influence on the merits of regulations and policies. Despite a substantial body of work directed at evaluating the costs of injuries, illnesses, and fatalities related to environmental and workplace risks (e.g., U.S. EPA, 1999, 2000; Viscusi & Aldy, 2003), we are still a long way from having a generally accepted casualty valuation scale for use in regulatory benefit-cost analysis. In particular, we know of no accepted studies that estimate the willingness to pay to prevent injuries from events comparable to terrorist attacks. It may be appropriate to assign different values for injuries from terrorism for two reasons. First, the types of injuries from explosions or exposures to weapons of mass destruction may be very different from the injuries and illness caused from chronic exposures and automobile accidents that dominate the willingness-to-pay literature. Second, the fact that terrorism events are intentional, poorly understood, unavoidable by the general public, and catastrophic might lead people to have a different willingness to pay to avoid their consequences as compared to other morbidity and mortality hazards. Together these factors suggest that research on the topic of valuing injuries and fatalities should continue.

Given the broad range of policy areas where casualty monetization is a critical input, a collaborative, multiagency initiative aimed at developing generalized casualty costing guidance may be warranted.

5. SUMMARY AND CONCLUSIONS

This article describes an approach for using probabilistic risk modeling in break-even benefit-cost analyses of terrorism security regulations. When we apply this approach to the example case of WHTI-L, our analysis indicates that the break-even risk reduction (the risk-reducing effectiveness needed for its benefit, in terms of reduced terrorism loss, to exceed its cost) depends strongly on uncertainties in the terrorism...
risk. Estimates of annualized terrorism loss with the RMS model depend primarily not only on the risk level, but also depend on the monetary value ascribed to casualties and the assumed costs of the regulation.

Based on the RMS standard risk estimate and a casualty cost scale anchored to $3 million per fatality, our estimate for the expected annualized loss from terrorism ranges from $2.7 billion to $3.2 billion. For this range in annualized loss and the regulatory costs estimated by IEC, WHTI-L would need to reduce terrorism risk in the United States by 13% to 11% in order for its benefit to equal its cost. Using a casualty cost scale anchored to $6 million per fatality increases the annualized loss estimate and decreases the critical risk reduction for WHTI-L to about 8%. A cost of injury casualty cost scale leads to a lower annualized loss and a greater required risk reduction. However, cost of injury estimates are generally considered to greatly underestimate the value of casualties because they do not account for the associated private welfare losses (e.g., Tolley et al., 1994).

Basing results on a lower risk level that results in halving the annualized terrorism loss would double the critical risk reduction, and a higher risk level that results in a doubling of the annualized terrorism loss would cut the critical risk reduction in half.

Our break-even analysis is based on a benefit achieved through reducing the overall terrorism risk, where the overall risk is the combined risk across thousands of potential scenarios involving different attack types and targets. An alternative approach of expressing benefit in terms of avoiding particular scenarios provides a different perspective on the break-even benefit requirements. However, results of the scenario avoidance approach can only be usefully interpreted in the context of assumptions about the probability that the chosen scenario will occur. Thus, a scenario-based approach is less relevant for measures like WHTI-L that are not directed toward preventing a specific mode of attack.

Ultimately, a break-even analysis tells us only what a regulation needs to achieve, not what it actually will achieve. Ideally, decisions about terrorism security regulations and policies would be informed by true benefit-cost analyses in which the estimated benefits are compared to costs. Such analyses for terrorism security efforts face substantial impediments stemming from the great uncertainty in the terrorism risk level and the very low recurrence interval for large attacks.

Several approaches can be used to estimate how a terrorism security program or regulation reduces the distribution of risks it is intended to manage. But, continued research to develop additional tools and data is necessary to support application of these approaches. These include refinement of models and simulations, engagement of subject matter experts, implementation of program evaluation, and estimating the costs of casualties from terrorism events.

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