

WORKING P A P E R

Using Probabilistic Terrorism Risk Modeling For Regulatory Benefit- Cost Analysis

Application to the Western Hemisphere Travel Initiative Implemented in the Land Environment

TOM LATOURRETTE AND HENRY H. WILLIS

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CENTER FOR TERRORISM
RISK MANAGEMENT POLICY

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For additional information about the Center for Terrorism Risk Management Policy, contact:

Robert Reville
RAND Corporation
1776 Main Street
P.O. Box 2138
Santa Monica, CA 90407
Robert_Reville@rand.org
(310) 393-0411, Ext. 6786

Michael Wermuth
RAND Corporation
1200 South Hayes Street
Arlington, VA 22202
Michael.Wermuth@rand.org
(703) 413-1100, Ext. 5414

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PREFACE

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 U.S. In response, the U.S. Customs and Border Protection (CBP) and U.S. Department of State are proposing a regulation specifying documentation requirements for people entering the U.S. via land borders from countries in the Western Hemisphere, referred to as the Western Hemisphere Travel Initiative (WHTI-L).

The White House Office of Management and Budget directs agencies to use benefit-cost analyses to evaluate proposed regulations during the regulatory review process. However, data and methods for estimating the benefits of terrorism security regulations like the WHTI-L are inadequate to support benefit-cost analysis.

This report introduces a framework for using probabilistic terrorism risk modeling in a break-even analysis of a regulatory action, demonstrates an application of the framework on the regulatory analysis of WHTI-L, and discusses how this type of analysis can be further integrated into the regulatory review process.

This work was conducted within the RAND Center for Terrorism Risk Management Policy, which is a partnership between RAND and Risk Management Solutions, Inc. It was funded through a subcontract from Industrial Economics, Incorporated of Cambridge, Massachusetts, a consulting firm under contract to CBP.

The primary audience for this work is CBP. It is intended to inform the regulatory review process of WHTI-L. The work also presents development of a novel approach that could support future regulatory analyses at the U.S. Department of Homeland Security. The findings should help the Department of Homeland Security and the White House Office of Management and Budget develop future regulatory policy surrounding terrorism security and community preparedness efforts.

CONTENTS

The RAND Center for Terrorism Risk Management Policy (CTRMP).....iii
Preface.....vii
Summary.....xi
Acknowledgments.....xv
Abbreviations.....xvi
1. Introduction.....1
2. Using Probabilistic Risk Modeling In Regulatory Benefit-Cost Analysis
.....3
 2.1 The RMS Probabilistic Terrorism Model.....4
 2.2 Break-Even Benefit-Cost Framework Using Probabilistic Risk
 Modeling5
3. Application of Probabilistic Terrorism Modeling to Break-Even
Benefit-Cost Analysis of WHTI-L9
 3.1 Costs of WHTI-L Regulation.....9
 3.2 Terrorism Losses.....10
 3.2.1 Monetization of Casualties12
 3.3 Results.....19
 3.3.1 Effect of Regulation Cost21
 3.3.2 Effect of Terrorism Risk Level21
 3.3.3 Effect of Casualty Costs23
 3.4 Important Assumptions.....25
4. Discussion.....27
 4.1 Probabilistic Risk Modeling Versus Scenario-Based Planning..27
 4.2 Beyond Break-Even Analysis: Determining How Much a Regulation
 Reduces Risk28
 4.2.1 Approaches to Estimating Benefits29
 4.2.2 Understanding How Risk Reduction Affects the Distribution
 of Risk30
 4.2.3 Estimating the Costs of Casualties31
5. Summary and Conclusions.....33
Appendix The RMS Probabilistic Terrorism Model.....35
 Estimating Attack Probability.....35
 Overall Probability of Attack36
 Relative Likelihoods of Attack Scenarios37
 City Tier Likelihood37
 Target Type and Individual Target Likelihoods38
 Attack Mode Likelihood39
 Estimating Attack Consequences.....40
 Applicability of the RMS Model to Department of Homeland Security
 Decisionmaking41
References.....43

SUMMARY

This report presents a framework for using probabilistic terrorism risk modeling in regulatory analysis. We describe an approach for conducting a break-even benefit-cost analysis in which the benefit of a proposed terrorism security regulation is the reduction in overall terrorism risk, where risk is expressed in terms of the annualized loss from damage caused by terrorist attacks. We demonstrate the framework with an example application involving a regulation under consideration (the Western Hemisphere Travel Initiative for the Land Environment, (WHTI-L)), and discuss how this type of analysis can be further integrated into the regulatory review process.

Our approach uses probabilistic terrorism risk modeling to estimate the overall risk from terrorist attacks in the U.S. The overall risk comprises the risk from numerous individual attack scenarios reflecting a wide variety of different attack types and individual targets. Risk is conveyed in terms of annualized loss by combining estimates of the consequences (casualties and property damage) for each scenario with estimates of the annual probability that that scenario will occur.

In our example application we estimate annualized loss from terrorist attacks with the Risk Management Solutions (RMS) Probabilistic Terrorism Model, a model developed for use by the insurance industry to estimate terrorism risk. Because the model focuses on the commercial property and casualty insurance market, its scope is limited to loss categories, such as commercial property, business interruption, and casualties to workers, that are normally covered under these insurance lines. The modeled losses exclude indirect economic losses, government property and workers, non-commercial property, non-employee casualties, psychological injuries, and liability losses. Despite these assumptions, the RMS model constitutes a new tool for incorporating probabilistic terrorism risk modeling into regulatory analysis.

We use our analysis to determine 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 U.S., to exceed its cost. Our

analysis indicates that the critical risk reduction depends strongly 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, a regulatory cost based on the WHTI-L option preferred by CBP, 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%. Using casualty costs based on the cost of injury approach 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).

The terrorism risk level reflects perceptions about the probability of attack, stemming from terrorist intentions and capabilities, and the anticipated consequences of attacks. Basing results on a lower risk level that results in halving the annualized terrorism loss would double the critical risk reduction (14% to 26%), and a higher risk level that results in a doubling of the annualized terrorism loss would cut the critical risk reduction in half (3.5% to 6.6%).

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 the number of times per year that a particular scenario is avoided does not include an assessment of the probabilities of different scenarios happening. Such an approach is generally less informative 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 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.

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ABBREVIATIONS

CBP	U.S. Customs and Border Protection
DHS	U.S. Department of Homeland Security
IEC	Industrial Economics, Inc.
MAIS	Maximum Abbreviated Injury Scale
NHTSA	National Highway Traffic Safety Administration
OMB	Office of Management and Budget
RMS	Risk Management Solutions, Inc.
VSL	Value of a Statistical Life
WHTI-L	Western Hemisphere Travel Initiative in the land environment

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:

- How, where and when will terrorists attack?
- How vulnerable are targets to attack?
- What are the consequences of terrorist attack?
- 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 report describes a framework for using probabilistic risk modeling to conduct break-even analyses of a regulatory action, 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.

2. USING PROBABILISTIC RISK MODELING IN REGULATORY BENEFIT-COST ANALYSIS

A common approach to characterizing the benefits of terrorism security efforts is to focus on the estimated consequences of particular individual scenarios that might be avoided as a result of the effort. An alternative approach is to consider the effect of the effort on the overall terrorism risk posed by many different types of attacks that could occur at many different targets (Willis et al., 2005). In such an approach, the overall risk is derived from the outcomes of numerous individual scenarios, each weighted by the probability that that scenario will occur. This approach is referred to as probabilistic risk modeling.

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. 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 this approach is the Risk Management Solutions (RMS) Probabilistic Terrorism Model.¹ 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 terrorist attack of any kind will occur and the relative likelihoods that attacks will occur in particular cities, against particular target types, and with different attack modes. Scenario probabilities are developed through a semi-annual structured expert elicitation process focusing on terrorists' intentions and capabilities.

Scenario consequences in the RMS model are based on physical modeling of attack phenomena and target characteristics and are cast in terms of property damage and casualties. Property damage comprises costs of damaged buildings, loss of contents of buildings, and loss from business interruption associated with property to which law enforcement prohibits entry immediately following a terrorist attack. Casualties are classified into six injury-severity categories. Because the RMS model was designed specifically for commercial property-casualty insurers, these casualty categories correspond to major categories used in the worker compensation insurance industry: medical only, temporary total disability, permanent partial disability-minor, permanent partial disability-major, permanent total disability, and fatal. These categories are discussed further in Section 3.2.1.

It is important to note that the RMS model focuses on losses relevant to the commercial property and casualty insurance market and so excludes loss categories that are not normally covered under these

¹ 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.

insurance lines. Such excluded losses include indirect economic losses, government property and workers, non-commercial property, non-employee casualties, psychological injuries, and liability losses. The implications of this insurance focus and other restrictions of the cost and benefit estimates used in this analysis are discussed in the results section. Additional details of the terrorism model are included in the Appendix or can be obtained from RMS (RMS, 2003).

2.2 BREAK-EVEN BENEFIT-COST FRAMEWORK USING PROBABILISTIC RISK MODELING

With the probabilistic risk modeling approach, terrorism risk can be expressed in terms of the annual expected loss from damage caused by terrorist attacks. This expected loss accounts for the probability that attacks will occur and the consequences of attacks. From this perspective, the benefit of a terrorism security regulation can be expressed as the reduction in the expected loss from damage caused by terrorism. Here we develop a general framework for a break-even benefit-cost analysis that employs this approach.

Benefit-cost analysis is a normative framework for determining whether or not a regulation is efficient. Within this context, a regulation is justified 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. This can be expressed as the negative of the difference between the annualized loss from terrorism with and without the regulation in place. The incremental cost of the regulation is the difference between cost incurred from the proposed regulation and the cost incurred for the current baseline condition with no action. This can be expressed as

$$(1) \quad -(L_n - L_b) \geq C_n - C_b$$

where L is the annualized loss from terrorism, C is the annualized cost incurred,² and the subscripts n and b indicate conditions with the

² Note that regulations could result in net savings so C could be either positive or negative.

regulation (new) and without the regulation (baseline), respectively. $C_n - C_b$ is simply the annualized cost of the regulation, C_r , and relationship (1) simplifies to

$$(2) \quad L_b - L_n \geq C_r.$$

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

$$(3) \quad R = (L_b - L_n)/L_b.$$

R is a dimensionless parameter characterizing the risk reducing effectiveness of a proposed regulation and ranges from 0 (no risk reduction) to 1 (complete mitigation of risk).

Combining (2) with (3) gives

$$(4) \quad R \geq C_r/L_b.$$

When inequality (4) holds, the benefits of a terrorism security regulation exceed the costs. The point at which the risk reduction just

equals C_x/L_b is the minimum risk reduction for which the regulation is justified, and we define the critical risk reduction, R_c , as

$$(5) \quad R_c = C_x/L_b.$$

There are four unusual cases to point out with this relationship. First, when $C_x > L_b$, R_c exceeds 1, which violates the bounds on R . We interpret this as a case when the regulation is never justified on a benefit-cost basis because its cost is more than the expected losses being avoided. Second, when $C_x = 0$ the regulation is justified as long as $L_b > 0$. Logically, any no-cost risk reduction investment is sensible. Third, if the regulation results in a net savings (i.e., C_x is negative), the equality in Equation (5) is not valid and the regulation is always justified. Finally, when $L_b = 0$, R_c is undefined. Here the regulation is not justified unless the regulation results in a net savings because the potential risk is zero.

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 U.S. 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 U.S. In response, Customs and Border Protection (CBP), jointly with the Department of State, is promulgating a regulation specifying documentation requirements for people entering the U.S. 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 U.S. from Canada, Mexico, or the Caribbean (IEC, 2006).

In the following section we use a probabilistic terrorism risk modeling approach in a break-even analysis using WHTI-L as an example application. Cost estimates (C_r) for the WHTI-L were obtained from the regulatory cost assessment conducted by Industrial Economics Incorporated (IEC, 2006). Estimates for baseline annual terrorism losses (L_b) were developed with the Risk Management Solutions (RMS) Probabilistic Terrorism Model (RMS, 2003). 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 (5).

3.1 COSTS OF WHTI-L REGULATION

Direct costs for WHTI-L were provided by Industrial Economics Incorporated (IEC, 2006). 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 to continue traveling under WHTI-L plus the consumer surplus lost from trips not taken 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 1) represent the annualized costs for a 10-year planning horizon.

Table 1
Estimated total direct costs (\$ Million) for WHTI-L

Alternative: Discount Rate:	Alternative 2: Passport book only		Alternative 3: Passport book, passport card, or trusted traveler card	
	3%	7%	3%	7%
No Children Exemption				
Decreasing cross-border travel rate	\$320	\$340	\$370	\$390
Steady-state cross-border travel rate	\$380	\$400	\$420	\$450
Increasing cross-border travel rate	\$490	\$510	\$500	\$520
Children Under 14 Exempt				
Decreasing cross-border travel rate	\$270	\$290	\$330	\$340
Steady-state cross-border travel rate	\$330	\$340	\$370	\$390
Increasing cross-border travel rate	\$390	\$400	\$420	\$430
Children Under 16 Exempt				
Decreasing cross-border travel rate	\$260	\$280	\$320	\$340
Steady-state cross-border travel rate	\$320	\$330	\$360	\$380
Increasing cross-border travel rate	\$370	\$380	\$400	\$420

Source: IEC (2006)

3.2 TERRORISM LOSSES

As noted above, the benefit of terrorism security regulations in terms of benefit-cost analysis is avoided terrorism losses. Economic theory suggests that the benefits that should be included in benefit-

cost analysis comprise private and external components. The private component includes factors such as the directly born cost of medical treatment, lost productivity, and decreased quality of life. The external component reflects the value of non-private avoided losses, such as health care costs paid by the public sector and productivity losses not borne directly by the victims (OMB, 2003). 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 annualized loss from terrorist attacks in the U.S. 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 2. 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 several ways to estimate the monetary values for casualties and none perfectly capture both the private and external costs. The next section discusses different ways that casualty costs are estimated and presents the values used in our analysis.

Table 2
Standard Risk Estimate From The RMS Model

Loss Category	Annualized Loss
No. casualties - Medical Only or Minor	7,120
No. casualties - Temporary Total	710
No. casualties - Permanent Partial - Minor	270
No. casualties - Permanent Partial - Major	170
No. casualties - Permanent Total	80
No. casualties - Fatal	450
Total casualties	8,800
Building	\$395,000,000
Contents	\$231,000,000
Business interruption	\$675,000,000
Total property	\$1,305,000,000

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.

3.2.1 Monetization of Casualties

Monetary estimates of the costs of casualties vary over a considerable range (Tolley et al., 1994) and it is therefore useful to examine the effect of using different estimates of these costs. Methods for monetizing health impacts include analysis of direct expenditures and lost productivity, eliciting comparisons of the utility of different health status conditions, estimating wage-premiums demanded for employment at increased risk, and contingent valuation techniques that derive values for morbidity states from willingness to pay for treatment or risk reduction. In this analysis, we estimated the costs of injuries using three methods: estimates of healthcare and productivity costs (cost of injury), willingness to pay estimates derived from a meta-analysis of the wage-rate literature (willingness to pay), and comparisons of utilities for different health states (quality of life).

Comparing results from the three methods used allows insight into how different approaches to valuing morbidity and mortality consequences change the conclusions of the analysis. 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 difficulty in monetizing casualties is that different valuation studies use different injury classification systems. The majority of expected casualties estimated from the RMS model are injuries or deaths resulting from physical trauma. Examples of attack modes that cause result is 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 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 6 levels of severity ranging from minor to fatal. Table 3 provides examples of injuries associated with each category and how we associated the MAIS categories to the RMS workers' compensation casualty categories.

Table 3
Comparison of RMS and MAIS Casualty Categories

RMS Casualty Category	MAIS Injury Severity Category	Conditions that would fall into the various categories in both the MAIS and RMS scale
Medical only or Minor	1: Minor Injury	Abrasion, laceration, strains, sprains, contusions: can be treated and released.
Temporary Total	2: Moderate Injury	Simple broken bone, loss of consciousness, serious strains and sprains: requires follow-up and several weeks or months to heal, but will heal completely.
Permanent Partial - Minor	3: Serious Injury	Complicated fracture, serious joint injury, concussion, minor crush injury: requires substantial follow-up and some minor disability will result.
Permanent Partial - Major	4: Severe Injury	Massive organ injury, heart laceration, loss of limb, crushed extremities: hospitalization, substantial temporary disability and moderate long-term disability.
Permanent Total	5: Critical Injury	Spinal cord syndrome, crush syndrome with kidney failure, massive head injury: extended hospitalization, significant long-term disability.
Death	6: Immediately Fatal	

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

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 aren't completely medically disabled, in which case the same injury would be a 3 on the MAIS and a 4 or 5 on the RMS scale. This will tend to bias the casualty distributions in the RMS scale towards more severe injuries relative to 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 be a 4 or 5 on the MAIS and 2 or 3 on the RMS scale. This will tend to bias the casualty distributions in the RMS scale towards less severe injuries relative to the MAIS. Taken together, these effects work to cancel each other, diminishing differences in the two classification systems.

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.

In contrast to the other approaches we used, this method does not formally account for private loss components such as welfare losses associated with persistent reduction in one's quality of life (i.e., pain and suffering). In accounting for external loss components but neglecting the much larger private components, cost of injury estimates represent lower bounds for the purposes of benefit-cost analyses. While estimates of the external and private components of casualty losses could, in principle, be summed to derive a total casualty loss estimate, few loss estimates are unambiguously restricted to include only private or only external components. Most estimates, including cost of injury estimates, contain elements of both. Adding such estimates would therefore overestimate the casualty loss (Tolley et al., 1994).

The estimates of health and productivity losses in this study 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 4.

Table 4
Casualty Cost Estimates

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

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

Willingness to Pay Estimates

The willingness to pay literature estimates the value of fatalities and injuries by stated and revealed preferences methods. Stated preference methods typically ask respondents to state their willingness to pay to avoid being injured. A common revealed preference method analyzes relationship between hourly wages and occupational fatality and injury risks. In theory, workers demand higher wages for incurring exposure to such risks. Thus, 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-\$70,000 (2000 US\$).

We used the high end of the range of injury values from the willingness to pay literature and assigned this value for all non-fatal injury categories from the RMS model. We excluded injuries in the lowest severity category because they are very minor and would not 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, it is likely an underestimate for the value of severe injuries. Resulting injury costs, reported in 2005 US\$, are listed in Table 4.

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).

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. The Center on the Evaluation of Value and Risk in Health at Tufts University (2006) maintains a registry of cost-effectiveness and relative preference weights for health states from the published literature. To derive monetized values for casualty estimates that capture welfare costs excluded by the NHTSA analysis, we reviewed this database to identify estimates of preference weights for injuries similar to those associated with the casualties of terrorist events.

As discussed above, injuries associated with terrorist attacks are most similar to trauma injuries trauma incidents and automobile accidents. One citation in the Tufts University registry published preference weights³ for injuries corresponding to the MAIS injury severity categories (Graham et al., 1997). 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 non-persistent health effects based on the work of Segui-Gomez (1996). The resulting preference weights are shown in Table 5. The preference weight values do not vary monotonically because of variance in the proportion of non-persistent injuries by MAIS category. In particular, estimates that a large proportion of MAIS 4 injuries are non-persistent results in a relatively high preference weight for this category and reduces the relative significance of these injuries.

We used the preference weights in Table 5 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

³ 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.

weights for very minor injuries is very unreliable. The resulting estimates for the monetary value of different injury levels are listed in Table 4.

Table 5
Preference weights for different injuries

Injury Level	Best Estimate
MAIS 2	0.89
MAIS 3	0.84
MAIS 4	0.93
MAIS 5	0.19
Fatality	0

Source: Graham et al. (1997)

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; OMB, 2003) on discounting inflation-adjusted costs and benefits 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 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. 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.⁴

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

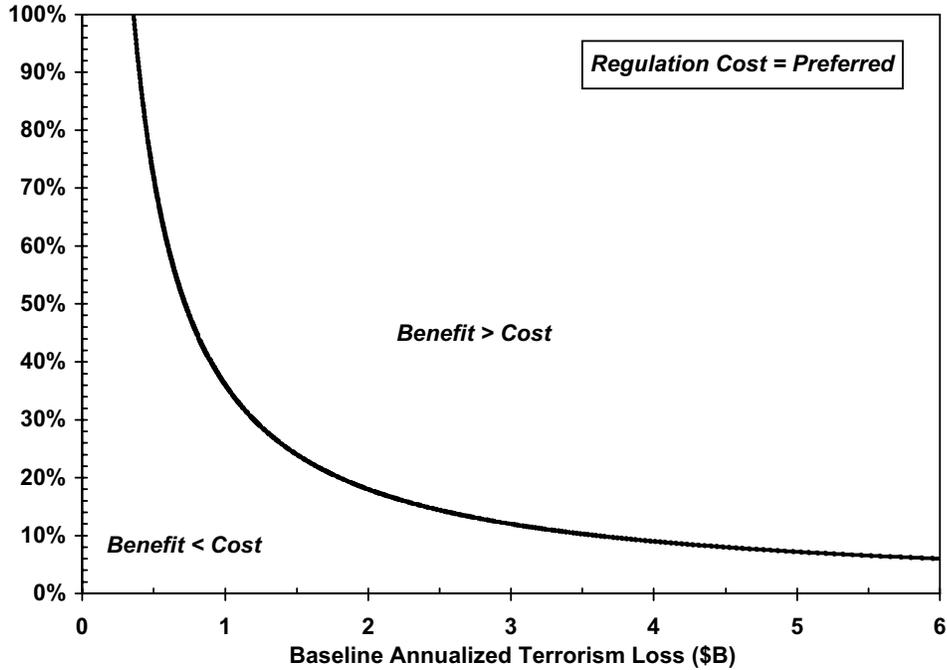
⁴ This result is obtained by calculating the net present value of losses across for 10-year period assuming real discount rates of 3% and 7% and subsequently calculating the annualized losses, again using real discount rates of 3% and 7%.

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 (5) 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. Figure 1 shows the general results for the regulatory cost associated with CBP's preferred version of WHTI-L (alternative 3, exemption for children under 16, steady-state cross-border travel rate, and 3% discount rate (\$360 million; see Table 1)). 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. Figure 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%.

Figure 1
Critical Risk Reduction as a Function of Annualized Terrorism Loss



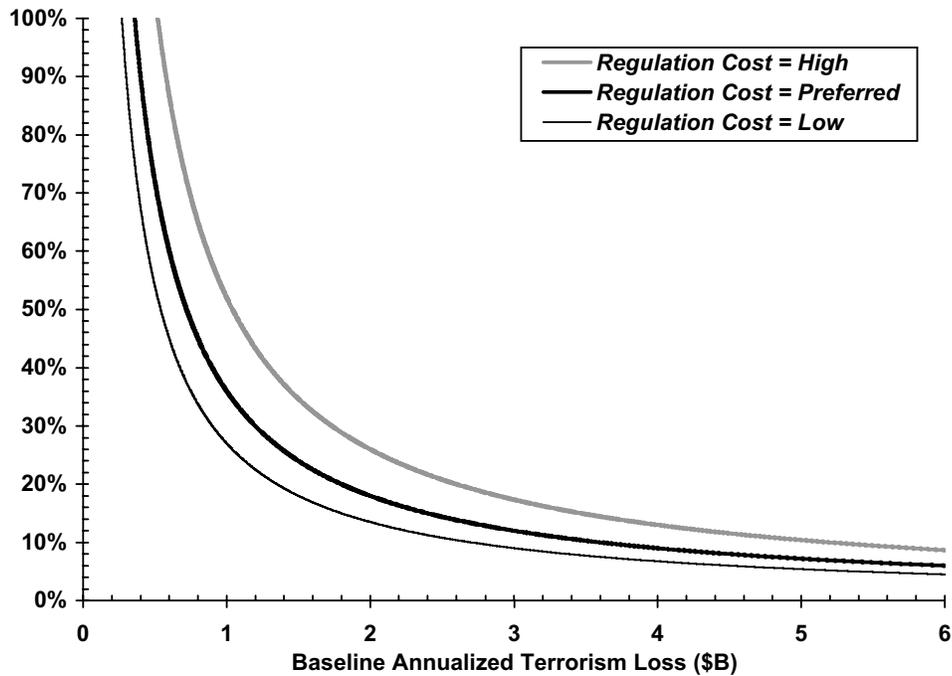
To explore the risk-reducing effectiveness required under different conditions, we present results for different assumptions about regulatory costs and benefits. In examining benefits, we explore the effect of two uncertainties in the baseline terrorism loss on the critical risk reduction: estimates of the terrorism risk level and the valuation of casualties.

Estimates of terrorism risk level include perceptions about the absolute probability of attack, the relative likelihoods of different attack types, and the consequences of attacks. As discussed above, we examine several different casualty cost estimates reflecting different approaches to valuing injuries and fatalities. Both terrorism risk level and casualty valuation influence the magnitude of the annualized terrorism loss and thus the critical risk reduction for a regulation.

3.3.1 Effect of Regulation Cost

Figure 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 Figure 2 range from \$270 million per year to \$520 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 1). These results indicate that the uncertainty in the cost of the regulation translates to a variation of about a factor of two in the critical risk reduction.

Figure 2
Effect of Uncertainty in Regulation Cost on Critical Risk Reduction



3.3.2 Effect of Terrorism Risk Level

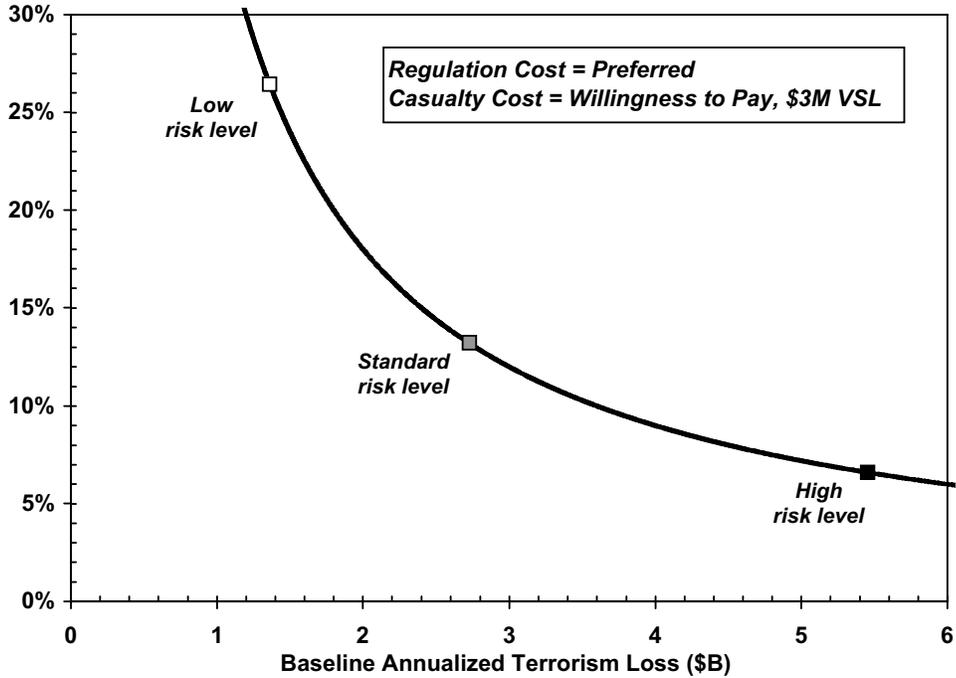
The terrorism risk level reflects the probability of attack, or the threat, and the consequences of attacks. The RMS model expresses uncertainty in terrorism threat using "threat outlooks," which represent

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.⁵ Uncertainty in consequence estimates can arise through variations in the hazard distribution (e.g., blast pressure transmission), vulnerability (e.g., the extent of 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. This results in a factor four of range in the baseline annualized terrorism loss. The resulting range in critical risk reduction is presented in Figure 3. The continuous curve is the same general relationship between critical risk reduction and annualized terrorism loss shown in Figure 1. The discrete points along the curve show annualized loss estimates and associated critical risk reductions for different assumptions about the terrorism risk level. The results shown in Figure 3 are for the preferred regulatory cost estimate and casualty costs based on willingness to pay estimates and a \$3 million VSL. These results show that a decrease in perceived risk leads to a smaller annualized loss and a greater critical risk reduction, and an increase in perceived risk leads to a greater annualized loss and a smaller critical risk reduction. The total range in critical risk reduction is a factor of four and ranges from 6.6% to 26% for the case shown in Figure 3.

⁵ Details of differences between these threat outlooks are provided in the Appendix.

Figure 3
Critical Risk Reduction for Different Risk Levels



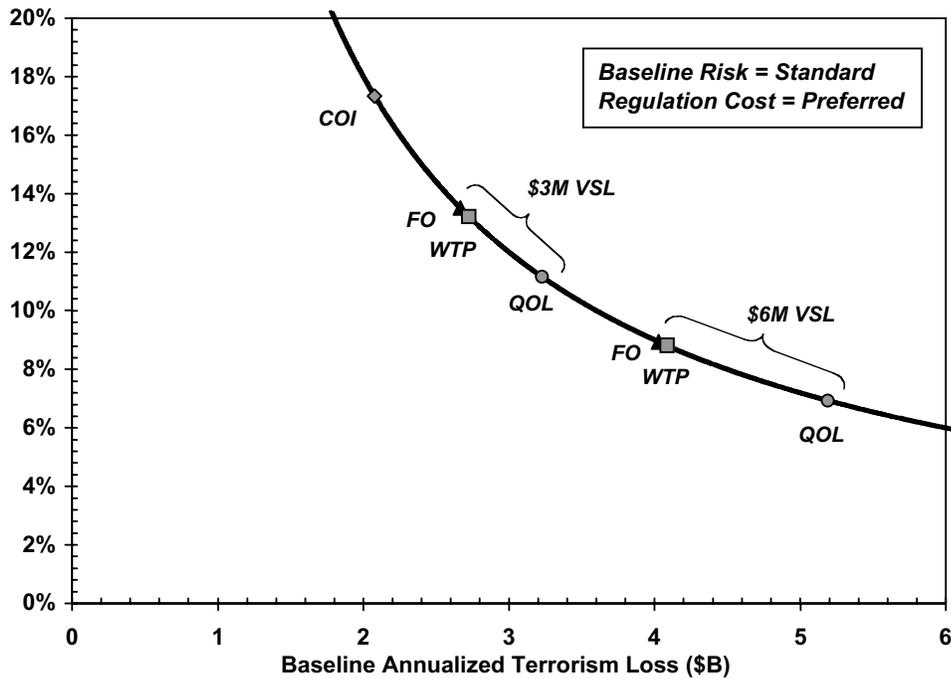
3.3.3 Effect of Casualty Costs

The effect of casualty costs on the critical risk reduction is illustrated in Figure 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 (e.g., Tolley et al., 1994), 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 2) and are the most expensive casualty type in any of these cost sets (Table 4). 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 almost indistinguishable from the cases in which casualty costs are included for fatalities only.

Figure 4
Critical Risk Reduction for Different Casualty Costs



Notes: COI = Cost of injury, FO = Fatalities only, WTP = Willingness to pay, QOL = Quality of life, VSL = Value of statistical life.

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 6). 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%.

**Table 6
Annualized Loss and Critical Risk Reduction For Different Conditions**

	Annualized Loss (\$B)			Critical Risk Reduction (%)		
	Low risk	Standard risk	High risk	Low risk	Standard risk	High risk
Cost of Injury	1.0	2.1	4.2	35	17	8.7
Willingness to pay (\$3M VSL)	1.4	2.7	5.5	26	13	6.6
Quality of Life (\$3M VSL)	1.6	3.2	6.5	22	11	5.6
Willingness to pay (\$6M VSL)	2.0	4.1	8.2	18	8.8	4.4
Quality of Life (\$6M VSL)	2.6	5.2	10	14	6.9	3.5

Notes: Results are for preferred regulation cost.

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 the costs associated with obtaining the necessary travel documents to continue traveling by land in the Western Hemisphere and the consumer surplus lost when fewer international trips are made. 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 and in more detail in the appendix, the model also excludes non-worker 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 workplace and automobile casualties. These types of events are qualitatively different than terrorists attacks that 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 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

The framework and example application presented in this report describe an approach for using probabilistic risk modeling in break-even benefit-cost analyses of terrorism security regulations. In this section we briefly explore the implications of using a probabilistic risk modeling approach and we outline options for estimating the benefits of terrorism security regulations in order to be able to conduct true benefit-cost analyses.

4.1 PROBABILISTIC RISK MODELING VERSUS SCENARIO-BASED PLANNING

With a probabilistic risk modeling approach the benefits of terrorism security are conveyed in terms of the reduction in overall terrorism risk. An alternative approach often used is to assess benefits in terms of avoidance of particular scenarios.

Whereas break-even analysis using probabilistic risk modeling frames a decision in terms of required risk reduction, the relevant break-even indicator when considering avoiding particular scenarios is typically the number of incidents avoided. In this case equation (5) can be revised to reflect this perspective:

$$(6) \quad N = C_x/L_i$$

where N is the number of incidents avoided per year and L_i is the loss per incident. Equation (6) indicates the number of incidents that must be avoided per year in order for the benefit of a regulation to equal its cost.

The choice of scenario to model will depend on the characteristics of the security regulation being considered. For the purposes of comparison to the risk-based approach, we demonstrate the scenario-based analysis by considering a highly catastrophic scenario that has been raised by other studies, detonation of a nuclear device (e.g., Abt, 2003). The estimated loss for the nuclear detonation scenarios included in the RMS model ranges from \$2 billion to \$625 billion, with an average

of \$42 billion for all 740 scenarios representing different detonation locations and device sizes. Substituting this average value, along with the best estimate of the annualized cost of WHTI-L (\$425 million, Table 1), into equation (6) gives $N = 0.01$. This means that WHTI-L would be justified on a benefit-cost basis if it prevents at least 0.01 nuclear detonations per year, or one nuclear detonation every 100 years. Using the higher loss estimate of \$625 billion gives $N = 0.0007$, or one nuclear detonation every 1400 years.

A scenario-based approach is most suited to situations where the security regulation targets specific weapon types or protects certain target types. In such cases the benefits are realized through a small number of types of attack. Measures like WHTI-L that address terrorism risk very broadly rather than preventing a specific type of attack are less amenable to a scenario-based analysis because the number of relevant scenarios may be too large to synthesize coherently and the scenario-based cannot adequately represent threat shifting that would occur as terrorists adapt to security measures.

4.2 BEYOND BREAK-EVEN ANALYSIS: DETERMINING HOW MUCH A REGULATION REDUCES RISK

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.

4.2.1 Approaches to Estimating Benefits

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. 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 is 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 and 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. Approaches for using modeling and simulation to assess the consequences of terrorism or risk management strategies include scenario-based models like the RMS model used in this study (Willis et al., 2005; Willis, *in press*; Carroll et al., 2005), agent-based models (N-ABLE, 2006; Tsvetovat and Carley, 2002), game theory (Kunreuther, 2005; Bier et al., 2005), economic-input output models (Haines et al., 2005; Gordon et al., 2006), probabilistic risk analysis (Rosoff and von Winterfeldt, 2006), and operations research approaches (Martonosi et al., 2005; Wein, 2006). Each approach 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, or 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 and 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.

4.2.2 Understanding How Risk Reduction Affects the Distribution of Risk

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 a distribution of consequences like this can be misleading (Haines, 2004). For example, there may exist opportunities to reduce the maximum consequences of a risk, i.e. cap the maximum losses. If the probability associated with consequences above the established cap is sufficiently small, such an option might provide sufficiently little reduction in overall risk that the benefit may not exceed the expected costs of the option. Nevertheless, it may be justifiable to take such an action if the consequences being averted are irreversible and/or catastrophic.⁶ To address this issue, it is

⁶ It is important to be as specific as possible about the term catastrophic when it is used. In this context, the term is used to describe events from which it would be difficult or impossible to return to the state that existed prior to the event. In the context of terrorism, a scenario involving a nuclear detonation in a city could arguably be such a scenario.

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.

4.2.3 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. This topic remains controversial, both in terms of both the suitability of different conceptual methods and the quality of the estimates available for any method. As illustrated in our analysis, including non-fatal casualties matters and casualty cost estimates vary considerably. Hence, the method used to value non-fatal 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 and Aldy, 2003), we are still a long-way from having 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. This indicates that research on this topic should continue. Given the broad range of policy areas where casualty monetization is a critical input, a collaborative, multi-agency initiative aimed at developing generalized casualty costing guidance may be warranted.

5. SUMMARY AND CONCLUSIONS

This report 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 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 U.S. 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 by about 35%. 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 terrorist 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.

APPENDIX
THE RMS PROBABILISTIC TERRORISM MODEL

Risk Management Solutions' Probabilistic Terrorism Model was developed primarily for use in the insurance industry to assist property-casualty insurers manage their exposure to catastrophic terrorism loss. The model estimates the risk from a wide range of potential terrorist attack scenarios and can be applied at any scale ranging from an individual building to the entire country. The model computes the terrorism risk from the overall probability of an attack occurring, the relative likelihood of thousands of individual attack scenarios, and the consequences of each scenario.

The overall probability of attack and the relative likelihoods of different types of attacks at different targets are estimated using expert judgment about capabilities and objectives of terrorist groups, target selection by terrorists, capability requirements for different attack modes, and propensity to stage multiple coordinated attacks. Consequences, in terms of property damage and casualties, are estimated from modeling of weapons effects and geocoded databases of structural characteristics of targets, population densities, human activity patterns, business activities, and values of buildings and their contents. While this appendix provides an overview of the RMS model, additional information on the RMS model can be obtained from the RMS, Inc. company website (<http://www.rms.com>) or by contacting RMS, Inc. directly.

ESTIMATING ATTACK PROBABILITY

Terrorist events have fortunately occurred infrequently compared to accidents and natural disasters. Given the sparse record, as well as the complex and dynamic social origins of terrorism, terrorism threat lacks a phenomenological basis from which to model attack probabilities quantitatively. This makes it difficult to look at the historical patterns of terrorism in an effort to guide homeland security policy. In lieu of frequency based estimates of probability of events occurring, risk analysis has developed means determining probabilities of events

occurring by using subjective judgments by experts (Morgan and Henrion, 1990).

The RMS model uses expert judgment to assess the relative likelihoods of various attack scenarios and the overall attack probability. Values for both the absolute attack probability and the relative likelihoods of individual scenarios are derived through a structured expert elicitation process that is informed by terrorist attack histories and contextual trends such as mentions of particular cities and targets in Arabic media. Expert elicitation conferences are held twice each year to assure that probability profiles are consistent with the most current information and analysis. Details of how this process is carried out can be obtained from RMS, Inc.

Overall Probability of Attack

RMS develops the overall annual probability of a terrorist attack occurring from several components:

- the probability that a terrorist attack of any kind will occur in the next year
- the probability that if an attack occurs it will be a single attack or a set of coordinated attacks
- the probability that if an attack occurs there will be other attacks within the year
- the probability that an attempted attack would be successful

RMS develops three different probability estimates for different assumptions about the terrorist threat level. These estimates reflect differing interpretations of available intelligence and consider capabilities and objectives of terrorist groups, access to particular weapon types, and effectiveness of counterterrorism efforts. The three threat outlooks are summarized below (RMS, 2003).

- **Reduced Threat Outlook:** Optimistic interpretations of the available intelligence that imply a low risk of terrorist loss in the United States. Al Qaeda attack probability is assumed reduced from its long-term historical average. Less-destructive attack modes are more likely and the chance of an Al Qaeda chemical, biological,

radiological, or nuclear attack is negligible. Other foreign threat groups will not be active.

- **Standard Threat Outlook:** Best assessment of the risk of large-scale terrorism loss in the United States throughout the year, resulting from all known terrorism threat groups. Probability of attack from Al Qaeda is below its long-term historical worldwide average. Medium-scale attack modes predominate, and the chance of a CBRN attack is small. Additional possibility of attacks from other foreign threat groups.
- **Increased Threat Outlook:** Pessimistic interpretations of the available intelligence that imply a heightened risk from terrorist loss in the United States during the year. Al Qaeda attack probability is assumed similar to its long-term historical average. Destructive attack modes are likely and the chance of an Al Qaeda CBRN attack is significant. Additional possibility of attacks from other foreign threat groups.

Relative Likelihoods of Attack Scenarios

Several factors influence the relative likelihoods of terrorist attacks in the RMS model. These factors can be classified into 4 components:

- the relative likelihood that any particular city will be attacked
- the relative likelihood that any particular target type will be attacked
- the relative likelihood that any specific target will be attacked because of its inherent iconic value or security
- the relative likelihood that any particular attack mode will be used in an attack

Relative likelihoods define the probability that, if an attack happens, it will be in a particular place, of a particular type, on a particular target type, and, in some cases, on a particular target.

City Tier Likelihood

The RMS model groups cities into 8 separate tiers according to relative likelihood of attack. The terrorist attack risk in the RMS model is heavily concentrated in a small number of cities, illustrated

by the fact that, if an attack occurs, there is an 89% likelihood that the attack will be in one of the top ten ranked cities.

Target Type and Individual Target Likelihoods

As with cities, RMS bins target types into separate groups according to the relative likelihood of attack. The model includes 35 different target types that are divided into 8 groups representing distinct levels of threat. Table A.1 lists the target types included in each group.

**Table A.1
RMS Target Type Groups**

Target Type Group	Target Types in Group
1	Government Buildings
2	Business Districts, Skyscrapers, Stock Exchanges, Hotels & Casinos, Airports, Nuclear Power Plants
3	Military, Train & Subway Stations, Stadiums, Bridges & Tunnels
4	Industrial Facilities, Oil & Gas, Tourist Attractions, Shopping Malls, Restaurants, Ports & Ships
5	Media HQ, Fortune 100 HQ, Theaters, Major Entertainment Centers, Gas Stations
6	Cruise Ships, Apartment Buildings, Foreign Consulates, United Nations
7	Water Reservoirs & Distribution, Passenger Trains, Airspace Zones
8	Power Plants, Dams, Railway Networks

The RMS model also provides the ability to incorporate attack likelihoods for specific individual targets based on their iconic value and security status. The iconic value parameter allows the attack likelihood for individual high profile targets, such as iconic buildings, to be increased. Conversely, the security parameter allows the attack likelihood for individual targets with particularly high security, such as the White House, to be decreased. In general, however, this feature is largely unutilized in the RMS model because the specific information needed to assess these parameters for individual

buildings is not available. That is, nearly all targets of a given target type are assigned the same iconic value and security levels.

Attack Mode Likelihood

The RMS models attacks for 37 different attack modes. Table A.2 provides a brief description of some general attack mode categories. Each attack mode is assigned a relative likelihood based, in part, by the notion of each mode's "logistics burden." The logistics burden is a cost assigned to each mode that reflects skill, labor, time, and financial resource requirements. More resource-intensive modes have a higher logistics burden, which decreases their relative likelihood.

**Table A.2
Modes of Attack Modeled in the RMS Terrorism Risk Model**

Attack Mode Category	Description of Attack Scenarios in Model
Surface-to-Air Missile	Commercial 747 airliner shot down
Bomb	600 lb; 1 ton; 2 ton; 5 ton; and 10 ton
Aircraft Impact	Hijacked 747 commercial airliner flown into a target
Conflagration	9,000-gallon gasoline tanker hijacked and set on fire
Sabotage: Industrial, Explosion	5-, 50-, and 150-ton TNT equivalent
Sabotage: Industrial, Toxic Release	5%, 40%, and 100% of Bhopal accident
Sabotage: Industrial, Explosion + Release	5 ton + 5% Bhopal; 50 ton + 40% Bhopal; and 150 ton + 100% Bhopal
Sabotage: Nuclear Plant, Radiation Release	0.5%; 5%; and 20% of inventory
Dirty Bomb: cesium 137	1,500 Curies and 15,000 Curies
Chemical: Sarin gas	Indoors: 10 kg; outdoors: 10 kg; 300 kg; and 1,000 kg
2% anthrax slurry released outdoors	1kg, 10 kg, and 75 kg of slurry
Weaponized anthrax released indoors	40g of weaponized anthrax
Smallpox	10, 100, and 1,000 initially infected
Genetically Engineered Smallpox	100 and 1,000 initially infected
Nuclear Bomb	1 kiloton and 5 kiloton

The relative likelihood of a terrorist attack depends strongly on the type of attack being considered. The variation in relative likelihood by attack mode spans several orders of magnitude. This large range in attack mode likelihoods is broadly consistent with the

variation in attack mode likelihoods seen in the historical terrorism record (LaTourrette et al., 2007).

ESTIMATING ATTACK CONSEQUENCES

Consequences of terrorist attack scenarios in the RMS model are estimated from three components: weapons effects, target characteristics, and exposure characteristics. Weapons effects comprise the type of weapon, delivery mechanism, the hazards to people and property, and the spatial and temporal footprint of those hazards. A 600-pound bomb, for example, is detonated in a car and damage occurs from blast pressure waves and debris impact that extends for tens of meters around the blast site. For each attack mode listed in Table A.2, RMS has developed physical event models that generate a hazard footprint that specifies a hazard level estimate as a function of location around the attack site. The size of the hazard footprint can vary from less than 100 meters (e.g., for a small bomb) to several hundred square kilometers (e.g., for a nuclear or outdoor biological attack).

Target characteristics include a number of building characteristics, such as height, number of stories, year built, and construction type, which influence the attack consequences. Characteristics may also include other factors specific to a particular target type. These target characteristics help define the vulnerability of people and structures to the hazard imposed by the weapon. For example, newer steel buildings will suffer less damage from a bomb than older masonry buildings will. Building characteristics are compiled from multiple sources, including the data from the Sanborn Map Company, Inc.⁷

The attack exposure refers to the population and additional structures impacted by an attack. The exposure includes the number and spatial distribution of people within the hazard footprint, as well as (for insurance loss calculation purposes) their occupational status and age distribution. The exposure also accounts for the characteristics

⁷ The Sanborn Map Company, Inc., maintains spatial coordinates as well as numerous building attributes for buildings in major metropolitan areas in over 21 cities across the U.S.

and density of structures within the hazard footprint. Along with those of the target itself, the characteristics of the exposure determine the losses from an attack in terms of the casualty distribution and property damage. Estimates of the number and demographics of building occupants are derived from local census data, journey-to-work data, building-use type, and building size. The number of occupants is also adjusted to account for the time of day. We examined the effects of mid-afternoon, weekday attacks. Most types of buildings would be most fully occupied at this time; hence, our estimates reflect the worst case in the sense of the number of people exposed to the attack.

The model converts damage from an attack into losses in the form of casualties and property damage. The model provides estimates of the number of victims in each of six different casualty categories: medical only, temporary total disability, permanent partial minor disability, permanent partial major disability, permanent total disability, and fatality. These categories correspond to the standard workers' compensation injury categories and are defined in the same way.

Property damage in the RMS model includes replacement value of damage to buildings and building contents as well as business interruption losses. Building and building content losses represent the replacement value of damage to structures. Business interruption losses represent losses resulting from a civil authority exclusion zone around the incident site; this includes only losses from business closure and does not include indirect losses such as decreased sales.

APPLICABILITY OF THE RMS MODEL TO DEPARTMENT OF HOMELAND SECURITY DECISIONMAKING

It is important to identify the scope and intentions of the RMS model and how these may impact its applicability to informing decisionmaking about government homeland security efforts. Because it is designed to help the insurance industry estimate and manage risk, the RMS model focuses on estimating risk in terms of insured loss. This has two important implications for what is and is not included in the model.

The target database includes over 3000 individual urban locations. Targets were selected based on the criteria that an attack could produce economic losses in excess of \$1 billion, more than 100 fatalities and/or

500 injuries, or massively symbolic damage. While this target database is expected to largely overlap with targets of interest to DHS, some important targets may be missing. This stems from the fact that the objective of the RMS model is to characterize risk in terms of insured losses; it does not consider interdependencies among critical infrastructures or economic systems that could result in broader indirect or macroeconomic consequences of terrorist attacks. Consequently, targets with low insured value but that may still result in large indirect losses and major disruption in the event of an attack, such as communication and energy infrastructure, are under-represented compared to other target lists (e.g., U.S. Department of Homeland Security, 2006). Adding targets is feasible, though requires additional model development.

There are also gaps in the RMS exposure database that stem from its development for the commercial property-casualty insurance industry. In general, the loss estimates include only on those losses that are normally eligible for insurance. This means that our estimates exclude losses that are not normally covered by insurance, such as indirect economic losses (e.g., business losses resulting from decreased sales), and losses to entities that are typically self-insured (government property and employees). In addition, the modeled losses are restricted to those covered by commercial property and workers' compensation policies; they do not consider losses to non-commercial property, non-employee casualties (e.g., business patrons (audiences, hotel guests, passengers in airport terminals and planes, shoppers, restaurant patrons), visitors, passers-by, people at home, people at school), psychological damage, or liability losses.

These issues illustrate some potential difficulties of using an insurance-based risk model for public policy decisionmaking. However, it is relatively straightforward to overcome many of these shortcomings through additional data collection.

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