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U.S. Department of Commerce
Technology Administration
National Institute of Standards and Technology

Office of Applied Economics
Building and Fire Research Laboratory
Gaithersburg, MD 20899

Cost-Effective Responses to Terrorist Risks in Constructed Facilities

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Abstract

The September 11th attacks on the World Trade Center and the Pentagon and the potential for future terrorist attacks have changed the way the owners and managers of constructed facilities approach homeland security-related issues.

This report presents a three-step protocol for developing a risk mitigation plan for optimizing protection of constructed facilities. This protocol helps decision makers assess the risk of their facility to damages from low-probability, high-consequence events; identify engineering, management, and financial strategies for abating the risk of damages; and use standardized economic evaluation methods to select the most cost-effective combination of risk mitigation strategies to protect their facility. By using these economic evaluation methods, the owners and managers of constructed facilities can reduce the life-cycle costs associated with low-probability, high-consequence events.

The development of a cost-effective risk mitigation plan is facilitated through the use of evaluation methods and software for implementing these methods. This report focuses on the development of a decision methodology covering step three of the protocol—the economic evaluation of alternative risk mitigation strategies—and a proposed software product for implementing the decision methodology.

The decision methodology is based on the life-cycle cost method. This method is supported by a voluntary industry standard, ASTM E 917. Three additional standardized methods are employed to demonstrate how the use of multiple measures of economic performance enhances decision making.

The report also includes information on a variety of disaster mitigation-related issues. These sections of the report provide guidance and insights for readers interested in learning more about ways in which economic analysis contributes to protecting constructed facilities against natural hazards and terrorist acts that occur infrequently, but result in devastating damages.

Keywords

Building economics; disaster mitigation; economic analysis; homeland security; life-cycle cost analysis; optimization; terrorism; risk assessment.

Preface

This study was conducted by the Office of Applied Economics in the Building and Fire Research Laboratory at the National Institute of Standards and Technology. The study develops a methodology for evaluating security-related investments and expenditures in constructed facilities. The intended audience is the National Institute of Standards and Technology as well as other government and private sector organizations that are concerned with evaluating how to efficiently allocate scarce financial resources among security-related investment alternatives.

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List of Acronyms

AACE	Association for the Advancement of Cost Engineering, International
AIRR	adjusted internal rate of return
ALOHA	Areal Locations of Hazardous Atmospheres
AMA	American Management Association
ANSS	Advanced National Seismic System
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials, International
BFRL	Building and Fire Research Laboratory
CATS-JACE	Consequence Assessment Tool Set-Joint Assessment of Catastrophic Events
CBECS	Commercial Buildings Energy Consumption Survey
CBRE	chemical, biological, radioactive, and explosive
CBW	chemical and biological weapons
CCTV	closed-circuit television camera
CERF	Civil Engineering Research Foundation
CFD	computational fluid dynamics
CII	Construction Industry Institute
COTS	commercial off-the-shelf
DFIRMs	Digital Flood Insurance Rate Maps
DOD	Department of Defense
DOE	Department of Energy
DTRA	Defense Threat Reduction Agency
FAA	Federal Aviation Administration
FBI	Federal Bureau of Investigation
FDS	Fire Dynamics Simulator
FEMA	Federal Emergency Management Agency
FIRMs	Flood Insurance Rate Maps
FIS	Flood Insurance Study
FY	fiscal year
GAO	General Accounting Office
GIS	geographic information systems
GSA	General Services Administration
HAZUS	Hazards U.S.
HAZUS-MH	Hazards U.S. Multi-Hazard
HE	high-explosive
HPAC	Hazard Prediction and Assessment Capability
HVAC	heating, ventilation, and air-conditioning
III	Insurance Information Institute
ISO	International Organization for Standardization
K-12	kindergarten through 12th grade
LCC	life-cycle cost
MARR	minimum acceptable rate of return
MECS	Manufacturing Energy Consumption Survey
MSA	metropolitan statistical area

NBC	nuclear, biological, and chemical
NEIC	National Earthquake Information Center
NFIP	National Flood Insurance Program
NIBS	National Institute of Building Sciences
NIST	National Institute of Standards and Technology
NTSB	National Transportation Safety Board
OAE	Office of Applied Economics
O&M	operations and maintenance
PVNS	present value of net savings
RAMPART	Risk Assessment Method—Property Analysis and Ranking Tool
RMS	Risk Management Solutions, Inc.
ROI	return on investment
SAVE	Society of American Value Engineers, International
SIR	savings-to-investment ratio
SPV	single-point vulnerability
TISP	The Infrastructure Security Partnership
TRIA	Terrorism Risk Insurance Act of 2002
USGS	U.S. Geological Survey
WMD	weapons of mass destruction

1 Introduction

1.1 Background

The September 11, 2001 attacks on the World Trade Center and the Pentagon, and the subsequent dispersion of anthrax through the postal system, have changed the way many in the United States approach security and safety. Human losses from the events of September 11th were 2 749 fatalities at the World Trade Center site, 189 fatalities at the Pentagon, and 44 passenger and crew fatalities at the Pennsylvania plane crash site. In addition, numerous individuals at these locations sustained serious injuries. In the weeks following the September 11th attacks, the spread of inhalation anthrax through the postal system caused the deaths of five individuals among the confirmed cases of the disease, as well as expenditures of almost $1 billion to test for, remediate, and prevent anthrax contamination.[1] Additional information on the tragic events of September 11th and other natural and man-made disasters is presented in Appendix A.

These events have prompted the owners and managers of constructed facilities[2] to address terrorist risks and protect the occupants, property, and functions of their facilities. Future attacks could result in harm to occupants; physical damage to buildings, industrial facilities, and infrastructure; business interruptions; and financial losses.

These realities have led to changes in the way key decision makers respond to the risk of terrorist attacks. Among these changes are the way that owners and managers think about the design, location, construction, management, and renovation of buildings, industrial facilities, and infrastructure. The range of responses available to decision makers is extensive, as is the potential expense. Parallel to the reality of the risks is the reality of budget constraints. Owners and managers of constructed facilities are confronted with the challenge of responding to potential terrorist attacks in a financially responsible manner. The two objectives—safeguarding assets and satisfying financial constraints—must be balanced through cost-effective responses to terrorist risks.

1.2 Purpose

This report is the second in a series about the application of economic evaluation methods to the security of constructed facilities.[3] The purpose of this report is to describe

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[1] Information on World Trade Center fatalities is from Lipton (Lipton, Eric. "New York Settles on a Number That Defines Tragedy: 2,749 Dead in Trade Center Attack," *New York Times*, January 23, 2004, p. B7). Information on non-World Trade Center facilities is from Hartwig (Hartwig, Robert. "The Long Shadow of September 11: Terrorism and Its Impacts on Insurance and Reinsurance Markets," July 2002, http://server.iii.org/yy_obj_data/binary/687221_1_0/sept11.pdf). Information about consequences of anthrax contamination is from the United States Postal Service (U.S. Postal Service. *2001 Comprehensive Statement on Postal Operations*, 2001, p. 76) and Gugliotta and White (Gugliotta, Guy and White, Ben. "Tests Clear Home, Mail of Anthrax Victim," *Washington Post*, November 24, 2001, p. A1).

[2] The term "constructed facilities," as used in this report, includes buildings, industrial facilities, and infrastructure (see Table A-1 in Appendix A for a proposed classification of constructed facilities).

[3] The first report demonstrates how to apply life-cycle cost analysis to a complex homeland security investment decision (Chapman, Robert E. *Applications of Life-Cycle Cost Analysis to Homeland Security Issues in Constructed Facilities: A Case Study*. NISTIR 7025 (Gaithersburg, MD: National Institute of Standards and Technology, 2003).).

economic evaluation methods for cost-effectively allocating limited resources to implement mitigation strategies to reduce personal harm, financial losses, and property damage. Given these limited resources in the face of numerous vulnerabilities and potential strategies, a tool to aid decision makers to prioritize and plan for protective measures is essential. Economic evaluation methods will enable key decision makers—the intended customers[4]—to produce a risk mitigation plan that responds to the potential for terrorist attacks in a financially responsible manner. By using economic evaluation methods to promote more informed decisions, both intended customers and other stakeholders will benefit from reduced exposure to terrorism-related losses.

1.3 Scope and Approach

To address terrorism threats, we propose an approach based on three risk mitigation strategies: (1) engineering alternatives; (2) management practices; and (3) financial mechanisms. How each of these mitigation strategies is integrated into a cohesive and practical risk mitigation plan is a complex decision problem. In order to make efficient decisions about protective measures, owners and managers of constructed facilities require information about threats and vulnerabilities and the effectiveness and cost of protective measures. Decision makers also require a method for processing this information to yield a cost-effective risk mitigation plan.

This report presents a three-step protocol for developing a cost-effective risk mitigation plan for constructed facilities. This protocol helps users determine the vulnerability of their facility to damages from low-probability, high-consequence events; identify engineering, management, and financial strategies for abating the risk of damages; and use standardized economic evaluation methods to select the most cost-effective package of risk mitigation strategies to protect their facility. By using these economic evaluation methods, owners and managers can reduce the life-cycle costs associated with terrorism. These life-cycle costs include initial investment, operations and maintenance costs, expected losses due to terrorist or other uncertain hazards, and other costs, such as disposal costs. Financial incentives to invest in protective measures, such as government grants, subsidies or cost sharing, also factor into the investment decision.

Creating a risk mitigation plan is complicated because investments often result in significant but infrequent lump-sum outlays; operations and maintenance costs are distributed over a period of many years; and costs affect stakeholders in different ways. These cost considerations introduce four complicating factors into the capital asset decision-making process: (1) Which mitigation strategies should we employ and how will they operate, both singly and in combination? (2) How do we produce a risk mitigation plan that demonstrates superior economic performance? (3) How do owners and managers of multiple properties identify which constructed facilities to protect and why? (4) Who bears which costs? To address these questions, a formal methodology is needed to insure that all relevant costs are captured and analyzed using well-defined

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[4] Customers are the intended users of the economic tools; they are either directly or indirectly empowered to decide which combination of mitigation strategies to employ. Stakeholders are organizations or individuals affected by mitigation activities or disaster-related losses. Therefore, customers are a subset of stakeholders.

metrics to identify an economically superior risk mitigation plan. Life-cycle cost analysis and the related economic methods covered in this report provide those metrics.

To implement the economic evaluation methods proposed in this report, the Office of Applied Economics (OAE) in the Building and Fire Research Laboratory (BFRL) at the National Institute of Standards and Technology (NIST) intends to produce a software product as a companion to this report. Embedded in this user-friendly, decision-support software will be a methodology based on well-established economic evaluation methods. The software will help the owners and managers of constructed facilities make choices to reduce expected losses due to terrorism and other hazards. The decision support software tool will be used with risk, threat, vulnerability, and consequence assessments to construct responses to terrorist threats.

This report contains six chapters and six appendices in addition to the Introduction. The chapters treat the core topics, and the appendices add in-depth elaboration in support of the chapters. The reader may refer to the appendices when you want to know more about a given topic.

Chapter 2 describes three types of risk mitigation strategies: engineering alternatives, management practices, and financial mechanisms. Engineering alternatives are design, material, or component choices in the construction or renovation of constructed facilities, their systems, or their subsystems. Management practices include the security, training, communications, and emergency procedures that an organization establishes and implements to prevent or respond to terrorist attacks. Decisions about facility location as well as access to its systems are also management tools. Financial mechanisms are another set of devices that facility owners and managers can utilize to reduce their exposure to terrorism risk. They include purchase of insurance policies and responding to external financial incentives to engage in engineering-based or management-based risk mitigation. Examples of such financial incentives are government subsidies for investments to harden a facility or rental premiums paid by tenants who value the facility's added safety features.

Chapter 3 describes a three-step protocol for creating a risk mitigation plan: risk assessment, identification of potential mitigation strategies, and economic evaluation of risk mitigation alternatives. It describes the risk assessment that facility owners and managers must conduct to characterize the threats to a facility as well as identify its vulnerabilities and areas of criticality. Once owners and managers assess the risk of terrorism to the constructed facility, they must identify potential strategies to mitigate this risk. The identification includes potential risk mitigation measures and predictions of the effectiveness of these measures. The final step in the protocol for creating a risk mitigation plan is economic evaluation of the risk mitigation alternatives. The finalized plan describes the most cost-effective combination of mitigation strategies

Chapter 4 presents the decision methodology which provides the technical basis for the economic evaluation of risk mitigation alternatives. The decision methodology is based on two types of analyses, four standardized economic evaluation methods,[5] and a cost-accounting framework. The chapter also includes a discussion of how to identify, classify, and estimate on a year-by-year basis the key benefits and costs entering into the

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[5] ASTM International. *ASTM Standards on Building Economics* (West Conshohocken, PA: ASTM International, 1999).

economic evaluation. The two types of analysis—baseline analysis and sensitivity analysis—are designed to complement and reinforce each other. The baseline analysis serves as a reference point for the sensitivity analysis. The sensitivity analysis provides the means for evaluating financial risks associated with a wide variety of project-related costs. Together they provide the necessary insights to produce the risk mitigation plan. The four economic evaluation methods—life-cycle cost, present value of net savings, savings-to-investment ratio, and adjusted internal rate of return—are designed to cover a wide spectrum of investment decisions. The focus of this report is on the life-cycle cost method. Guidance is given, however, on applying the other three methods and on how the use of multiple measures of economic performance enhances decision making. The chapter concludes with a discussion of how the cost-accounting framework facilitates the decision-making process by identifying unambiguously who bears which costs, how costs are allocated among several widely-accepted budget categories, and how costs are allocated among key building components and the three types of risk mitigation strategies.

Chapter 5 describes the proposed software product. The software will implement the economic evaluation methods described in Chapter 4. The material presented in Chapter 5 includes screen shots from the forthcoming beta version of the software product scheduled for public release in September 2004. The chapter describes how the software product makes use of the cost-accounting framework and illustrates the linkage between the software product and the framework through reference to a series of data input screens.

Chapter 6 describes several decision-making scenarios for risk mitigation planning under varying conditions of ownership. It describes considerations for protecting a single facility; multiple collocated structures (including both interconnected and independent facilities) that share an owner; and geographically distributed structures belonging to the same owner. The various decision-making scenarios give rise to different criteria for the allocation of protective resources among the constructed facilities.

Chapter 7 concludes with a discussion of areas for future research.

Appendix A expands upon the material presented in Section 1.1 by presenting an inventory of the constructed facilities at risk in the United States as well as the risks, hazards, and consequences that these facilities face. Included in the discussion of these risks is a proposed classification of hazards according to the responsiveness of different dimensions of hazards to risk mitigation measures. The dimensions of each hazard are: probability of an event; type or magnitude of an event; and shift in the risk of an event. This classification is intended to characterize and highlight some indirect effects that risk mitigation measures may have on the overall risk posed by these hazards.

Appendix B builds on two topics introduced in Chapter 4, the identification and classification of benefits and costs. Appendix B develops hierarchies of benefits and costs and relates them to a hierarchy of stakeholders. These hierarchies provide important linkages between the economic evaluation methods and the cost-accounting framework. The appendix also includes a “priority setting” procedure that facilitates the collection of the types of data needed to generate the year-by-year estimates used as inputs to the economic evaluation methods.

Appendix C augments the Chapter 4 description of the savings-to-investment ratio method by addressing cases in which the decision criterion presented in Section 4.2.3 needs to be qualified.

Appendix D uses four analytical models to provide the theoretical foundations for the single facility risk mitigation decision-making scenarios described in Chapter 6. The first model presents and describes the economic optimization conditions for investment in engineering alternatives in a single period. The second and third models allow for expenditures to implement management practices and financial mechanisms, respectively, in each period of the study period. The fourth model describes the optimal allocation of resources over time when investments in engineering alternatives as well as expenditures for management practices and financial mechanisms are allowed in multiple time periods.

Appendix E presents a simple economic representation of the negative externalities that arise when some, but not all, facility owners and managers implement risk mitigation plans. When a facility owner or manager implements a risk mitigation plan that is observable to a potential attacker, it may reduce the probability that the newly protected facility will suffer a terrorist attack. The added protection may, however, lead to a transfer of this risk to other facilities that did not receive observable security upgrades (i.e., perceived “soft” targets).

Appendix F contains a glossary of terms that will be helpful in understanding and implementing the three-step protocol.

2 Risk Mitigation Strategies

The focus of this report is the cost-effective use of strategies to mitigate the risk of terrorism to constructed facilities. We examine three types of risk mitigation strategies available to building owners and managers to accomplish this goal: (1) engineering alternatives; (2) management practices; and (3) financial mechanisms. Each of these mitigation strategies may complement the other two to achieve the broad objectives of building owners and managers to reduce injuries, fatalities, property damage, loss of use, and business interruptions due to terrorist incidents.[6]

The objectives of the risk mitigation strategies are to:

1. ***Detect*** security breaches. Detection measures are intended to alert building officials to attempted breaches before they occur (or just as they are occurring). Detection may allow building security or other personnel to prevent the attack, delay or avert its full effects, or capture the attackers. Examples of possible detection measures are closed-circuit television (CCTV) cameras, alarms, motion or thermal sensors, x-ray machines, metal detectors, and security patrols. These measures may be evident or inconspicuous, and may incur one-time or recurring costs.
2. ***Deter*** terrorists from attacking. Mitigation can deter an attack by increasing either the resources potential attackers need to inflict a given level of damage to the facility or the probability of being thwarted or apprehended. Mitigation may deter terrorist attacks by making the terrorists' objectives more difficult, dangerous, or costly to achieve.[7] Deterrents are most effective when they are obvious, whereas other measures may be most effective when they are undetectable or secret.[8] Examples of deterrents are controlled access points, security personnel, and physical perimeter controls such as concrete barriers or tire shredders.
3. ***Protect*** the facility if an attack occurs. Hardening and reinforcing the building skin, creating redundancies in critical systems, and increasing setback distances are some examples of protective measures. Included in this category are measures designed to contain or delay the attack or the onset of its consequences,

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[6] Each type of strategy may also be used to offset inadequacies or constraints on the use of the other two. For example, a building in an urban setting may be located on a busy street with a setback of only several yards or meters. Physical restrictions on an existing building may prevent the building owner or manager from increasing the setback to reduce the building's vulnerability to a bomb attack. To counterbalance the owner's or manager's inability to use the management practice of building location in their risk mitigation plan, they may instead rely on engineering alternatives to reduce this vulnerability, such as by reinforcing existing beams and columns or installing more shatter-resistant laminated safety glass.

[7] Deterrence partially depends on the desire of the attacker to escape and survive. For attackers unconcerned with their survival or escape after an attack, the deterrent effect of engineering alternatives that may increase their risk of capture may be negligible. Measures that make a breach more difficult may still have deterrent effect.

[8] It is possible that the existence of security measures may embolden potential terrorists, if a successful breach is perceived as a demonstration of the terrorist organization's capabilities. In this case, introducing security measures may increase the probability of an attack, even if an attempted attack on a strongly defended target may entail greater risks, higher costs, or alteration to a plan of action on the part of the terrorists. See Drake (Drake, C.J.M. *Terrorists' Target Selection* (London: Macmillan Press, Ltd, 1998)), pp. 111-112.

to "buy time" to activate countermeasures, or to implement damage controls. Two examples of such measures are automatic depressurization of a room where airborne contaminants are detected to prevent or reduce the spread of the contaminants to other areas, and installation of bulletproof wallboard to protect against shrapnel and other projectiles caused by an explosion.

4. ***Apprehend*** transgressors. These measures help onsite security or law enforcement personnel apprehend individuals attempting or committing a security breach. Examples of these resources are trained security personnel, use of attack dogs, video surveillance, searchlights, and sealed corridors or other exit controls.
5. ***Recover and restore*** operations and the mission of the facility. Building in system redundancies, establishing sheltering procedures, stocking shelters with emergency provisions and first aid, and diversifying the locations of critical facilities and systems are examples of measures that building owners and managers can take to improve survival and facilitate a facility's recovery.

Some strategies may serve multiple objectives. Measures designed to deter attempted attacks could help detect breaches, protect the building, or apprehend the transgressors. Such measures contribute to the overall risk mitigation effort throughout the timeline of an emergency: deterrence and detection prior to an attack, protection during an attack, and apprehension and recovery after an attack.

While the goals of risk mitigation strategies may be detection, deterrence, protection, apprehension, and recovery and restoration, the measures to achieve them may affect existing objectives of constructed facilities. These effects may be countervailing. The potential for competing objectives may be greatest in the area of fire safety. Exit controls designed to impede an attacker's escape after a breach, for example, may also impede occupants from evacuating a building or emergency first responders from entering during a fire hazard. In another example, concrete bollards placed around a building to increase its setback may become shrapnel if a bomb explodes nearby. On the other hand, measures such as employee evacuation drills may serve parallel objectives and contribute to fire safety efforts. Where competing objectives exist and are unavoidable, the tradeoffs may be evaluated through probabilistic scenario development, multiattribute analysis, and other analysis methods.

2.1 Engineering Alternatives

Engineering alternatives are one approach for building owners and managers to mitigate losses from disasters. They are technical options in the construction or renovation of constructed facilities, their systems, or their subsystems to reduce the likelihood or consequences of disasters. Engineering alternatives are actualized through designs, materials, and components.

Detection is one objective of engineering alternatives. Examples of engineering alternatives intended to detect illicit activities are heating, ventilation, air-conditioning (HVAC) sensors to detect airborne contaminants; thermal sensors to detect body heat or motion (or occupancy) sensors in areas that are typically unoccupied; X-ray equipment in mail rooms and building entrances; and metal detectors at building entrances.

Second, engineering alternatives may be intended to deter terrorists from attempting an attack on the facility by increasing the risk to the terrorist of being detected, captured, or thwarted. Measures that deter terrorists from attacking a building reduce the probability of an attack on that building, but may cause terrorists to go elsewhere. For engineering alternatives to be effective at deterring terrorist attacks, they must be visible. Examples of such alternatives are high-elevation air intake units, CCTV cameras, or sprinkler systems.[9]

Finally, engineering alternatives may be used to protect against terrorist threats. Protective engineering alternatives are intended to reduce harm to occupants, damage to the structure, and disruption of business if a terrorist attack occurs. Protective engineering alternatives may improve the structural integrity of a building, facilitate evacuation of occupants, or circumvent compromised systems. For example, use of laminated safety glass, reinforced or additional structural columns, fire-resistant materials, and increased floor loads would enable a building to better withstand an attack of conventional explosives. Tire shredders used in conjunction with a long setback distance from vehicle-accessible areas would reduce the blast effects of explosives on the building and its occupants. Installation of additional stairwells and building exits may expedite occupant evacuation, facilitate access for emergency and rescue personnel, and improve survival. Improvements to HVAC systems and operations, such as isolation or negative pressurization of mail rooms, loading docks, lobbies, or other vulnerable or critical areas; improved filtration and air cleaning; ability to purge recirculated indoor air with fresh air; air quality sensors; and compartmentalized (such as floor-by-floor) air ventilation systems may improve the ability of building owners and managers to respond to and contain the losses from chemical or biological attacks.

There is some overlap among engineering alternatives that deter, detect, and protect against terrorist attacks. Detection and protective engineering alternatives that are observable to potential terrorists may deter them from attacking. CCTV, for example, is designed to detect unauthorized activities, but its visibility may deter these activities. Risk mitigation strategies may also be hazard-specific. Reinforced building shell, shatter-resistant glass, and increased setback distances are examples of engineering alternatives that protect against high-explosive (HE) conventional blast. Building pressurization and improvements in HVAC systems and operations address chemical and biological hazards. Building structure, installation of sprinklers, and choice of materials, for example, address fire hazards.

Engineering alternatives are also governed by state and local building codes. Well-enforced building codes require building owners and managers to use appropriate designs, safeguards, or materials that improve occupant survival during emergencies such as a terrorist attack. Numerous and unobstructed stairwells, for example, facilitate timely

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[9] Deterrence may not require the would-be terrorist to have specific knowledge about implementation of mitigation measures. Ayres and Levitt (Ayres, Ian, and Levitt, Steven D. "Measuring Positive Externalities from Unobservable Victim Precaution: An Empirical Analysis of Lojack," *Quarterly Journal of Economics*, Vol. 113, No. 2, February 1998, pp. 43-77.) demonstrate this result in the context of Lojack and auto thefts. They assume that potential thieves do not know exactly which cars in a city are equipped with Lojack but do know the proportion of cars that have the device. Ayres and Levitt show that, even if potential thieves do not have specific knowledge of Lojack use in an area, the probability of auto theft falls when a higher proportion of automobiles are installed with Lojack.

occupant evacuation. Codes that specify the use of certain materials may protect a building from a blast.

2.2 Management Practices

Building owners and managers can use management practices to reduce their risk from terrorism. These management practices can be procedural or technical. Some practices relate to security, training, and communications. Others relate to location of the building and access to its systems and subsystems. Some management practices complement engineering alternatives, while others substitute for them.

Security practices are the use of security personnel and procedures to prevent terrorist breaches from happening by detection or deterrence. They may be used to perform identification checks at building entrances, conduct background checks on individuals with access to sensitive areas and information, patrol facilities, and monitor CCTVs. Security personnel may also be used to capture attackers or facilitate recovery if a breach occurs.

Training practices are used primarily to prepare responses to terrorist breaches. Building owners and managers may institute periodic emergency response drills for building occupants. These drills may include information about evacuation routes or sheltering procedures to improve survival during emergencies.[10] Security and facility management personnel may receive training about proper techniques for responding to breaches and containing damage. Training may also be used for prevention: building security personnel and occupants may be trained in detection of suspicious activities and notification procedures.

Building owners and managers may also develop and implement communications practices to coordinate responses with emergency personnel and to relay information and instructions to occupants during emergencies. Communications practices include setting up emergency phone numbers or instituting building-wide audio or e-mail broadcast mechanisms. Coordinated communications can play a key role in occupant safety. For example, according to *The New York Times*, after the North Tower of the World Trade Center was struck on September 11, 2001, there was confusion in the South Tower about whether to evacuate, which led some occupants of upper floors who had begun to descend the stairs to return to their offices.[11] Building owners and managers can develop communications procedures to coordinate with first responders, security staff, and other emergency personnel responding to the incident. Finally, communications practices can be used by firms occupying the building to facilitate recovery, assess consequences, and minimize disruptions to the organization's mission or business.

Another management practice available to building owners and managers relates to the building structure. Decisions concerning location (such as within the country, region, or city) come into play for new construction and for acquisitions of existing buildings. Setback distances, which have effects that are interdependent with some engineering alternatives, are a component of the management decision about location.

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[10] Hays, Constance L. "As Important as the Corporate Disaster Plan Is How Fast the Employees Carry It Out," *New York Times*, September 12, 2001, p. C10.

[11] Moss, Michael and Bagli, Charles V. "Instincts to Flee Competed with Instructions to Remain," *New York Times,* September 13, 2001, p. A6.

For new construction, managers may choose a site within a lot that satisfies a minimum setback distance. When acquiring existing property, managers may make a choice based on the physical characteristics of the available properties. Other structure-related management decisions concern access to the building itself and its sensitive areas. These access areas include attached garages, mail rooms, loading docks, side entrances, connected buildings, driveways, and rooftops, for example. Sensitive areas include rooms housing HVAC equipment, sensors, and controls; servers, network connections, and other information technology (IT) assets; and CCTV monitoring equipment.

Emergency preparation is another management practice to reduce terrorist risk. Some preparations are intended to improve survival: establishing evacuation assembly or shelter areas, appointing evacuation coordinators, stockpiling essential supplies and provisions in shelters, and ensuring redundant electrical and HVAC systems. Some preparations are intended to expedite recovery. These include system redundancies, data backups, and remote facilities.[12] Although such preparations come into play only if an emergency occurs, they may be critical to the survival of occupants and the recovery of organizations housed in the facility.

2.3 Financial Mechanisms

Building owners and managers can explore financial mechanisms to reduce their pecuniary risks from terrorism. There are two types of financial mechanisms to address risk mitigation: insurance and financial incentives. Building owners and managers may reduce their risk exposure to disasters by purchasing insurance for worker's compensation, property damage, business interruptions, event cancellation, and liability. Financial incentives fall into two categories: government incentives and market-based incentives.

Government incentives are explicitly designed public policy instruments that encourage decision makers to make certain choices over others. Market-based incentives reward decision makers for making some choices over others through private transactions. In the case of risk mitigation, these incentives are policies, measures, or characteristics that enhance the motivation of building owners and facility managers to implement risk mitigation measures in their buildings.

2.3.1 Insurance

Insurance is a financial mechanism that building owners and managers can pursue to reduce risk. While insurance against terrorist risk may be attractive to building owners to reduce exposure in the event of a terrorist attack, the provision of terrorism coverage in the period after the September 11th attacks was limited. Until the passage of the Terrorism Risk Insurance Act of 2002 (TRIA) in November 2002, terrorism exclusions were permitted in 45 states, the District of Columbia, and Puerto Rico.[13] As of April

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[12] Chapman, Robert E., Gass, Saul I., Filliben, James J., and Harris, Carl M. *Evaluating Emergency Management Models and Data Bases: A Suggested Approach*. NISTIR 88-3826 (Gaithersburg, MD: National Institute of Standards and Technology, 1989).

[13] The legislation removed permissions for these exclusions. California, Florida, Georgia, New York, and Texas had not approved terrorism exclusions as of April 2002.

2002, only seven carriers offered stand-alone terrorism coverage for U.S. properties, with capacity limits per location ranging from $50 million to $500 million and deductibles for property damage between $5,000 and $50 million.[14] The largely unregulated reinsurance industry, to which primary insurers turn to further diversify risk and which, by some estimates, bore two-thirds of the covered losses of the September 11th attacks, reduced its exposure to terrorism after September 11th by selectively excluding terrorism coverage, reducing limits, increasing pricing, and raising collateral requirements. The severe post-September 11th shortage of reinsurance against terrorism meant that, for insurers to provide their clients with the same amount of coverage they offered prior to September 11th, they had to find capital from other sources. During the fall of 2001, it was not unusual for investors to require a return on investment (ROI) of 20 percent to invest in terrorism coverage. This requirement led many insurers to exclude terrorism as part of their commercial property policies.[15]

Other factors affecting the viability of insurance as a risk mitigation tool prior to passage of the TRIA include high premiums, cancellation clauses, and the absence of multi-year terms. Premiums, which were based on location, building security, and amount of coverage, ranged from 0.5 % to 1 % of the insured value. For some locations in New York City, however, premium amounts were as high as 10 % of the insured value. Some policies included clauses that allowed the insurer to cancel a policy with as little notice as 30 days, which opened the possibility of an insurer canceling policies when the terrorism climate worsened, such as during a period of heightened terror alert. Such cancellation clauses limited the time horizon of certainty for building owners to just one month. Lastly, the availability of only single-year policies was especially problematic for multi-year construction projects, many of which required three-year insurance policies for financing.[16]

The unavailability of insurance coverage, uncertainty of coverage, inadequate duration of insurance policies, and the high price of coverage in the marketplace shifted the preponderance of terrorism risk to building owners. The General Accounting Office (GAO) has cited anecdotal evidence of the effect of inadequate insurance capacity and high premiums on commercial construction lending and investment.[17] The non-residential construction sector experienced a slowdown during 2001 and 2002 (see Tables 2-1 and 2-2). While the explanation may lie in the weak economy, it is possible that lack of insurance may have also played a role. During 2002, the real value of private non-residential construction put in place fell 18.6 %, compared to a drop of 6.3 % in 2001. The industrial, office, and hotel/motel components of private non-residential construction

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[14] The seven carriers were: Lloyd's of London syndicates, American International Group, ACE USA, AXIS Specialty, Berkshire Hathaway, Endurance Re, and Renaissance Re. While the stated range of capacity limits is wide, more common per location limits were in the $5 million to $200 million range. See Betterley (Betterley, Richard S. "The Terrorism Coverage Market: Hope for Coverage in a Difficult Market," *The Betterley Report,* April 2002).

[15] Kunreuther, Howard, Michel-Kerjan, Erwann, and Porter, Beverly. "Assessing, Managing and Financing Extreme Events: Dealing with Terrorism," *NBER Working Paper 10179,* December 2003.

[16] Betterley, "The Terrorism Coverage Market," p. 4.

[17] U.S. General Accounting Office. "Terrorism Insurance: Rising Uninsured Exposure to Attacks Heightens Potential Economic Vulnerabilities," Testimony of Richard J. Hillman Before the Subcommittee on Oversight and Investigations, Committee on Financial Services, House of Representatives, February 27, 2002.

were hardest hit. Industrial construction put in place fell by almost 45 % in 2002, more steeply than any other segment (compared to a 10.4 % drop during the year before). The value of office construction put in place declined in 2002 by over 29 %, compared to a smaller 9.3 % decline in 2001. The value of hotel and motel construction put in place fell over 30 % in 2002, compared to a decline of 14.3 % in 2001.[18]

Table 2-1 Annual Value of Construction Put in Place: 1998 to 2002

in Millions of Constant (1996) dollars

	1998	1999	2000	2001	2002
Private Construction Nonresidential Buildings	177 644	173 429	178 074	166 852	135 764
Industrial	37 720	29 206	27 194	24 358	13 475
Office	39 333	42 552	47 534	43 126	30 536
Hotels, motels	13 794	14 274	13 944	11 950	8 359
Other commercial	49 915	50 870	51 635	50 077	45 404
Religious	6 139	6 590	6 858	6 908	6 676
Educational	9 039	8 621	9 726	10 371	10 434
Hospital and institutional	12 853	12 102	12 342	12 295	14 161
Miscellaneous	8 850	9 214	8 842	7 766	6 719

Source: U.S. Census Bureau.

Table 2-2 Annual Percent Change in Value of Construction Put in Place: 1999 to 2002

Real Year-on-Year Percent Change

	1999	2000	2001	2002
Private Construction Nonresidential Buildings	-2.4 %	2.7 %	-6.3 %	-18.6 %
Industrial	-22.6 %	-6.9 %	-10.4 %	-44.7 %
Office	8.2 %	11.7 %	-9.3 %	-29.2 %
Hotels, motels	3.5 %	-2.3 %	-14.3 %	-30.1 %
Other commercial	1.9 %	1.5 %	-3.0 %	-9.3 %
Religious	7.3 %	4.1 %	0.7 %	-3.4 %
Educational	-4.6 %	12.8 %	6.6 %	0.6 %
Hospital and institutional	-5.8 %	2.0 %	-0.4 %	15.2 %
Miscellaneous	4.1 %	-4.0 %	-12.2 %	-13.5 %

Source: U.S. Census Bureau.

The consequences of inadequate terrorism insurance on construction lending and investment prompted calls for Federal government action. On November 26, 2002, President Bush signed into law the Terrorism Risk Insurance Act of 2002,[19] which sets a ceiling on potential insurance payouts, provides substantial burden sharing, and increases the capacity of insurers. Among its provisions are mandatory participation by insurers, rescission of state exclusions, transitional terrorism coverage for insured losses in all

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[18] U.S. Census Bureau, *Value of Construction Put in Place: January 2003*, Series C30 (March 2003). Table 1, January 2003. Percentages are based on constant 1996 dollar values.

[19] For brief descriptions of government terrorism insurance policies in other countries, see Appendix 1 of Jaffee and Russell (Jaffee, Dwight and Russell, Thomas. "Extreme Events and the Market for Terrorism Insurance," Fisher Center for Real Estate and Urban Economics, Working Paper 02-282, April 2002.) and Hartwig (Hartwig, "The Long Shadow of September 11," p.79).

property and casualty policies, and a Federal backstop for terrorism losses. The legislation only covers events that result in losses of at least $5 million. The insurer's deductible is calculated annually as a predetermined percentage of direct earned premiums from the 2002 calendar year. This percentage will increase each year, from 1 % in 2002 to 7 % in 2003, 10 % in 2004, and 15 % in 2005. Of the claims exceeding the deductible, the Federal government will assume 90 % of the excess, with the insurer responsible for the remaining 10 %. The legislation sets an annual aggregate cap of $100 billion on insured losses on government or insurer liability, and the program will phase out completely on December 31, 2005.

Difficulties remain, however, if insurers are determined to be the appropriate mechanism for dealing with terrorism risks. The barriers to serving that function are legal obstacles to industry-wide pooling, regulatory restrictions, financial requirements to raise large sums of private investment to cover risk, and actuarial challenges in terrorism risk modeling.[20] The first three are institutional, however, which can be addressed by government action. The last barrier, actuarial challenges, is a technical and informational one not as easily ameliorated by public policy and reflects concerns that insurers have when the risk is considered to be highly ambiguous. In a study of underwriter pricing behavior, Kunreuther et al[21] found that for the case where both the probability and losses were ambiguous, the premiums were between 1.43 and 1.77 times higher than if underwriters priced a non-ambiguous risk. Similar behavior was observed in a study of actuaries in insurance companies.

Swiss Re[22] identifies the general criteria for an insurable risk: the ability to assess the probability and magnitude of losses; randomness and unpredictability of an event; mutuality of risks to encourage pooling and diversification of risks, geographic and otherwise; and economic feasibility to charge a premium which reflects the risk. In the case of terrorism, these criteria do not hold, although the mandated participation of the TRIA expands the risk community and diversifies the risk base. The relative infrequency of terrorism, a "low-probability, high-consequence" event, complicates the task of pricing its risk.

In addition to the TRIA, the Federal government has also used regulatory devices to ease the burden caused by the unavailability or high cost of terrorism insurance. For example, in March 2003, the Department of Housing and Urban Development announced that new Federal Housing Administration-insured multifamily mortgages under $50 million would not be required to carry terrorism insurance.[23]

Carrying insurance reduces the financial exposure of owners of constructed facilities to terrorist attacks, but payments on claims represent a transfer of the costs of an attack from the insurer to the insured. It does not address the issue of reducing the

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[20] Kollar, John J. "Terrorism Insurance Coverage in the Aftermath of September 11th," *A Public Statement by the Extreme Events Committee of the American Academy of Actuaries,* April 17, 2002.

[21] Kunreuther, Howard, Meszaros, Jacqueline, Hogarth, Robin, and Spranca, Mark. "Ambiguity and Underwriter Decision Processes," *Journal of Economic Behavior & Organization*, Vol. 26, No. 3, May 1995, pp. 337-352.

[22] Schaad, Werner. "Terrorism—dealing with the new spectre," *Swiss Re Focus Report,* 2002.

[23] Koprowski, Gene. "Soft Targets," *Homeland Defense Journal*, Vol. 1, No. 1, April 2003, pp. 34-37.

injuries to occupants and destruction of property in the event of an attack.[24]

The role of the Federal government as an insurance backstop is a tangible example of its formal stake in the private behavior of building owners and managers. Any protective measures that a facility adopts would, in the event of a terrorist attack, ease the burden of the Federal government and private insurers if they reduce casualty or property damage claims due to an extreme event. This intertwining of objectives may make the Federal government and private insurers willing to offer such incentives.[25]

2.3.2 Financial Incentives

2.3.2.1 Government Financial Incentives

Federal, state, and local governments can institute direct incentives that reduce the price that building owners and managers pay to protect their buildings. These incentives include subsidies or tax write-offs for investments in protective measures. Other examples of government-initiated financial incentives are formal cost sharing of the protective investments and loan guarantees to ease the short-term financial burdens of structural upgrades.

Tobin[26] has described several additional types of incentives to encourage property owners to reduce the vulnerability of their buildings in the context of earthquake hazards. These include assessment limits, grants, credits, and rebates; reduced retrofitting costs; technical assistance; exemptions from some planning and zoning requirements; and penalties (i.e., disincentives). The California Department of Insurance, for example, has earthquake grant and loan programs that provide financial assistance to low- and moderate-income residential property owners for seismic improvements. Several California municipalities also provide loans to qualified homeowners for such improvements.

Government financial incentives to guide implementation of risk mitigation measures may be appropriate where private incentives differ from public benefits. Such discrepancies arise when the consequences of risk mitigation are not fully appropriable to building owners and managers. One example may be taken from a blast scenario. A building that is fortified with reinforced concrete columns and laminated safety glass may generate less shrapnel if it is attacked than an unfortified building. The reduction in shrapnel in turn means that surrounding buildings are less adversely affected. If the neighboring buildings are not owned by the same party, then the benefit of lower damage due to the building's fortification does not accrue to the building owner who paid for the measures. The consequence is a socially sub-optimal level of risk mitigation.

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[24] This statement is true unless insurers offer incentives for policyholders to implement risk mitigation measures.

[25] The Federal Government's obligations under the Terrorism Risk Insurance Act are not its only stake in reducing terrorism losses. For example, the Federal Government bore a substantial portion of the costs of the September 11th attacks.

[26] Tobin, L. Thomas. "California Case Study: Examples of Incentives to Encourage Earthquake Resistant Communities," presented at the Wharton School, Economic Incentives for Building Safer Communities Wharton Risk Management and Decision Processes Center Roundtable, June 11, 2002.

Conversely, it is possible for a building owner's risk mitigation activities to adversely affect other parties. One potential example is the use of concrete bollards. While they may increase a building's setback from public roads and reduce its vulnerability to a blast source, an explosion may render the bollards concrete shards, contributing to the shrapnel problem. The possibility that risk mitigation measures can have both positive and negative social consequences from a terrorist attack suggests that any public policies to promote the adoption of risk mitigation measures must consider all the implications of the incentives.

2.3.2.2 Market-Based Financial Incentives

Financial incentives for risk mitigation in constructed facilities may also be market based. The transmission of these incentives occurs through a multitude of private relationships and transactions. Building owners have commercial relationships with insurers, tenants, employees, potential buyers, and lenders. These parties may each benefit from a building's reduced vulnerability. Therefore, each of these relationships is a potential transmission mechanism of rewards for risk mitigation activities.

Insurance companies benefit from risk mitigation measures through fewer claims due to lower risk of an attack and smaller claims if an attack occurs. To encourage owners to adopt risk mitigation, insurers may reduce insurance premiums for buildings that have protective measures. Building owners may also be able to attain more favorable insurance policies, such as those that are longer term, have lower deductibles, or have fewer exclusions.

Building owners who lease commercial space may find that tenants value a building's safety features and are willing to pay a leasing premium. For owner-occupied buildings, employees may also value the added safety of a less vulnerable building. The perception of danger may affect employees' willingness to work in a particular location.[27]

Potential buyers are another party from which a building owner can extract rewards for the building's risk mitigation measures. The installation of protective capital in a building is an improvement that increases the value of the asset. The building owner may realize the benefit of increased property value when the property is turned over.

Owners of leveraged buildings may also receive incentives from their lenders to protect their assets. Lenders would suffer direct financial losses if the destruction of a building led to the building owner's insolvency. To encourage owners to make choices that reduce the likelihood of such destruction, lenders may offer preferential financing terms on the building loan. Another possibility would be for the financer to make funds available to the owner to implement the risk mitigation improvements. Another way building owners are potentially rewarded in their relationships with financial institutions for their risk mitigation efforts is through the increased collateral value of their buildings.

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[27] The new Federal building which opened in December 2003 kitty-corner to the site of the bombed Alfred P. Murrah Building in Oklahoma City provides one example. In spite of safety features incorporated into the design of the new building, several Federal employees have refused to move to the location. One basis of the refusal is the perception that the concentration of Federal agencies in one building makes it less safe. See *Federal Employees News Digest* (*Federal Employees News Digest*, "Employees Fighting Transfer to New Building," Vol. 53, No. 14, October 27, 2003), p. 5.

One challenge to the implementation of a system of financial incentives by the Federal government and by private insurers is the need for performance metrics for risk mitigation measures. Calibrating incentives requires information about the linkage between risk mitigation measures and reduced losses. To ensure that the incentive is proportionate to the reduction in expected loss, there must be quantification of the benefits. This information can be based on predictions or actual outcomes. Predictive information is *ex ante* and of broader scope, although less precise. Engineering experimentation, simulations, and analysis can be used to model structural damage, casualties, and other losses associated with various fortification measures under various attack scenarios. Outcome-based data include actual claims or vulnerability history (data on thefts, break-ins, and other crime inside and in the immediate vicinity of the building) after the measures are implemented. These outcomes can be compared cross-sectionally (with nearby buildings) or intertemporally (with pre-installation performance). While these quantifications are certain and known, this type of metric is *ex post.* As such, it is not as useful in inducing building owners to install hardening measures, although the data on these outcomes can be used to parameterize predictive models.

This chapter has proposed to building owners and managers three types of approaches—engineering alternatives, management practices, and financial mechanisms—to formulate a risk-mitigation plan. Characterizing these three types of approaches is only one part of the solution. A method to assess their need, identify their applicability, and evaluate the alternatives is necessary. Chapter 3 develops a three-step protocol for building a plan using these three approaches.

3 A Three-Step Protocol for Creating a Risk Mitigation Plan

Producing a risk mitigation plan requires three essential components: risk assessment, identification of potential mitigation strategies, and economic evaluation. Risk assessment is used to identify the risks confronting a facility. It includes development of possible scenarios of attack, probability assessment for these scenarios, and identification of the facility's vulnerabilities and critical areas.[28] Identification of mitigation strategies—engineering alternatives, management practices, and financial mechanisms—provides performance data for the possible combinations of risk mitigation strategies. The third component, economic evaluation, enables building owners and managers to choose the cost-effective combination of risk mitigation strategies and the optimal sequence for implementing them.

3.1 Risk Assessment

The first step to creating a risk mitigation plan is a risk assessment for the facility. Risk assessment is made up of assessments of threat, vulnerability, and criticality for each facility. Threat assessment identifies scenarios of attack, develops an understanding of the motivations behind different terrorist groups' selection of targets, and determines probabilities (absolute or relative) of attack. Vulnerability assessment includes identification of, for example, single-point vulnerabilities (SPVs), the absence or inadequacy of system redundancies, collocation of critical systems components, and exposed or easily accessible areas of the facility or its systems. Criticality assessment determines how essential the facility, its system, and its contents are to the organization's mission and function. This last element is necessary for decision makers to establish priorities for protective resources.

Threat assessment requires specific information about terrorist intentions, resources, and capabilities. Much of this information is primarily gathered and analyzed by government intelligence and law enforcement organizations. The three leading private risk modeling firms, EQECAT, AIR Worldwide, and Risk Management Solutions (RMS), have also completed development of proprietary terrorism risk models. While some of this information is available to the public, access is typically restricted. To make best use of the information that is publicly available, alternative approaches to threat assessment are needed. Analysts without access to classified or proprietary data need a framework to define procedures to make "best-guess" assessments of these characteristics and predictions of probabilities using the information that is publicly available.

Vulnerability assessment is typically performed by architecture and engineering firms and security experts. Vulnerabilities can be identified through, for example, visual inspection of the facility site, floor plans, and geographic information systems (GIS) resources. Criticality assessment is based on the mission and business of the organization located at the facility and the functions of its systems.

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[28] Some may also include consequence assessment as a fourth element of risk assessment. Here, consequence assessment is included as a part of the second component of the risk mitigation plan, identification of mitigation strategies.

3.1.1 Software-Based Risk Assessment

Researchers have developed a number of risk assessment tools to model terrorist decision processes as well as risks from natural hazards and other manmade hazards. One such tool is the Risk Assessment Method—Property Analysis and Ranking Tool (RAMPART) software, developed at Sandia National Laboratories as a contractor for the General Services Administration (GSA).[29] RAMPART combines building- and site-specific information elicited from facility managers with geography-based seismic, weather, and crime data using its expert system of rules to predict the vulnerability of a building to several categories of consequences due to man-made and natural hazards. In RAMPART, categories of consequences include casualties, damage to property and contents, and loss of use and mission. RAMPART addresses natural hazards (hurricanes, earthquakes, flooding, and winter storms) and several manmade hazards (crime inside the building, crime outside the building, and terrorism).[30]

Another software tool designed to provide individuals, businesses, and communities with information and tools to mitigate hazards and reduce losses from disasters is Hazards U.S. (HAZUS).[31] HAZUS is a natural hazard loss estimation methodology developed by the National Institute of Building Sciences (NIBS) with funding from the Federal Emergency Management Agency (FEMA). HAZUS allows users to compute estimates of damage and losses from natural hazards using GIS technology. Originally designed to address earthquake hazards, HAZUS is being expanded into HAZUS Multi-Hazard (HAZUS-MH), a multi-hazard methodology with new modules for estimating potential losses from wind (including hurricane) and flood hazards. HAZUS-MH will also contain a third party model integration capability that will provide access and operational capability to a wide range of natural and man-made hazard models that will supplement the natural hazard loss estimation capability in HAZUS-MH. For chemical, biological, radiological, nuclear, and explosive threats, for example, HAZUS-MH can be used with the ALOHA dispersion software model to predict the footprints of plumes downwind from the releases.[32]

3.1.2 Risk Assessment Guidance Documents

In addition to these software products, several guidance documents are available to help facility managers assess the risks facing their structures. FEMA has developed a series of guidance manuals to assist state and local communities in planning for risk

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[29] Hunter, Regina L. "Risk Assessment Method—Property Analysis and Ranking Tool: Risk Analysis Software for the GSA Property Manager," *mimeo*, Sandia National Laboratories, 2001.

[30] RAMPART is designed for application to Federal facilities, but this limitation only means that some hazard data exist only for GSA-owned or -managed buildings. The software could be used for privately owned, non-GSA buildings, but the analysis will not include all four natural hazards. In addition, while the hazard data for the natural hazards and crime are based on existing incidence data or probability estimates, determination of the terrorism hazard is based entirely on data values entered by the user. These data are processed according to an "expert system of rules" devised by researchers at Sandia. This data limitation is primarily due to insufficient empirical data on building-related terrorist incidents in the United States.

[31] http://www.fema.gov/hazus/hz_meth.shtm

[32] Bouabid, Jawhar. "HAZUS-MH and Technological Hazards," November 2002, http://www.fema.gov/hazus/zip/dl_tech.zip.

mitigation. These manuals address the need for risk assessment for a variety of hazards. They describe the processes of identifying hazards,[33] identifying and developing mitigation strategies,[34] implementing risk mitigation plans,[35] and applying these processes to man-made hazards.[36] *Understanding Your Risks* addresses natural hazards but offers descriptions of the risk assessment process that can be generalized to other types of hazards. The four-step process consists of: (1) identifying the hazards; (2) profiling the hazard events to determine magnitudes and pinpoint more specific asset vulnerabilities; (3) inventorying assets; and (4) estimating losses. *Developing the Mitigation Plan* provides state and local decision makers with the tools to identify mitigation objectives and strategies. *Bringing the Plan to Life* describes the steps that planners can take to implement the strategies that were identified in *Developing the Mitigation Plan* to accomplish the stated risk mitigation objectives. *Integrating Human-Caused Hazards* directly relates to terrorism and "technological disasters." All four FEMA guidance manuals are designed to be used at the community level rather than at the level of individual businesses or buildings. But building owners and managers may benefit from increased awareness of local hazards and the types of personnel and expertise that FEMA recommends, particularly if they undertake risk mitigation in coordinated fashion with local emergency responders.

FEMA recently launched a new series of publications directed at providing design guidance for mitigating terrorist risks. The objective of the Risk Management Series is to reduce physical damage to structural and nonstructural components of buildings and related infrastructure, and to reduce casualties resulting from conventional bomb attacks, as well as attacks using chemical, biological, and radiological agents. Emphasis is on improving security in high occupancy buildings to better protect the nation from potential threats by identifying key actions and design criteria to strengthen buildings from forces that might be anticipated from a terrorist attack. The first publication in the series, FEMA 426,[37] is a reference manual. FEMA 426 provides guidance to architects and engineers on how to reduce physical damage to buildings, related infrastructure, and people caused by terrorist attacks. The manual presents incremental approaches that can be implemented over time to decrease the vulnerability of buildings to terrorist threats. The second publication, FEMA 427,[38] is a primer. FEMA 427 introduces a series of

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[33] Federal Emergency Management Agency. *Understanding Your Risks: Identifying Hazards And Estimating Losses*. FEMA 386-2 (Washington, DC: Federal Emergency Management Agency, August 2001).

[34] Federal Emergency Management Agency. *Developing The Mitigation Plan; Identifying Mitigation Actions and Implementing Strategies*. FEMA 386-3. (Washington, DC: Federal Emergency Management Agency, April 2003).

[35] Federal Emergency Management Agency. *Bringing the Plan to Life: Implementing the Hazard Mitigation Plan*. FEMA 386-4. (Washington, DC: Federal Emergency Management Agency, August 2003).

[36] Federal Emergency Management Agency. *Integrating Human-Caused Hazards Into Mitigation Planning*. FEMA 386-7 (Washington, DC: Federal Emergency Management Agency, September 2003).

[37] Federal Emergency Management Agency. *Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings*. FEMA 426 (Washington, DC: Federal Emergency Management Agency, December 2003).

[38] Federal Emergency Management Agency. *Primer for Design of Commercial Buildings to Mitigate Terrorist Attacks*. FEMA 427 (Washington, DC: Federal Emergency Management Agency, December 2003).

concepts that can help building designers, owners, and state and local governments mitigate the threat of hazards resulting from terrorist attacks on new buildings. FEMA 427 contains extensive qualitative design guidance for limiting or mitigating the effects of terrorist attacks focusing primarily on explosions, but also addressing chemical, biological, and radiological attacks. The third publication, FEMA 428,[39] is a primer on school projects. The purpose of FEMA 428 is to provide the design community and school administrators with the basic principles and techniques to make a school that is safe from terrorist attacks. The fourth publication, FEMA 429,[40] is a primer on risk management. The purpose of FEMA 429 is to introduce the building insurance, finance, and regulatory communities to the issue of terrorism risk management in buildings and the tools currently available to manage these risks. Additional publications are planned in the Risk Management Series. For additional information on new or planned publications in the series, visit the Risk Management Series Publications web site.[41]

On July 31, 2002, the Department of Defense (DOD) published a Uniform Facilities Criteria (UFC) for unrestricted distribution entitled, "DoD Minimum Antiterrorism Standards for Buildings." The objective of these standards is to improve the survival of DOD personnel from terrorist attacks.[42] Although the UFC system applies to the military departments, DOD agencies, and DOD field activities, the standards identify and highlight several key aspects of site planning, structural design, architectural design, and electrical and mechanical design that play a role in protecting buildings from explosives threats. The criteria apply to construction projects beginning in FY2004, new leases in FY 2006, and lease renewals by FY 2010. They provide an example of explicit tradeoffs among two approaches to improving survival from a terrorist attack on a constructed facility: setback distance and structural hardening. DOD's focus on minimum setback distance as the primary approach separates it from GSA and the Department of State, which place more emphasis on building hardening.[43]

The American Management Association (AMA) recently published *The Facility Manager's Emergency Preparedness Handbook*.[44] This handbook is intended as a reference for emergency preparedness planning. It provides guidelines, tools, and checklists to facility managers to prepare for several types of emergencies. A sample of these emergencies includes: terrorism, fire emergency, lockout, and workplace violence.

In 2003, R.S. Means published *Building Security: Strategies & Costs*[45] to assist building owners and facility managers to assess risk and vulnerability to their buildings,

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[39] Federal Emergency Management Agency. *Primer to Design Safe School Projects in Case of Terrorist Attacks*. FEMA 428 (Washington, DC: Federal Emergency Management Agency, December 2003).

[40] Federal Emergency Management Agency. *Insurance, Finance, and Regulation Primer for Terrorism Risk Management in Buildings*. FEMA 429 (Washington, DC: Federal Emergency Management Agency, December 2003).

[41] www.fema.gov/fima/rmsp.shtm

[42] U.S. Department of Defense. *DoD Minimum Antiterrorism Standards for Buildings*, UFC 4-010-01, July 31, 2002.

[43] Bradshaw, III, Joel C. "Protecting Personnel at Risk: DOD Writes Anti-Terrorism Standards to Protect People in Buildings," *AMPTIAC Quarterly*, Vol. 6, No. 4, February 2003, pp. 11-15.

[44] Lewis, Bernard T. and Payant, Richard P. *The Facility Manager's Emergency Preparedness Handbook* (New York: AMACOM Books, 2003).

[45] Owen, David D. and R.S. Means Engineering Staff. *Building Security: Strategies & Costs* (Kingston, Massachusetts: Construction Publishers & Consultants, 2003).

develop emergency response plans, and make choices about protective measures and designs. *Building Security* also includes pricing information for several security-related components, systems, and equipment, as well as the labor required for installation. In addition to materials and equipment, the cost data also includes information about other security and prevention measures such as command (guard) dogs, exterior plants, and planters.

The American Society of Mechanical Engineers (ASME), through funding from the Department of Homeland Security, is developing a guidance document on risk assessment to inform resource allocation decisions for the protection priorities of critical infrastructure. This guidance document will provide a review of the existing approaches to assessing risk, highlight the common terminology and basis for reporting results, and present recommended methodology and best practices.

3.1.3 Qualitative Approaches to Risk Assessment

There are also qualitative approaches to modeling terrorist risk to constructed facilities. Rather than attempting to compute an absolute measure of risk, the authors of these approaches propose methodologies to measure the relative risk facing different facilities or structures. Because their result is a ranking of priorities, they provide guidance in the budget prioritization process.

Paté-Cornell and Guikema[46] propose an overarching model with probabilistic scenarios of attack and consequences, deriving von Neumann-Morgenstern expected utilities.[47] The authors identify scenarios of attack and generate probabilities of these scenarios based on information about the intentions and resources of the potential attackers and the "attractiveness" of the target. They also assign values to the utility or disutility that the decision makers derive from the realization of the scenarios. Based on this information, the authors run influence diagrams and compute the maximum expected utility for the two agents, the attackers and the defenders. For defenders, the ranking of the scenarios by expected disutility allows policymakers to set priorities among countermeasures. Scenarios can be alternatively ranked based on damage level or on probability of occurrence.

Kowalski[48] presents a methodology to compute the risk of chemical or biological attack that a building faces relative to the risk to other buildings. He extends Zilinskas'[49] formulation of risk as a function of the product of hazard (i.e., degree of danger posed) and exposed population. Kowalski applies this formulation of risk to the case of buildings by including ordinal or indexed values of a building's profile and vulnerability. The relative risk, or normalized probability, is thus computed in Equation (3.1) as the geometric mean of the four factors, hazard (H), occupancy (O), profile (P), and vulnerability (V):

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[46] Paté-Cornell, Elisabeth and Guikema, Seth. "Probabilistic Modeling of Terrorist Threats: A Systems Approach to Setting Priorities Among Countermeasures," *Military Operations Research*, Vol. 7, No. 4, 2002, pp. 5-23.

[47] Von Neumann, John and Morgenstern, Oskar. *Theory of Games and Economic Behavior* (Princeton, New Jersey: Princeton University Press, 1953).

[48] Kowalski, Wlayslaw Jan. *Immune Building Systems Technology* (New York: McGraw-Hill, 2003).

[49] Zilinskas, Raymond A. *Biological Warfare* (Boulder, CO: Lynne Rienner Publishers, Inc., 2000).

$$R = \sqrt[4]{H \cdot O \cdot P \cdot V} \qquad (3.1)$$

Kowalski assigns values to each of these four variables subjectively. Because all chemical and biological weapons (CBWs) are potentially fatal, he assigns a value of $100\,\%$ to the hazard factor.[50] Building occupancy is assigned a value between 1 (extremely low) to 100 (extremely high) to indicate relative occupancy. The author treats building profile in a similar fashion. Building profile can be decomposed into two components: profile of the facility itself and profile of the building's tenants.[51] Vulnerability, which is similarly measured, is determined by accessibility and threat to occupants. Publicly accessible buildings with little or no immunity are considered high vulnerability, while well-fortified, high security facilities would be considered low vulnerability.

The computed risk is a normalization of the probabilities associated with these four factors. The normalizations allow for different buildings to be ranked by the level of relative risk. Normalization using the geometric mean in Equation (3.1) is based on the assumption that the probabilities of the four factors are independent and the four factors are weighted equally. This formulation can be generalized to take into account other risk factors, such as location, or explicitly stated threats to the facility. The vulnerability factor could also be separated into its two components, building security and building immunity. The normalized risk for *n* multiplicity of factors, expressed as a probability, is the *n*th root of the product of values of these factors.

Alternatively, relative risk can be computed as an average of the risk factors. Whether these factors are weighted differently will depend on subjective assessment of their relative importance to the overall risk that a building faces. For both methods of computing risk, geometric mean and arithmetic mean, lower values of this measure of relative risk indicate lower risk to the facility.

3.1.4 Sources of Hazards Data

Data about the frequency and consequences of natural and man-made hazards are helpful when assessing the risks that a particular facility faces from these hazards. Historical patterns of natural disasters, in particular, may indicate which areas are more prone to these specific hazards in the future. Some analysts may also refer to past incidences of man-made hazards, such as crime, as predictors of future occurrences. Statistics about the frequency, severity, and damages from natural hazards in the United States are available at national and local geographic levels. Historical data on earthquakes, hurricanes, winter storms, tornadoes, coastal and river flooding are available through multiple U.S. government sources.

The U.S. Geological Survey (USGS) is one source of such information. The USGS has produced six maps illustrating the areas within the 48 contiguous states with

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[50] If this approach were applied to other hazards that do not carry a high potential for fatality, including natural hazards, the hazard factor may be less than 100.

[51] A building's profile is high if it is a signature or landmark structure. It may also be high if it houses high-profile tenants, such as political entities, law enforcement organizations, or prominent companies.

"relatively high risk or relatively frequent actual occurrences" of six natural hazards: floods, earthquakes, landslides, volcanic eruptions, hurricanes, and tornadoes.[52] A starting point for data gathering about these hazards is available at USGS.[53] Researchers at the USGS Coastal and Marine Geology Program are also developing models to predict the occurrences, severity, and consequences of natural disasters such as hurricanes, earthquakes, and floods.[54] Moreover, the USGS National Earthquake Information Center (NEIC),[55] National Seismic Hazard Mapping Project,[56] and Advanced National Seismic System (ANSS)[57] provide data and hazard maps for earthquakes. The earthquake hazard data are available by zip code or by latitude and longitude. The USGS Coastal and Marine Geology Program has several projects associated with hurricane and coastal storm prediction. The Coastal Classification Mapping Project[58] characterizes and classifies pre-storm ground conditions for states located along the Gulf of Mexico that, when combined with data about beach stability and prior storm impact studies,[59] provide indications of an area's vulnerability to hurricanes or other extreme coastal storms. To address other flooding hazards, the Office of Surface Water at the USGS has developed several flood frequency analysis software products.[60]

FEMA is a primary source of information from the Federal Government concerning flood hazards due to rivers and streams and along coastal areas and lake shores. The agency manages the National Flood Insurance Program (NFIP). In addition to administering the flood insurance program and issuing floodplain management regulations, the NFIP maintains a bank of flood insurance maps, available both on hard copy and digital media, from its Map Service Center.[61] Some of these maps are available online and interactively produce public flood maps by street address. The NFIP also provides Flood Insurance Study reports (FIS) containing data on flood risk and flood-prone areas. The FIS reports, which are available at the sub-county, city, or community level, are the bases of the Digital Flood Insurance Rate Maps (DFIRMs) and Flood Insurance Rate Maps (FIRMs). Online city-level hazard maps to promote awareness of general risks from several natural hazards—flood hazard areas, earthquakes (recent and historical), historical hail storms, hurricanes, wind storms, tornadoes—are also available through a FEMA National Partnership.[62]

The National Weather Service collects state and national data about the consequences of severe weather in the United States.[63] Data for 1995 through 2003 cover lightning, tornado, tropical cyclone, heat, flood, cold weather, winter storm, wind, and other hazards. Consequences are grouped by number of fatalities and injuries and amount of property damage and crop damage.

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[52] http://www.usgs.gov/themes/hazards.html

[53] http://www.usgs.gov/themes/hazpics.html

[54] http://pubs.usgs.gov/fs/natural-disasters/index.html

[55] http://wwwneic.cr.usgs.gov

[56] http://eqhazmaps.usgs.gov

[57] http://www.anss.org

[58] http://coastal.er.usgs.gov/coastal-classification/index.html

[59] http://coastal.er.usgs.gov/hurricanes/index.html

[60] http://water.usgs.gov/osw/techniques/floodfreq.html

[61] http://www.msc.fema.gov

[62] http://www.esri.com/hazards/

[63] http://www.nws.noaa.gov/om/hazstats.shtml

Data about natural hazard risks are also provided through private industry sources. The insurance industry is a key source. The Insurance Information Institute (III)[64] and the Insurance Services Office[65] collect and provide data about property claims, although the latter's products are primarily designed to serve insurers. Some private insurers publish hazard incidence and consequence data. Swiss Re produces *sigma*, a publication series which includes annual reports of natural catastrophes and man-made disasters across the world.[66] These reports list the dates, locations, events, casualties, and damage associated with catastrophes. Natural catastrophes are grouped by floods, storms, earthquakes, drought and forest fires, cold and frost, hail, and other.

Data about the frequency and geography of man-made hazards in the United States are also available through public and private sources. The Federal Bureau of Investigation (FBI) collects statistics concerning the reported incidences of crime through the Bureau of Justice Statistics[67] and National Institute of Justice Data Resources[68] programs. Data from these programs are also available at the National Archive of Criminal Justice Data,[69] which is housed by the University of Michigan's Inter-university Consortium for Political and Social Research. These data include incidents by state, by reporting local agency, such as county police departments, and by metropolitan statistical area (MSA).

For some hazards, information is available through reports, rather than data. Chemical accidents are one example. The Chemical Safety Board compiles news reports of chemical incidents throughout the country.[70] Terrorism is another example where information is provided through incident reports. The U.S. Department of State and the FBI both maintain chronologies of significant terrorist incidents. The State Department's *Patterns of Global Terrorism* is available for 1995 through 2002.[71] The FBI series, *Terrorism in the United States*, is available for 1996 through 1999.[72]

3.2 Identification of Potential Mitigation Strategies

3.2.1 Engineering Analysis

Engineering analysis is an essential counterpart to risk assessment and economic evaluation. Engineering analysis helps identify potential mitigation strategies and provides the information used to assess the consequences of the attack scenarios developed in the risk assessment. While engineering analysis is useful in estimating the exposures and vulnerabilities of facilities, it also serves a critical role in the identification of potential mitigation strategies. Engineering analysis is used to: (1) identify risk mitigation measures; (2) evaluate the performance of these strategies under different

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[64] http://www.iii.org

[65] http://www.iso.com

[66] http://www.swissre.com/INTERNET/pwswpspr.nsf/fmBookMarkFrameSet?ReadForm&BM=../vwAllbyIDKeyLu/CMUR-4V8AVQ

[67] http://bjsdata.ojp.usdoj.gov/dataonline/

[68] http://www.ojp.usdoj.gov/nij/dataprog.htm

[69] http://www.icpsr.umich.edu/NACJD/index.html

[70] http://www.csb.gov/CIRC/index.cfm

[71] http://www.state.gov/s/ct/rls/pgtrpt/

[72] http://www.fbi.gov/publications/terror/terroris.htm

scenarios and conditions; and (3) map these approaches to probabilistic damage outcomes.

3.2.2 Software-Based Engineering Analysis

Engineering analysis can be software based. One example of an analysis tool that predicts and simulates damage from airborne contaminants is NIST's CONTAMW[73] software package. CONTAMW captures user-defined building structure characteristics to simulate and model the spatial distribution of airborne contamination over time, based on information about the physical properties of the contaminants and design characteristics of the structure and its subsystems. This analysis tool could be used for the probabilistic assessment of damage under chemical or biological attack scenarios. It was used to model the transport of the anthrax spores in the Hart Senate Office Building in October 2001. It provides important input data for evaluation of risk mitigation measures relating to emergency first responders and building egress.

NIST researchers have also developed the Fire Dynamics Simulator (FDS) and the companion Smokeview software.[74] FDS is a computational fluid dynamics (CFD) model of fire-driven fluid flow, while Smokeview is a visualization program that displays the results of the FDS simulations. Using user-defined data about the building's structure, materials, and contents, FDS simulates the spread of flames, smoke, and heat within the structure.

Several other government and private sector modeling, prediction, and simulation software tools are available. The Department of Defense's Modeling and Simulation Information Analysis Center of the Defense Modeling and Simulation Office has compiled a list of these resources.[75] These software tools perform predictions, simulations, and assessments of consequences, hazards, detection, and environmental impacts. One software cited in the list links setback distance with exterior building materials, explosive characteristics, and structural damage and casualties.[76] The software can be used to determine the tradeoffs between setback distance and wall and window construction materials needed to protect the building or mitigate the damage from a terrorist attack.

There are several additional software tools available that perform damage and risk assessment from various natural and manmade hazards over larger geographic regions. The Consequence Assessment Tool Set with Joint Assessment of Catastrophic Events (CATS-JACE) was developed with support from Defense Threat Reduction Agency (DTRA) and FEMA. This software estimates damage and assesses consequences to population, infrastructure, and resources from a number of incidents. These incidents

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[73] http://www.bfrl.nist.gov/IAQanalysis/CONTAMWdesc.htm

[74] http://fire.nist.gov/fds/

[75] http://www.msiac.dmso.mil/wmd/msres.asp

[76] This software computes the overpressure caused by an explosive device of a given size and type based on the types of materials used to construct the building walls and windows. The overpressure and distance from the blast determine building structural damage and whether people within the building or near the explosion will experience physical harm ranging in severity from aural injury to fatality. Once the user selects the characteristics of the explosive device and the structure, the software computes radii associated with minor, medium, and major levels of damage or injury.

include: chemical/nuclear facility accidents; incidents involving weapons of mass destruction (WMD), such as nuclear, biological, and chemical (NBC) weapons; and high-explosive (HE) blasts. It encompasses natural hazards, such as hurricane, earthquake, and tornadoes, and analysis is not geographically limited to the United States.[77] HPAC is a hazard prediction model for NBC hazards from the destruction of NBC facilities. It provides the capability to predict the effects of releases of hazardous materials into the atmosphere and the impact of these releases on populations using particulate transport models and meteorological data.

Another type of tool is crisis information management software (CIMS). CIMS is designed to augment emergency management agency responses to crisis situations and enhance emergency management planning and mitigation. The National Institute of Justice has published a report that describes the results of testing of ten commercial CIMS products to compare their characteristics and features.[78]

CONTAMW, Smokeview, CATS-JACE, and HPAC simulate the timing, transmission, and consequences of varying hazards. This information is used to identify the needs and identify mitigation strategies to reduce risks to owners, occupants, and users of constructed facilities. To address these hazards and consequences, building owners and managers need to identify combinations of engineering alternatives, management practices, and financial mechanisms. To illustrate, take the hypothetical example of a building owner seeking to reduce the threat from high explosives to an existing property. The building owner would like to protect occupants from injuries and fatalities, reduce damage to the structure, minimize loss of use and contents, and reduce financial losses. While the building owner cannot change the location in the short run, he can achieve these objectives by implementing several less drastic strategies. Table 3-1 lists some of the potential strategies.[79] Varying the combinations of these strategies presents the building owner with numerous possibilities. For example, Combination A could be represented by E2, E3, M2, F3. Combination B may be E1, E2, M5, F1, and F2. Associated with each potential strategy are protective, risk-reducing effects and costs to implement and maintain the measures.

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[77] The CATS-JACE software functions within a commercial GIS software which serves as the operating system for CATS. It is distributed with DTRA’s Hazard Prediction and Assessment Capability (HPAC).

[78] National Institute of Justice. *Crisis Information Management Software (CIMS) Feature Comparison Report*, NCJ 197065, October 2002, Special Report, http://www.ojp.usdoj.gov/nij/pubs-sum/197065.htm.

[79] The list of strategies included in Table 3-1 is not intended to be exhaustive of the potential risk mitigation measures among which a building owner or manager can choose.

Table 3-1 Potential Risk Mitigation Strategies

Mitigation Strategies		
Engineering alternatives	**Management Practices**	**Financial Mechanisms**
E1: Install reinforced concrete columns	**M1**: Perform identification checks at facility access points	**F1**: Purchase business interruption insurance
E2: Install fire sprinkler system	**M2**: Implement random security sweeps	**F2**: Purchase property loss insurance
E3: Replace existing tempered glass with laminated safety glass	**M3**: Relocate parking spaces that are adjacent to building	**F3**: Purchase an option to lease nearby building space
E4: Install fabricated window coverings to reduce explosive fragments	**M4**: Begin quarterly building evacuation and emergency response drills for employees	**F4**: Purchase an option to buy a nearby building
E5: Apply flame retardant coating to building	**M5**: Coordinate communications with local first responders	**F5**: Participate in government cost sharing program
⋮	⋮	⋮

3.3 Economic Evaluation

The final component of a risk mitigation plan is economic evaluation. Economic evaluation is critical to the process of choosing risk mitigation strategies to minimize life-cycle costs (LCC), which include expected losses from terrorist attacks and other hazards. Economic evaluation is used to combine the risk, threat, vulnerability, and consequence assessments with information about mitigation strategies and their costs to determine the most cost-effective combination of strategies to protect constructed facilities.

The economic evaluation takes into account the possibility of interdependence and substitution among different strategies. For example, a building's large setback distance from public roads and garages conveys protection from explosive devices that affects the need for structural measures. For buildings in urban settings with limited setback distances, however, decisions about structural enhancements would be different. The economic evaluation methods are sufficiently flexible to address the possibility that different measures can compensate for situations that are difficult or impractical to change.

Chapters 4 and 5 describe the economic tools which are used to determine the cost-effectiveness of protective measures. These economic tools are the economic evaluation methods and the proposed software tool for implementing these methods. The economic evaluation methods discussed in Chapter 4 have the flexibility to address a variety of financial strategies to mitigate the risk to buildings. These strategies include the purchase of insurance against hazardous events. It also includes the provision of additional financial incentives from government entities or insurance companies. Such incentives may include tax incentives, cost sharing, or reductions in insurance premiums. The proposed software tool is described in Chapter 5.

4 Decision Methodology: Choosing the Most Cost-Effective Risk Mitigation Plan

This chapter describes a methodology for measuring the economic performance of alternative combinations of risk mitigation strategies. The methodology includes several methods of economic evaluation and provides a case illustration of how to use them to choose the most cost-effective risk mitigation plan.

The decision methodology is based on two types of analysis, four methods of economic evaluation, and a cost-accounting framework. The two types of analysis are baseline analysis and sensitivity analysis. They are described in Section 4.1. The four evaluation methods are life-cycle cost, present value of net savings, savings-to-investment ratio, and adjusted internal rate of return. They are described in Section 4.2. The cost-accounting framework is described in Section 4.3.

An economic evaluation may be divided into four stages: (1) identification; (2) classification; (3) quantification; and (4) presentation. The identification stage identifies the investment alternatives to be evaluated. The identification stage involves identifying and listing all of the “effects” of the alternatives being analyzed. In principle, this set of effects produces a checklist of all items that should be taken into consideration. The second stage entails classifying these effects into investment and non-investment cost categories. The third stage produces year-by-year estimates of the values of each of the cost categories. Readers wishing an in-depth discussion of how to identify and classify benefits and costs are referred to Appendix B. Appendix B also includes a “priority setting” procedure for linking classes of benefits and costs to key stakeholder groups. The priority setting procedure is designed to assist the analyst in collecting the type of data needed for the year-by-year estimates. The final stage is the presentation and analysis of the measures of economic performance in a form that clearly details the important assumptions underlying the economic evaluation and the implications of these assumptions for the study’s conclusions.

4.1 Types of Analysis

4.1.1 Baseline Analysis

The starting point for conducting an economic evaluation is to do a baseline analysis. In the baseline analysis, all data elements, and any functional relationships among these elements entering into the calculations, are fixed. For some data, the input values are considered to be known with certainty (e.g., a physical constant or a value that is mandated by legislation). Other data are considered uncertain and their values are based on some measure of central tendency, such as the mean or the median. Baseline data represent a fixed state of analysis. For this reason, the analysis results are referred to as the baseline analysis. Throughout this report, the term baseline analysis is used to denote a complete analysis in all respects but one; it does not address the effects of uncertainty.

4.1.2 Sensitivity Analysis

Sensitivity analysis measures the impact on project outcomes of changing the values of one or more key data elements or input variables about which there is uncertainty. Sensitivity analysis can be performed for any measure of economic performance (e.g., life-cycle cost, present value of net savings, savings-to-investment ratio, adjusted internal rate of return). Since sensitivity analysis is easy to use and understand, it is widely used in the economic evaluation of government and private-sector applications. Office of Management and Budget *Circular A-94* recommends sensitivity analysis to federal agencies as one technique for treating uncertainty in data elements or input variables.[80] Therefore, a sensitivity analysis complements the baseline analysis by evaluating the changes in output measures when selected data or input variables are allowed to vary about their baseline values. Readers interested in a comprehensive survey on methods for dealing with uncertainty for use in government and private-sector applications are referred to the study by Marshall[81] and the subsequent video[82] and workbook.[83]

4.2 Overview of Evaluation Methods

Several methods of economic evaluation are available to measure the economic performance of a new technology, a building, a building system, or like investment, over a specified time period. These methods include, but are not limited to, life-cycle cost, present value of net savings, savings-to-investment ratio, and adjusted internal rate of return. These methods differ in their mathematical formulation and, to some extent, in their applicability to particular types of investment decisions.

To ensure consistency in computation, application, and interpretation, the four methods described in this section are based on ASTM International standard practices.[84] The four "standardized" evaluation methods used in this report are generic. Readers interested in an in-depth survey covering these as well as other methods are referred to Ruegg and Marshall.[85]

Once all costs have been identified and classified, it becomes necessary to develop year-by-year estimates for each of the cost categories for each alternative under analysis. We denote the alternatives as A_j (where the index for j ranges from $0, \ldots, N,$ for a total of $N+1$ alternatives).

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[80] Executive Office of the President. *OMB Circular A-94* (Washington, DC: Office of Management and Budget, 1992).

[81] Marshall, Harold E. *Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Building Investments*. NIST Special Publication 757 (Gaithersburg, MD: National Institute of Standards and Technology, 1988).

[82] Marshall, Harold E. *Uncertainty and Risk—Part II in the Audiovisual Series on Least-Cost Energy Decisions for Buildings* (Gaithersburg, MD: National Institute of Standards and Technology, 1992).

[83] Marshall, Harold E. *Least-Cost Energy Decisions for Buildings—Part II: Uncertainty and Risk Video Training Workbook*. NISTIR 5178 (Gaithersburg, MD: National Institute of Standards and Technology, 1993).

[84] ASTM International. *ASTM Standards on Building Economics*, pp 25-57.

[85] Ruegg, Rosalie T. and Marshall, Harold E.. *Building Economics: Theory and Practice*, (New York: Chapman and Hall, 1990).

Each alternative under consideration meets certain feasibility requirements. First, it must satisfy all of the specified functional requirements. Second, it must not exceed any stated budget constraints. The first requirement insures that all technical criteria (e.g., thermal performance and indoor air quality) and all regulatory constraints (e.g., building codes and standards) are met. The second requirement excludes any proposals which cannot be implemented due to insufficient funds.

Chapter 6 summarizes how alternatives are analyzed and optimally configured subject to budget constraints. The material presented in this chapter assumes that all alternatives are feasible in that they meet the functional requirements and have been screened vis-à-vis any stated budget constraints. Thus, there is no requirement that alternatives be optimally configured, although the evaluation methods presented in this chapter are all applicable to choosing among a set of optimally configured alternatives.

Associated with each alternative are investment cost categories k (where the index k ranges from $1,\dots, K_j$) and non-investment cost categories m (where the index m ranges from $1,\dots, M_j$). The potential for future terrorist attacks, as well as other natural and man-made hazards, are measured by the expected value of annual losses. Associated with each alternative are expected loss categories p (where the index p ranges from $1,\dots, P_j$). Some of the expected loss categories accrue to investment costs and some accrue to non-investment costs. Expected losses are modeled separately from investment costs and non-investment costs to better characterize the nature of low-probability, high-consequence events.[86]

It is important to note that some costs entering the analysis may be negative. For example, the salvage and sale of equipment and components at the end of the study period result in a salvage value whose present value equivalent is subtracted from other investment costs. Similarly, improvements to indoor air quality may result in productivity improvements which favorably impact occupants; these "savings" are subtracted from non-investment costs. Any pure benefits which result (e.g., increased rental income due to improvements) are subtracted from non-investment costs (i.e., benefits are treated as negative costs).

At the heart of the economic evaluation methodology is an economic concept referred to as the time value of money. This concept relates to the changing purchasing power of money as a result of inflation or deflation, along with consideration of the real earning potential of alternative investments over time. The discount rate reflects the decision maker's time value of money. The discount rate is used to convert, via a process known as discounting, costs which occur at different times to a base time. Throughout this report, the term "present value" will be used to denote the value of a cost found by discounting cash flows (present and future) to the base time. The base time is the date (base year) to which costs are converted to time equivalent values.

In order to describe each of the four standardized methods of economic performance—life-cycle cost, present value of net savings, savings-to-investment ratio, and adjusted internal rate of return—we define a series of terms.

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[86] The information needed to perform the expected loss calculations is a byproduct of the risk assessment (see Section 3.1) and the identification of potential mitigation strategies (see Section 3.2).

t = a unit of time;[87]

T = the length of the study period in years;

d = the discount rate expressed as a decimal.

The prefix, *PV*, is used to designate dollar denominated quantities in present value terms. The present value is derived by discounting (i.e., using the discount rate) to adjust all costs—present and future—to the base year (i.e., t=0). The present value terms are: the present value of investment costs (*PVI*), the present value of non-investment costs (*PVC*), and the present value of expected losses (*PVE(L)*). Because *PVE(L)* includes some loss categories which accrue to investment costs and some which accrue to non-investment costs, we denote the present value of investment costs inclusive of losses as *PVI'* and the present value of non-investment costs inclusive of losses as *PVC'*.

The cost terms that make up the mathematical formulations for the four standardized methods are given in Equations (4.1) through (4.6). While there may be many different ways of classifying costs (i.e., classification schemes), their explicit treatment in both the mathematical formulation and the standardized methods ensures that a close coupling results between the mathematical formulation and each standardized method.

The investment costs for alternative A_j in year t are expressed as:

$$I_{jt} = \sum_{k=1}^{K_j} I_{kjt} \tag{4.1}$$

where I_{kjt} = the estimated cost accruing to the k^{th} investment cost category for alternative A_j in year t.

The non-investment costs for alternative A_j in year t are expressed as:

$$C_{jt} = \sum_{m=1}^{M_j} C_{mjt} \tag{4.2}$$

where C_{mjt} = the estimated cost accruing to the m^{th} non-investment cost category for alternative A_j in year t.

The expected losses for alternative A_j in year t may now be expressed as:

$$E\left(L_{jt}\right) = \sum_{p=1}^{P_j} E\left(L_{pjt}\right) \tag{4.3}$$

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[87] Denote the beginning of the study period as the base year (i.e., t=0) and end of the study period as T. Thus, the length of the study period in years is T.

where L_{pjt} = the expected loss accruing to the p^{th} loss category for alternative A_j in year t.

The present value of investment costs for alternative A_j are expressed as:

$$PVI_j = \sum_{t=0}^{T} \left(\sum_{k=1}^{K_j} I_{kjt} \right) / (1+d)^t \tag{4.4}$$

The present value of non-investment costs for alternative A_j are expressed as:

$$PVC_j = \sum_{t=0}^{T} \left(\sum_{m=1}^{M_j} C_{mjt} \right) / (1+d)^t \tag{4.5}$$

The present value of expected losses for alternative A_j are expressed as:

$$PVE\left(L_j\right) = \sum_{t=0}^{T} \left(\sum_{p=1}^{P_j} E\left(L_{pjt}\right) \right) / (1+d)^t \tag{4.6}$$

4.2.1 Life-Cycle Cost Method[88]

The life-cycle cost (LCC) method measures, in present-value or annual-value terms, the sum of all relevant costs associated with owning and operating a constructed facility over a specified period of time. The basic premise of the LCC method is that to an investor or decision maker all costs arising from that investment decision are potentially important to that decision, including future as well as present costs. Applied to constructed facilities, the LCC method encompasses all relevant costs over a designated study period, including the costs of designing, purchasing/leasing, constructing/installing, operating, maintaining, repairing, replacing, and disposing of a particular design or system. Should any pure benefits result (e.g., increased rental income due to improvements), include them in the calculation of LCC.

The LCC method is particularly suitable for determining whether the higher initial cost of a constructed facility or system specification is economically justified by lower future costs (e.g., losses due to natural or manmade hazards) when compared to an alternative with a lower initial cost but higher future costs. If a design or system specification has both a lower initial cost and lower future costs relative to an alternative, an LCC analysis is not needed to show that the former is economically preferable.

The LCC for alternative A_j may now be expressed as:

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[88] For a detailed description of the ASTM life-cycle cost standard, see ASTM International. "Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems," E 917, *Annual Book of ASTM Standards: 2002*. Vol. 04.11. West Conshohocken, PA: ASTM International.

$$LCC_j = \sum_{t=0}^{T} \left(\sum_{k=1}^{K_j} I_{kjt} + \sum_{m=1}^{M_j} C_{mjt} + \sum_{p=1}^{P_j} E\left(L_{pjt}\right) \right) / (1+d)^t \tag{4.7}$$

The LCC for alternative A_j may also be expressed in present value terms as:

$$LCC_j = PVI_j + PVC_j + PVE\ (L_j) \tag{4.8}$$

or, by explicitly including losses in investment costs and non-investment costs, as:

$$LCC_j = PVI'_j + PVC'_j \tag{4.9}$$

Denote the alternative with the lowest initial investment cost (i.e., first cost) as A_0; it is referred to as the base case. Then:

$$I_{00} < I_{j0} \quad \text{for } j = 1, \ldots, N \tag{4.10}$$

The LCC method compares alternative, mutually exclusive, designs or system specifications that satisfy a given functional requirement on the basis of their life-cycle costs to determine which is the least-cost means (i.e., minimizes life-cycle cost) of satisfying that requirement over a specified study period. With respect to the base case, alternative A_j is economically preferred if, and only if, $LCC_j < LCC_0$.

4.2.2 Present Value of Net Savings[89]

The present value of net savings (PVNS) method is reliable, straightforward, and widely applicable for finding the economically efficient choice among investment alternatives. It measures the net savings from investing in a given alternative instead of investing in the foregone opportunity (e.g., some other alternative or the base case).

The PVNS for a given alternative, A_j, vis-à-vis the base case, A_0, may be expressed as:

$$PVNS_{j:0} = LCC_0 - LCC_j \tag{4.11}$$

Any pure benefits that result (e.g., increased rental income due to improvements) are included in the calculation of PVNS, since they are included in the LCC calculation.

With respect to the base case, if $PVNS_{j:0}$ is positive, alternative A_j is economic; if it is zero, the investment is as good as the base case; if it is negative, the investment is uneconomical.

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[89] For a detailed description of the ASTM present value of net savings standard, see ASTM International. "Standard Practice for Measuring Net Benefits for Investments in Buildings and Building Systems," E 1074, *Annual Book of ASTM Standards: 2002*. Vol. 04.11. West Conshohocken, PA: ASTM International.

4.2.3 Savings-to-Investment Ratio[90]

The savings-to-investment ratio (SIR) is a numerical ratio whose size indicates the economic performance of a given alternative instead of investing in the foregone opportunity. The SIR is savings divided by investment costs. The LCC method provides all of the necessary information to calculate the SIR. The SIR for a given alternative, A_j, is calculated vis-à-vis the base case. The numerator and denominator of the SIR are derived through reference to Equation (4.9).

The numerator equals the difference in the present value of non-investment costs inclusive of losses between the base case and the given alternative, A_j. The resultant expression, denoted as present value of savings, is given by:

$$PVS_{j:0} = PVC'_0 - PVC'_j \tag{4.12}$$

The denominator equals the difference in the present value of investment costs inclusive of losses for the given alternative, A_j, and the base case.[91] The resultant expression, denoted as present value of increased investment costs, is given by:

$$PVII_{j:0} = PVI'_j - PVI'_0 \tag{4.13}$$

The SIR for a given alternative, A_j, vis-à-vis the base case may be expressed as:

$$SIR_{j:0} = \frac{PVS_{j:0}}{PVII_{j:0}} \tag{4.14}$$

A ratio less than 1.0 indicates that A_j is an uneconomic investment relative to the base case; a ratio of 1.0 indicates an investment whose benefits or savings just equal its costs; and a ratio greater than 1.0 indicates an economic project. Readers interested in a mathematical derivation of the SIR calculation and how to interpret the calculated value of the SIR for three special cases are referred to Appendix C.

4.2.4 Adjusted Internal Rate of Return[92]

The adjusted internal rate of return (AIRR) is the average annual yield from a project over the study period, taking into account reinvestment of interim receipts. Because the AIRR calculation explicitly includes the reinvestment of all net cash flows, it

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[90] For a detailed description of the ASTM savings-to-investment ratio standard, see ASTM International. "Standard Practice for Measuring Benefit-to-Cost and Savings-to-Investment Ratios for Investments in Buildings and Building Systems," E 964, *Annual Book of ASTM Standards: 2002*. Vol. 04.11. West Conshohocken, PA: ASTM International.

[91] Do not use the savings-to-investment ratio as a decision criterion if $PVI'_j \leq PVI'_0$. See Appendix C for a discussion of this and other topics associated with the calculation of the savings-to-investment ratio.

[92] For a detailed description of the ASTM adjusted internal rate of return standard, see ASTM International. "Standard Practice for Measuring Internal Rate of Return and Adjusted Internal Rate of Return for Investments in Buildings and Building Systems," E 1057, *Annual Book of ASTM Standards: 2002*. Vol. 04.11. West Conshohocken, PA: ASTM International.

is instructive to introduce a new term, terminal value (TV). The terminal value of an investment, A_j, is the future value (i.e., the value at the end of the study period) of reinvested net cash flows excluding all investment costs. The terminal value for an investment, A_j, is denoted as TV_j.

The reinvestment rate in the AIRR calculation is equal to the minimum acceptable rate of return (MARR), which is assumed to equal the discount rate, d, a constant. When the reinvestment rate is made explicit, all investment costs are easily expressible as a time equivalent initial outlay (i.e., a value at the beginning of the study period) and all non-investment cash flows as a time equivalent terminal amount. This allows a straightforward comparison of the amount of money that comes out of the investment (i.e., the terminal value) with the amount of money put into the investment (i.e., the time equivalent initial outlay).

The AIRR is defined as the interest rate, r_j, applied to the terminal value, TV_j, which equates (i.e., discounts) it to the time equivalent value of the initial outlay of investment costs. It is important to note that all investment costs are discounted to a time equivalent initial outlay using the discount rate, d.

Several procedures exist for calculating the AIRR. These procedures are derived and described in detail in the report by Chapman and Fuller.[93] The most convenient procedure for calculating the AIRR is based on its relationship to the SIR. This procedure results in a closed-form solution for a given alternative, A_j, vis-à-vis the base case, $r_{j:0}$. The AIRR is that value of $r_{j:0}$ for which:

$$r_{j:0} = (1+d)(SIR_{j:0})^{\frac{1}{T}} - 1 \tag{4.15}$$

With regard to the base case, if $r_{j:0}$ is greater than the discount rate (also referred to as the hurdle rate), alternative A_j is economic; if $r_{j:0}$ equals the discount rate, the investment is as good as the base case; if $r_{j:0}$ is less than the discount rate, the investment is uneconomical.

4.2.5 Appropriate Application of the Evaluation Methods[94]

The four evaluation methods presented in the previous sections provide the basis for evaluating the economic performance of homeland security-related investments in constructed facilities. The equations underlying the methods presented earlier are all consistent with ASTM standard practices. All of the methods are appropriate for evaluating accept or reject type decisions. But among the methods are several

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[93] Chapman, Robert E. and Fuller, Sieglinde K. *Benefits and Costs of Research: Two Case Studies in Building Technology*. NISTIR 5840 (Gaithersburg, MD: National Institute of Standards and Technology, 1996).

[94] For a comprehensive treatment of how to choose among economic evaluation methods, see the NIST/BFRL video (Marshall, Harold E. *Choosing Economic Evaluation Methods—Part III in the Audiovisual Series on Least-Cost Energy Decisions for Buildings* (Gaithersburg, MD: National Institute of Standards and Technology, 1995).) and workbook (Marshall, Harold E. *Least-Cost Energy Decisions for Buildings—Part III: Choosing Economic Evaluation Methods Video Training Workbook.* NISTIR 5604 (Gaithersburg, MD: National Institute of Standards and Technology, 1995).).

distinctions that relate to the type of investment decision that the decision maker is facing.

Investment decisions associated with alternative building designs or systems are frequently project-related, where a project could be the construction of a new building, the renovation of an existing constructed facility (e.g., a bridge), or the modernization of an existing system (e.g., an HVAC upgrade). For a given project, the decision maker has to choose among a number of competing alternatives, all of which satisfy the same functional requirements. If the project is to upgrade a building's HVAC system and to address a number of generic security concerns, then each of the alternatives being considered will satisfy the functional requirements specified by the building's owner/manager or some other designated decision maker. The four evaluation methods provide the means for identifying which alternative is the most cost-effective choice for implementing the project. At a higher level of aggregation, construction-related investment decisions often involve collections of projects. This section summarizes both the types of investment decisions and the applicability of the evaluation methods to these decision types.

There are four basic types of investment decisions for which an economic analysis is appropriate:

(1) whether to accept or reject a given alternative/project;

(2) the most efficient alternative/project size/level, system, or design;

(3) the optimal combination of interdependent projects (i.e., the right mix of sizes/levels, systems, and designs for a group of interdependent projects); and

(4) how to prioritize or rank independent projects when the available budget cannot fund them all.

Each type of investment decision is important. First and foremost, decision makers need to know whether or not a particular alternative/project or program should be undertaken in the first place. Second, how should a particular project/program be configured? The third type of decision builds on the second and introduces an important concept, interdependence. Consequently, for a given set of candidate projects and implied interdependencies, the problem becomes how to choose that combination of projects that minimizes LCC (or equivalently maximizes PVNS). The fourth type of decision introduces a budget constraint. The aim is how to get the most impact for the given budget.

Table 4-1 provides a summary of when it is appropriate to use each of the evaluation methods described earlier. Note that the LCC and PVNS methods are appropriate in three of the four cases. Only in the presence of a budget constraint is the use of either LCC or PVNS inappropriate and even in that case it plays an important role in computing the aggregate measure of performance.

In summary, no single evaluation method works for every decision type. First and foremost, managers want to know if a particular project is economic. Reference to Table 4-1 shows that all of the evaluation methods address this type of decision. Second, as issues of design, sizing, and packaging combinations of projects become the focus of attention—as often occurs in conjunction with budget reviews—the LCC and PVNS methods emerge as the principle means for evaluating a project's or program's merits.[95] Finally, the tightening budget picture involves setting priorities. Consequently, decision makers need both measures of magnitude, provided by LCC and PVNS, and of return, provided by either the SIR or the AIRR, to assess economic performance. Multiple measures, when used appropriately, ensure consistency in both setting priorities and selecting projects for funding.

Table 4-1 Summary of Appropriateness of Each Standardized Evaluation Method for Each Decision Type

Decision Type	*LCC*	*PVNS*	*SIR*	*AIRR*
Accept/Reject	Yes	Yes	Yes	Yes
Design/Size	Yes	Yes	No	No
Combination (Interdependent)	Yes	Yes	No	No
Priority/Ranking (Independent)	No	No	Yes	Yes

Source: "Standard Guide for Selecting Economic Methods for Evaluating Investments in Buildings and Building Systems." E1185. ASTM International, 2002.

4.2.6 Applying the Evaluation Methods: A Case Study

The data center case study presented in this section illustrates how to apply the evaluation methods for a prototypical commercial building.[96] It is based on an actual building renovation project. However, for purposes of confidentiality, a number of key building features have been changed. The case study, as in the actual building renovation project, focuses exclusively on two of the three mitigation strategies—engineering alternatives and management practices—for protection against terrorism.

The data center undergoing renovation is a single-story structure located in a suburban community. The renovation has been planned for some time to upgrade the data center's HVAC, telecommunications and data processing systems and to address a number of generic security concerns. Specific risks evaluated in the case study are associated with the vulnerability of information technology resources, and the potential for damage to the facility and its contents from chemical, biological, radiological, and explosive (CBRE) hazards.

The site upon which the data center is located is traversed by a thoroughfare that has been used by local residents since the data center was constructed. Alternative routes are available and convenient to local residents, subject to a short detour. Plans have been made by the community to put in a new street which better links the affected

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[95] If incremental values of the SIR or AIRR are computed, they can be used to make design/size and packaging decisions. See Ruegg and Marshall, *Building Economics*, pp. 54-58 and 85-87.

[96] For an in-depth description of the data center case study, see Chapman, *Applications of Life-Cycle Cost Analysis to Homeland Security Issues in Constructed Facilities,* pp. 21-68.

neighborhoods and does not traverse the data center's site. The new street will be available for use within two years of the renovation.

Senior management is considering two alternative renovation strategies. The basic renovation has an initial investment cost of $1 100 000 ($1 100K); it is designated as the Base Case. The enhanced renovation has an initial investment cost of $1 750K; it is designated as the Proposed Alternative. The renovation strategy that results in the lowest life-cycle cost will be the recommended alternative for use in the risk mitigation plan.

Two types of analyses are employed to evaluate the merits of the Proposed Alternative vis-à-vis the Base Case. First, a baseline analysis is performed in which all values are fixed. Second, a sensitivity analysis based on Monte Carlo simulation is performed in which 21 key input variables are allowed to vary in combination according to an experimental design. These analysis types complement and reinforce each other.

The case study covers a 25-year period beginning in 2003. Life-cycle costs are calculated using a 4 % real discount rate for the baseline analysis. In the sensitivity analysis, the discount rate varies from 0 % to 8 %. Information on cost items is needed in order to calculate life-cycle costs. Cost items are classified under two broad headings: (1) input costs and (2) event-related costs.

Input costs represent all costs tied to the building or facility under analysis that are not associated with an event. Input costs include the initial capital investment outlays for facilities and site work, future costs for electricity for lighting and space heating and cooling, future renovations, and any salvage value for plant and equipment remaining at the end of the study period. Input costs are classified as either investment costs or non-investment costs; they are represented mathematically by Equations (4.1) and (4.2).

Input costs serve to differentiate the Base Case and the Proposed Alternative. The life-cycle cost method (ASTM E 917) defines the base case as the alternative with the lowest initial capital investment cost. The additional costs of the "enhanced" renovation result not only in expected reductions in event-related costs, they also reduce the annual costs for electricity and telecommunications services and increase staff productivity due to improved indoor air quality. Finally, the change in the traffic pattern resulting from the enhanced renovation generates an increase in commuting costs for local residents until a new road is opened in two years.

Event-related costs are based on annual outcomes, each of which has a specified probability of occurrence. Each outcome has a non-negative number of cost items associated with it (i.e., an outcome may have no cost items associated with it if it results in zero costs). In this case study, we model the risks associated with cyber attacks and CBRE attacks exclusively. The event modeling methodology, however, can also be used to model multiple hazards, such as those associated with earthquakes, high winds, or an accident resulting in widespread damage due to fire or chemical spills.

Annual probabilities for the outcomes associated with each attack scenario are postulated along with associated outcome costs. The annual probabilities and outcome costs differ by renovation strategy. However, both the Base Case and the Proposed Alternative have similar types of outcome costs. Should a cyber attack occur, it results in damage to financial records and identity theft for a small set of corporate customers. Should a CBRE attack occur, it results in several non-fatal injuries, physical damage to the data center, interruption of business services at the data center, and denial of service to corporate customers during recovery. Event-related costs are represented mathematically by Equation (4.3).

Exhibit 4-1 summarizes the key findings from the baseline analysis. It provides a brief description of each renovation strategy and covers the background, approach, and results of the economic evaluation. Exhibit 4-1 is based on the summary format described in ASTM Standard Guide E 2204.[97] The material presented in Exhibit 4-1 provides a concise statement of why the Proposed Alternative is the "preferred" choice and documents the reasons for its selection.

The life-cycle cost figures presented in Section 3.a of Exhibit 4-1 enable us to calculate several additional economic measures that taken together provide useful information to decision makers. First, the difference between the life-cycle cost of the Base Case and the Proposed Alternative equals the present value of net savings (PVNS) resulting from choosing the Proposed Alternative. For the baseline analysis, the PVNS of the Proposed Alternative amounts to \$682K. Second, the way in which the Budget Category cost items are defined enables us to calculate both the savings-to-investment ratio (SIR) and the adjusted internal rate of return (AIRR). The SIR equals the difference in non-investment costs—the savings stemming from the use of the Proposed Alternative rather than the Base Case—divided by the increased capital investment cost for the Proposed Alternative. Reference to Section 3.a of Exhibit 4-1 shows that the increased capital cost of the Proposed Alternative of \$604K results in savings of \$1 286K. These figures translate into an SIR of 2.13 (i.e., every dollar invested in the Proposed Alternative is expected to generate \$2.13 in cost savings). Using the computed value of the SIR, we can calculate the AIRR. In this case, the AIRR over the 25-year study period is 7.2 %, which exceeds the hurdle rate of 4 %. Finally, the use of multiple economic measures provides alternative views of the same decision process. Specifically, PVNS provides a measure of magnitude, whereas the SIR is a multiplier, and the AIRR is an annual rate of return.

Exhibit 4-1 provides a compact summary of the results of the baseline analysis. Although the baseline analysis guides the formulation of the risk mitigation plan, it does not address the implications of uncertainty in the values of the key input variables. A sensitivity analysis augments the baseline analysis by providing the decision maker with additional background and perspective. The sensitivity analysis uses the same data and assumptions as the baseline analysis for its starting point. The objective of the sensitivity analysis is to evaluate how uncertainty in the values of 21 input variables translates into changes in each of five key economic measures. The five economic measures evaluated in the sensitivity analysis are: (1) the life-cycle costs of the Base Case (LCC_{BC}); (2) the life-cycle costs of the Proposed Alternative (LCC_{Alt}); (3) the present value of net savings (PVNS) resulting from the Proposed Alternative; (4) the savings-to-investment ratio (SIR) produced by the additional capital investment in the Proposed Alternative; and (5) the adjusted internal rate of return (AIRR) on the additional capital investments associated with the Proposed Alternative. The calculation of each economic measure is based on a "sample of 1,000 observations" produced by the Monte Carlo simulation.

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[97] ASTM International. "Standard Guide for Summarizing the Economic Impacts of Building Related Projects," E2204, *Annual Book of ASTM Standards: 2002*. Vol. 4-12. West Conshohocken, PA: ASTM International.

Exhibit 4-1 Summary of the Data Center Case Study

1.a Significance of the Project:

The data center undergoing renovation is a single-story structure located in a suburban community. The floor area of the data center is 3 716 m^2 (40 000 ft^2). The replacement value of the data center is $20 million for the structure plus its contents. The data center contains financial records that are in constant use by the firm and its customers. Thus, any interruption of service will result in both lost revenues to the firm and potential financial hardship for the firm's customers. The occupants of the data center are part of the same parent company, but not part of the same corporate division responsible for facilities construction and renovation.

The building owners employ two different renovation strategies. The first, referred to as the Base Case, employs upgrades which are consistent with pre-9/11 levels of security. Thus, the Base Case represents maintenance of the *status quo*. The second, referred to as the Proposed Alternative, recognizes that in the post-9/11 environment the data center faces heightened risks in two areas. These risks are associated with the vulnerability of information technology resources and the potential for damage to the facility and its contents from chemical, biological, radiological, and explosive (CBRE) hazards. Two scenarios—the potential for a cyber attack and the potential for a CBRE attack—are used to capture these risks.

1.b Key Points:

1. The objective of the renovation project is to provide cost-effective operations and security protection for the data center.
2. The renovation has been planned for some time to upgrade the data center's HVAC, telecommunications and data processing systems and to address a number of generic security concerns.
3. Two upgrade alternatives are proposed:
   - Base Case (Basic Renovation) and
   - Proposed Alternative (Enhanced Renovation), which augments the Base Case by strengthening portions of the exterior envelope, limiting vehicle access to the data center site, significantly improving the building's HVAC, data processing and telecommunications systems, and providing better linkage of security personnel to the telecommunications network.

2. Analysis Strategy: How Key Measures are Estimated

The following economic measures are calculated as present-value (PV) amounts:

(1) **Life-Cycle Costs** (LCC) for the Base Case (Basic Renovation) and for the Proposed Alternative (Enhanced Renovation), including all costs of acquiring and operating the data center over the length of the study period. The selection criterion is lowest LCC.

(2) **Present Value Net Savings** (PVNS) that will result from selecting the lowest-LCC alternative. PVNS > 0 indicates an economically worthwhile project.

Additional measures:

(1) **Savings-to-Investment Ratio** (SIR), the ratio of savings from the lowest-LCC to the extra investment required to implement it. A ratio of SIR >1 indicates an economically worthwhile project.

(2) **Adjusted Internal Rate of Return** (AIRR), the annual return on investment over the study period. An AIRR > discount or hurdle rate indicates an economically worthwhile project.

Data and Assumptions:

- The Base Date is 2003.
- The alternative with the lower first cost (Basic Renovation) is designated the Base Case.
- The study period is 25 years and ends in 2027.
- The discount or hurdle rate is 4.0 % real.
- Annual probabilities for the outcomes for each attack scenario are given along with outcome costs.
- Annual probabilities and outcome costs differ by renovation strategy.
- Both the Base Case and the Proposed Alternative have similar types of outcome costs. Should a cyber attack occur, it results in damage to financial records and identity theft for a small set of corporate customers. Should a CBRE attack occur, it results in several non-fatal injuries, physical damage to the data center, interruption of business services at the data center, and denial of service to corporate customers during recovery.

Exhibit 4-1 Summary of the Data Center Case Study (Cont.)

3.a Calculation of Savings, Costs, and Additional Measures

Savings and Costs in Thousands of Dollars ($K)

PV of Investment Costs	**Base Case**	**Proposed Alt.**
Capital Investment	$1 168K	$1 772K

Increased Total PV Investment for Proposed Alt. $604K

PV of Non-Investment Costs	**Base Case**	**Proposed Alt.**
O&M Costs	4 082K	3 201K
Other Costs	687K	282K
	$4 769K	$3 483K

PV of Non-Investment Savings for Proposed Alt. $1 286K

LCC	**Base Case**	**Proposed Alt.**
PV of Investment Costs	1 168K	1 772K
PV of Non-Investment Costs	4 769K	3 483K
	$5 937K	$5 255K

PVNS from Proposed Alternative $682K

Savings-to-Investment Ratio (SIR)

PV of Non-Investment Savings	$1 286K
Divided by PV of Incr. Investment	604K

SIR = 2.13

Adjusted Internal Rate of Return (AIRR)

$(1+0.04)\ 2.13^{1/25} - 1 = 0.072$

AIRR = 7.2 %

which exceeds the hurdle rate of 4.0 %

3.b Key Results:

- **LCC**
  - Base Case $5 937K
  - Proposed Alt. $5 255K
- **PVNS from Alt.** $682K
- **SIR** 2.13
- **AIRR** 7.2 %

3.c Traceability:

Life-cycle costs and supplementary measures were calculated according to ASTM standards E 917, E 964, E 1057, and E 1074.

Variations in the values of the 21 variables translate into the value of each outcome (e.g., the SIR) in such a manner that the impacts of uncertainty can be measured quantitatively.[98] Three of the 21 variables apply to both the Base Case and the Proposed

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[98] Readers wishing greater detail on the sensitivity analysis are referred to the companion document, NISTIR 7025. The companion document provides detailed information on each of the 21 input variables evaluated in the sensitivity analysis, including their "best" case and "worst" case settings and how the probability distribution for each variable was specified. Among the key variables included in the sensitivity analysis were the discount rate, the probability and severity of an attack, the costs of the basic and enhanced renovations, the costs of business interruption should an attack occur, and the damages to the data center associated with an attack. Special attention was given to the event-related costs and their drivers (e.g., the probability and severity of an attack) because greater uncertainty is associated with their values than for input costs (e.g., renovation costs). The companion document includes a deterministic sensitivity analysis as well as the Monte Carlo simulation presented in this report. The deterministic sensitivity analysis was used to identify those variables having the greatest impact on life-cycle costs. This was accomplished by varying each input variable singly while holding all other input variables at their baseline values. The variables having the greatest impact on life-cycle costs were the discount rate,

Alternative. Eight of the variables apply to the Base Case. The 10 remaining variables apply to the Proposed Alternative.

The results of Monte Carlo simulation are presented in both tabular and graphical formats. The tabular format—Table 4-2—records information on each of the five economic measures; it reports a variety of computed statistics for each economic measure. Figure 4-1 records the distribution of the observed values for the life-cycle costs of the Base Case and the Proposed Alternative side-by-side as an indication of the degree to which the Proposed Alternative is preferred to the Base Case.

The statistical measure and its corresponding value are recorded under the heading Statistical Measure in Table 4-2. Seven statistical measures are reported to characterize the results of each Monte Carlo simulation. The calculation of these statistical measures is based on a "sample of 1 000 observations" produced by the Monte Carlo simulation. These statistical measures are: (1) the minimum; (2) the 25th percentile, denoted by 25%; (3) the 50th percentile (i.e., the median), denoted by 50%; (4) the 75th percentile, denoted by 75%; (5) the maximum; (6) the mean; and (7) the standard deviation. The minimum and the maximum define the range of values for the results of the Monte Carlo simulation. The 50th percentile and the mean are measures of central tendency. The 25th and 75th percentiles define the interquartile range, a range that includes the middle 50 percent of the observations. The interquartile range is also a crude measure of central tendency. The standard deviation measures the variability of the results of the Monte Carlo simulation. The values reported for LCC_{BC}, LCC_{Alt}, and PVNS are all in thousands of 2003 dollars.

Table 4-2 Summary Statistics Due to Changes in All of the Variables

Economic Measure	**Statistical Measure**						
	Minimum	**25 %**	**50 %**	**75 %**	**Maximum**	**Mean**	**Standard Deviation**
LCC_{BC}	4 344.264	5 090.509	6 007.620	7 196.295	9 022.518	6 216.082	1 300.610
LCC_{Alt}	4 012.033	4 648.762	5 319.521	6 157.292	7 428.776	5 450.631	925.923
PVNS	45.546	438.144	707.783	1 049.742	1 884.364	765.451	396.182
SIR	1.055	1.718	2.196	2.864	6.144	2.357	0.827
AIRR	0.042	0.063	0.073	0.085	0.118	0.074	0.014

Table 4-2 summarizes the results of the Monte Carlo simulation. A close examination of Table 4-2 reveals several interesting outcomes. First, the range of values—the difference between the minimum and maximum—is very wide. For example, the minimum value of life-cycle costs for the Base Case (LCC_{BC}) is approximately $4.3 million, whereas the maximum is approximately $9.0 million. Life-cycle costs for the Proposed Alternative (LCC_{Alt}) range from slightly more than $4.0 million to almost $7.5 million. Second, the computed value of the mean equals or exceeds the computed value of the median for each of the economic measures. This is because a small number of very large observations are pulling up the computed value of the mean. Finally, the computed values of the mean of each of the five economic

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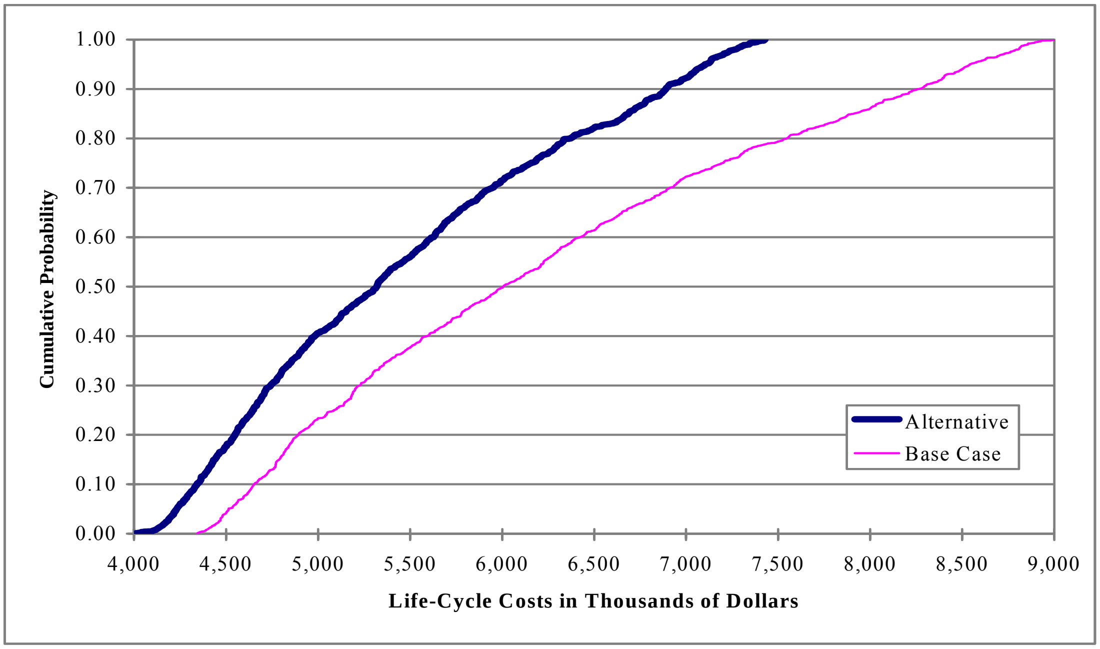
renovation costs, and the probability and severity of an attack. See Chapman, *Applications of Life-Cycle Cost Analysis to Homeland Security Issues in Constructed Facilities,* pp. 41-68.

measures are higher than the corresponding baseline value. This is due to a small number of very large observations.

Life-cycle cost results of the sensitivity analysis are shown graphically in Figure 4-1. The life-cycle costs of the Base Case are compared to those of the Proposed Alternative, LCC_{Alt}. The results of the Monte Carlo simulation produced 1 000 observations of LCC_{BC} and 1 000 observations of LCC_{Alt}. These observations were used to produce the two traces shown in Figure 4-1. The figure was constructed by first sorting the values of LCC_{BC} and LCC_{Alt} from smallest to largest. The resultant cumulative distribution function was then plotted. The vertical axis records the probability that the economic measure—LCC_{BC} or LCC_{Alt}—is less than or equal to a specified value. The values recorded on the horizontal axis cover the range of values encountered during the Monte Carlo simulation.

Figure 4-1 Life-Cycle Costs for Each Alternative in Thousands of Dollars Due to Changes in All of the Variables



In analyzing Figure 4-1, it is useful to keep in mind that the values of LCC_{BC} and LCC_{Alt} from the baseline analysis were \$5 937K and \$5 255K, respectively. Comparisons between Figure 4-1 and Table 4-2 are also helpful in interpreting the results of the Monte Carlo simulation. First, notice that the life-cycle cost trace of the Proposed Alternative in Figure 4-1 always remains to the left of the life-cycle cost trace of the Base Case. Thus, for any given probability (e.g., 0.40), the life-cycle cost of the Proposed Alternative (\$5 000K) is less than the life-cycle cost of the Base Case (\$5 600K). Similarly, for any given life-cycle cost (e.g., \$5 000K), the probability of being less than or equal to that cost is higher for the Proposed Alternative (0.40) than for the Base Case (0.23). Second, the horizontal distance between the Proposed Alternative and the Base Case gets larger as the cumulative probability moves from 0.00 to 1.00. This translates into a wider range of life-cycle costs for the Base Case (i.e., maximum minus minimum);

it is reflected in the higher standard deviation for the Base Case recorded in the last column of Table 4-2. Figure 4-1 clearly demonstrates that the Proposed Alternative is the most cost-effective renovation strategy.

Both the baseline and sensitivity analyses demonstrate that the Proposed Alternative results in lower life-cycle costs and is hence the more cost-effective choice. The additional economic measures shown in Exhibit 4-1 and Table 4-2 underscore the superior performance of the Proposed Alternative.

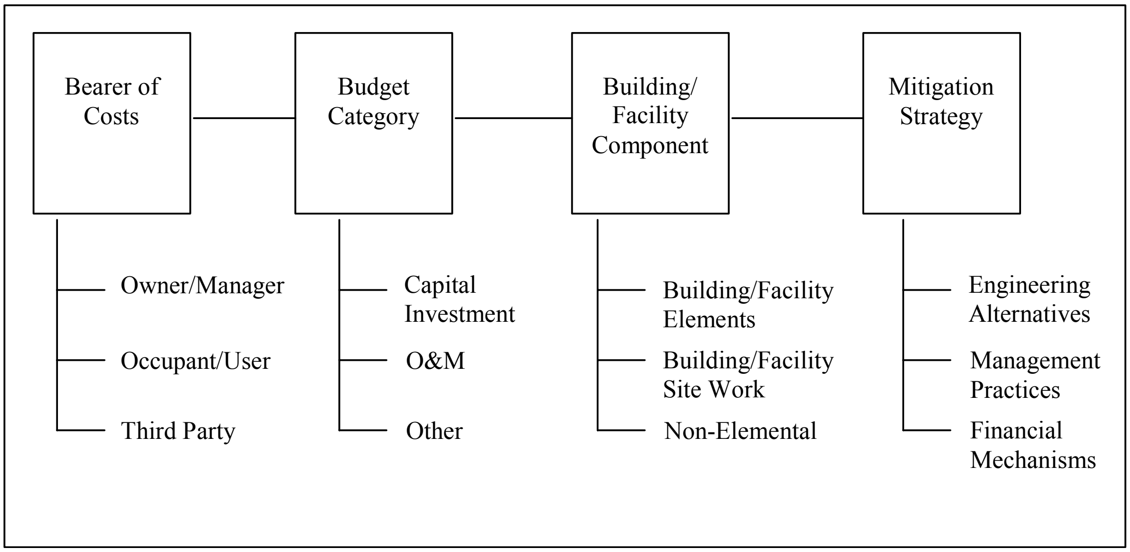
4.3 The Need for a Detailed Cost-Accounting Framework

The cost categories defined in Equations (4.1) through (4.6) provide the basis for calculating life-cycle costs. The flexibility of the life-cycle cost method, however, enables us to go beyond the generic cost categories represented in these equations. The result is a more focused representation of costs, referred to as the detailed cost-accounting framework. The objective of producing this framework is to promote better decision making by identifying unambiguously who bears which costs, how costs are allocated among several widely-accepted budget categories, how costs are allocated among key building components, and how costs are allocated among the three mitigation strategies. A detailed cost-accounting framework is needed because costs affect stakeholders in different ways. Thus, knowing who bears which costs leads to a better understanding of stakeholder perspectives and helps create mutually beneficial solutions. Finally, the cost-accounting framework promotes a detailed, consistent breakdown of life-cycle costs so that a clear picture emerges of the cost differences between competing alternatives.

The description of the cost-accounting framework given here employs a project-oriented approach. Such an approach is instructive since most construction activity is summarized on a project basis. This approach also helps to link the methodology to the software product. A project could be the construction of a new building, industrial facility, or infrastructure. A project could also be the renovation of an existing constructed facility.

Costs are classified along four dimensions within the detailed cost-accounting framework: (1) bearer of costs; (2) budget category; (3) building/facility component; and (4) mitigation strategy. To differentiate these costs from the generic cost categories, they are referred to as cost types and cost items. Each dimension contains a collection of cost types. The cost types are used as placeholders for summarizing and reporting aggregated cost information. Each cost type is a collection of cost items. Each cost item has a unique set of identifiers that places it within the cost-accounting framework. Each dimension captures the full spectrum of costs (i.e., all costs summed across each dimension add up to the same total). A schematic representation of the cost-accounting framework is given in Figure 4-2. Within Figure 4-2, each of the four dimensions of costs is listed within a box. Beneath each box are listed the cost types associated with that cost dimension.

Figure 4-2 Overview of the Cost-Accounting Framework: Dimensions and Cost Types



The first dimension, Bearer of Costs, covers all stakeholder groups. A stakeholder group is defined as any collection of organizations or individuals directly affected by the project (e.g., by construction or risk mitigation activities or by disaster-related losses). The first dimension, Bearer of Costs, has three cost types based on who bears the costs. The three cost types are: (1) Owner/Manager; (2) Occupant/User; and (3) Third Party. Owner/Manager costs are all costs incurred by the project's owner or agent. These costs include but are not limited to design costs, capital investment costs, and selected types of repairs to the constructed facility. Occupant/User costs accrue to the direct users of the project. Occupant/User costs frequently include operations and maintenance costs and selected types of repairs not covered by the project's owner or agent. Occupant/User costs can also include delay costs and business interruption costs due to temporary closures for repair and reconstruction activities. Third-Party costs are all costs incurred by entities who are neither the project's owner or agent nor direct users of the project. One example of a Third-Party cost is the lost sales for a business establishment whose customer access has been impeded (e.g., due to a road closure during construction/reconstruction). Another example is damage to the environment from a construction process that pollutes the water, land, or atmosphere.

The second dimension, Budget Category, has three cost types based on which category of the budget the funds come from. These cost types are: (1) Capital Investment; (2) O&M (Operations and Maintenance); and (3) Other. These cost types correspond to widely used budget categories for private and public sector cost accounting. It is important to note that the dollar amounts accruing to all three cost types are inclusive of any expected losses. In the context of the previous section, Capital Investment costs accrue to the investment cost category and O&M and Other costs accrue to the non-investment cost category. NIST Handbook 135 is especially helpful in determining how to allocate cost items among Capital Investment and O&M.[99] All acquisition costs, including costs related to planning, design, purchase, and construction, are investment-related costs and fall under the Capital Investment cost type. Residual values (resale, salvage, or disposal costs) and capital replacement costs are also investment-related costs. Capital replacement costs are usually incurred when replacing major systems or components and are paid from capital funds. Cost items falling under the O&M cost type include energy and water costs, maintenance and repair costs, minor replacements related to maintenance and repair, and insurance premiums paid by owners and/or occupants to reduce their risk exposure. O&M costs are usually paid from an annual operating budget, not from capital funds. Other costs are non-capital costs that cannot be attributed to the O&M cost type. An example of an Other/Third-Party cost is damage to the environment stemming from the project.

The third dimension, Building/Facility Component, has three cost types. These cost types are: (1) Building/Facility Elements; (2) Building/Facility Site work; and (3) Non-Elemental. The first two cost types are associated with the elemental classification UNIFORMAT II.[100] Elements are an integral part of any construction project; they are often referred to as component systems or assemblies. Each element performs a given function regardless of the materials used, design specified, or method of construction employed. Non-Elemental costs are all costs that cannot be attributed to specific functional elements of the project. An example of a Non-Elemental/Capital/Owner cost is the purchase of a right-of-way, or easement.

The fourth dimension, Mitigation Strategy, has three cost types. The three cost types correspond to the three risk mitigation strategies described in Chapter 2; they are: (1) Engineering Alternatives; (2) Management Practices; and (3) Financial Mechanisms. Chapter 2 provides an in-depth discussion of the three mitigation strategies, as well as examples of generic cost items falling under each of the three mitigation strategies. Examples of specific cost items employed in the case study are: (1) capital costs associated with either the basic or enhanced renovation, which are allocated to Engineering Alternatives, and (2) increases in commuting costs for local residents due to the change in the traffic pattern resulting from the Proposed Alternative, which are allocated to Management Practices.

The previous discussion serves to highlight some of the differences in perspective between public sector and private sector decision makers. A private sector decision maker may not be concerned with costs that are external to their firm. This perspective has a significant impact on what is included and what is excluded in the Third Party and Other cost types. Generally, this is in contrast to the public sector decision maker who must assess all costs to whomsoever they accrue. In the case of homeland security activities, however, the private sector perspective is often more in line with the public sector's perspective. Natural hazards, industrial accidents, and terrorist acts that occur infrequently, but whose consequences are devastating, highlight the importance of

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[99] Fuller, Sieglinde K., and Petersen, Stephen R. *Life-Cycle Costing Manual for the Federal Energy Management Program*. NIST Handbook 135 (Gaithersburg, MD: National Institute of Standards and Technology, 1996).

[100] ASTM International. "Standard Classification for Building Elements and Related Site Work—UNIFORMAT II," E 1557, *Annual Book of ASTM Standards: 2002*. Vol. 04.11. West Conshohocken, PA: ASTM International.

including Third Party and Other cost types in the private sector's life-cycle cost calculus. Including these costs also helps to identify areas for public policy analysis (e.g., the role of financial incentives), bringing private sector and public sector perspectives into closer alignment.

The case study introduced earlier employs the cost accounting framework to demonstrate how it promotes better decision-making. The cost-accounting framework, as employed in the case study, illustrates how costs affect stakeholders in different ways. This leads to a better understanding of stakeholder perspectives and helps create mutually beneficial solutions. Finally, the cost-accounting framework promotes a detailed, consistent breakdown of life-cycle costs so that a clear picture emerges of the cost differences between competing alternatives.

Table 4-3 summarizes the results of the baseline analysis for the Base Case and the Proposed Alternative. All costs reported in Table 4-3 are life-cycle costs. Since Table 4-3 includes all input and event-related costs, it represents a complete picture of the baseline analysis.

The Life-Cycle Cost for the Base Case of \$5 937 608 equals the sum of the cost items listed under each Cost Classification (i.e., \$5 937 608 = \$3 297 962 + \$1 971 941 + \$667 705 = \$1 168 484 + \$4 081 892 + \$687 233 = \$2 826 402 + \$155 626 + \$2 955 581 = \$3 873 520 + \$2 064 088). ***Thus, whether we look at costs from the Bearer perspective, from the Budget Category perspective, by Component, or by Mitigation Strategy, all costs are included and classified accordingly.***

Life-cycle costs for the Proposed Alternative are calculated in exactly the same manner as for the Base Case. The Life-Cycle Cost for the Proposed Alternative is \$5 254 903. Note that this cost is less than the Life-Cycle Cost of the Base Case. This is because the Proposed Alternative includes a number of features that produce future cost savings. These cost savings partially offset the increased Capital Investment costs for the Proposed Alternative. As a general rule, whenever the potential for a spillover benefit exists (e.g., improved indoor air quality), consider incorporating it into the risk mitigation plan ***and*** evaluating its impact on life-cycle cost.

Reference to Table 4-3 demonstrates that the Proposed Alternative is the most cost-effective choice, since it results in the lowest life-cycle cost (i.e., \$5 254 903 versus \$5 937 608). Table 4-3 also provides a concise snapshot of how the Base Case and the Proposed Alternative affect different stakeholder groups. Note that Occupant/User and Third Party costs are higher for the Base Case, whereas Owner/Manager costs are higher for the Proposed Alternative. Understanding who bears which costs is an essential component of the risk mitigation plan. In this case, two of the sets of "Bearer" costs (Owner/Manager and Occupant/User) are borne by the same "parent company." If one were to "drill down" on Third Party costs, we would find that the bulk of these costs are borne by the data center's customers. Thus, as we exploit information from the cost accounting framework, additional strengths of the Proposed Alternative emerge.

This chapter presents a decision methodology which enables the reader to conduct a comprehensive economic evaluation of alternative risk mitigation plans. Chapter 5 describes a proposed software product designed specifically to implement the decision methodology.

Table 4-3 Summary of Life-Cycle Costs for the Data Center Case Study

Cost Classification	Decision Criterion/ Cost Type	Base Case (in $)	Proposed Alternative (in $)
	Life-Cycle Cost	5 937 608	5 254 903
Bearer:	Owner/Manager	3 297 962	3 472 413
	Occupant/User	1 971 941	1 505 989
	Third Party	667 705	276 501
Category:	Capital Investment	1 168 484	1 771 858
	O&M	4 081 892	3 200 685
	Other	687 233	282 359
Component:	Building/Facility Elements	2 826 402	3 028 991
	Building/Facility Site Work	155 626	246 355
	Non-Elemental	2 955 581	1 979 557
Strategy:	Engineering Alternatives	3 873 520	3 509 327
	Management Practices	2 064 088	1 745 576
	Financial Mechanisms	0	0

5 Proposed Software Product for Implementing the Decision Methodology

The proposed software product, being developed by the Office of Applied Economics (OAE), is designed to implement the decision methodology described in Chapter 4. The software product supports the fourth stage of the economic evaluation—the presentation and analysis of the measures of economic performance in a form that clearly details the important assumptions underlying the economic evaluation and the implications of these assumptions for the study's conclusions. The software product will provide decision support to building owners and managers who would like to protect their facilities and occupants in a cost-effective manner. It will allow building owners and managers to make comparisons among several alternative risk mitigation measures under different user-defined disaster scenarios.

The user-friendly software will systematically prompt the user to enter information about the costs and timing of implementing protective measures, with the costs disaggregated by Bearer, Budget Category, Building Component, and Mitigation Strategy. Embedded in the software will be the decision rules, which will take into account the life-cycle costs, the cost implications of the different alternatives, and any relevant financial incentives of the alternatives.

The economic evaluation of the alternative risk mitigation strategies will also depend on the probabilities that the user assigns to the various event outcomes. The software will allow the user to enter parameters for hazards and risk, including the probability of occurrence, and the type and magnitude of damage and losses.

The software product has two analysis options: (1) baseline analysis and (2) sensitivity analysis. These analysis options link directly to four key features of the software product. These features are concerned with: (1) the cost-accounting framework; (2) the "Cost Summary" window of the software product; (3) selected data inputs; and (4) selected output reports. These features are described in Section 5.1 through 5.4.

The finalized version of the proposed software product (version 2.0) is scheduled for public release in March 2006. Prior to the release of version 2.0 in March 2006, OAE will make available for public release a beta version (September 2004) and version 1.0 (March 2005) of the software product. Readers interested in obtaining the software are encouraged to visit the OAE cost-effectiveness tool (CET) status line at http://www.bfrl.nist.gov/oae/software/cet.html. The status line will provide up-to-date information on the software development effort and instructions for downloading the software. Readers who download and use the software are encouraged to contact OAE with comments. Additional information on the features associated with each public release—the beta version, version 1.0, and version 2.0—is presented in Section 5.5, where the software's analysis features are linked to its rollout schedule.

5.1 How the Software Links to the Cost-Accounting Framework

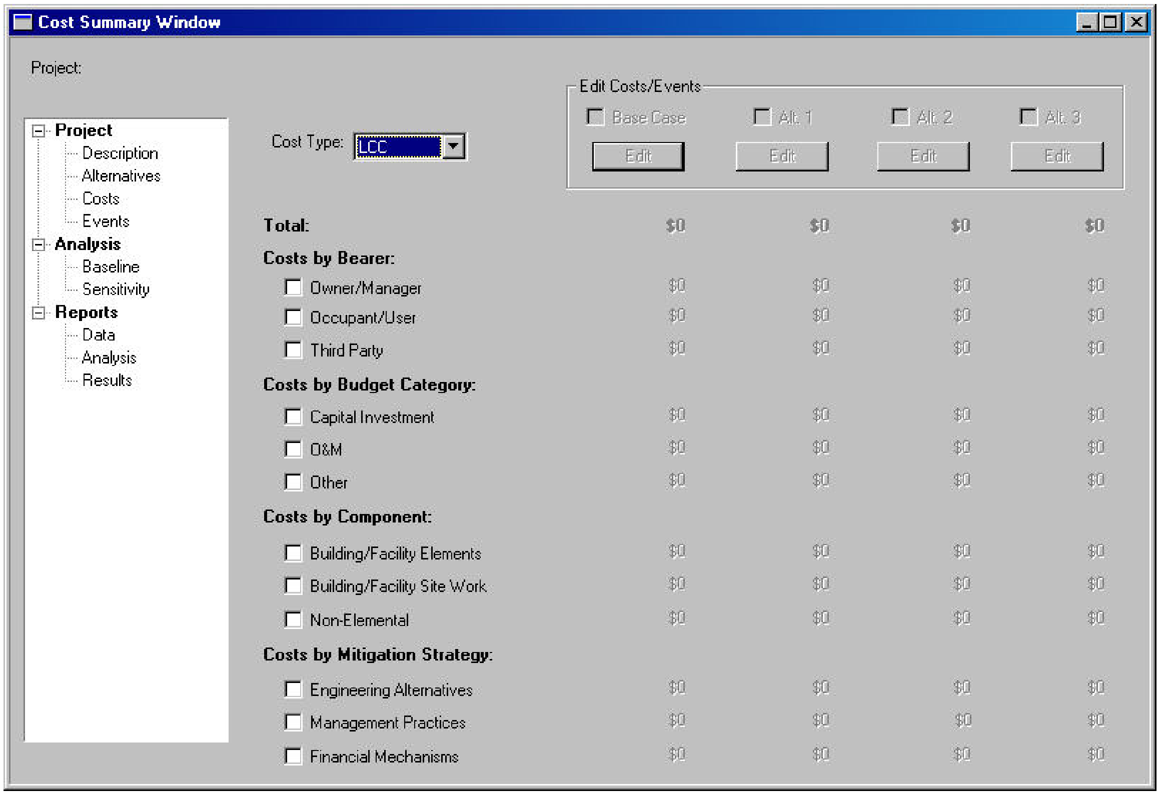
The software product employs the same cost-accounting framework as described in Section 4.3 and illustrated in Figure 4-2 and Table 4-3. As the user of the software product inputs data on each cost item, each cost item is classified according to its Bearer, Budget Category, Building Component, and Mitigation Strategy. The input screens, Cost

Summary window, and output reports for the baseline analysis option of the software product are all identical in their use of the cost-accounting framework. The sensitivity analysis option of the software product employs the same cost-accounting framework. This promotes a close coupling between the sensitivity analysis and the baseline analysis. The “roll ups” to the cost types and cost classifications for individual cost items are identical to those used in the baseline analysis. Thus, any changes in life-cycle cost are traceable to variations in input variables about their baseline values. Such an approach promotes in-depth analyses via the “drill down” feature described later in this chapter.

5.2 Cost Summary Window and Main Menu

The Cost Summary window is displayed whenever a new project is started or an existing project file is opened. When a project is created, the Cost Summary window is blank. Figure 5-1 is an example of the Cost Summary window display when starting a new project. As the user enters data into the software, the Cost Summary window displays the current value of life-cycle costs for each cost type and alternative being analyzed. It is recommended that the user keep the Cost Summary window open while working in the software. If the user wishes to close the window, it can be reopened at any time.

Figure 5-1 Cost Summary Window When Starting a New Project



Project:

Cost Type: LCC

	☐ Base Case	☐ Alt. 1	☐ Alt. 2	☐ Alt. 3
Total:	$0	$0	$0	$0
Costs by Bearer:				
☐ Owner/Manager	$0	$0	$0	$0
☐ Occupant/User	$0	$0	$0	$0
☐ Third Party	$0	$0	$0	$0
Costs by Budget Category:				
☐ Capital Investment	$0	$0	$0	$0
☐ O&M	$0	$0	$0	$0
☐ Other	$0	$0	$0	$0
Costs by Component:				
☐ Building/Facility Elements	$0	$0	$0	$0
☐ Building/Facility Site Work	$0	$0	$0	$0
☐ Non-Elemental	$0	$0	$0	$0
Costs by Mitigation Strategy:				
☐ Engineering Alternatives	$0	$0	$0	$0
☐ Management Practices	$0	$0	$0	$0
☐ Financial Mechanisms	$0	$0	$0	$0

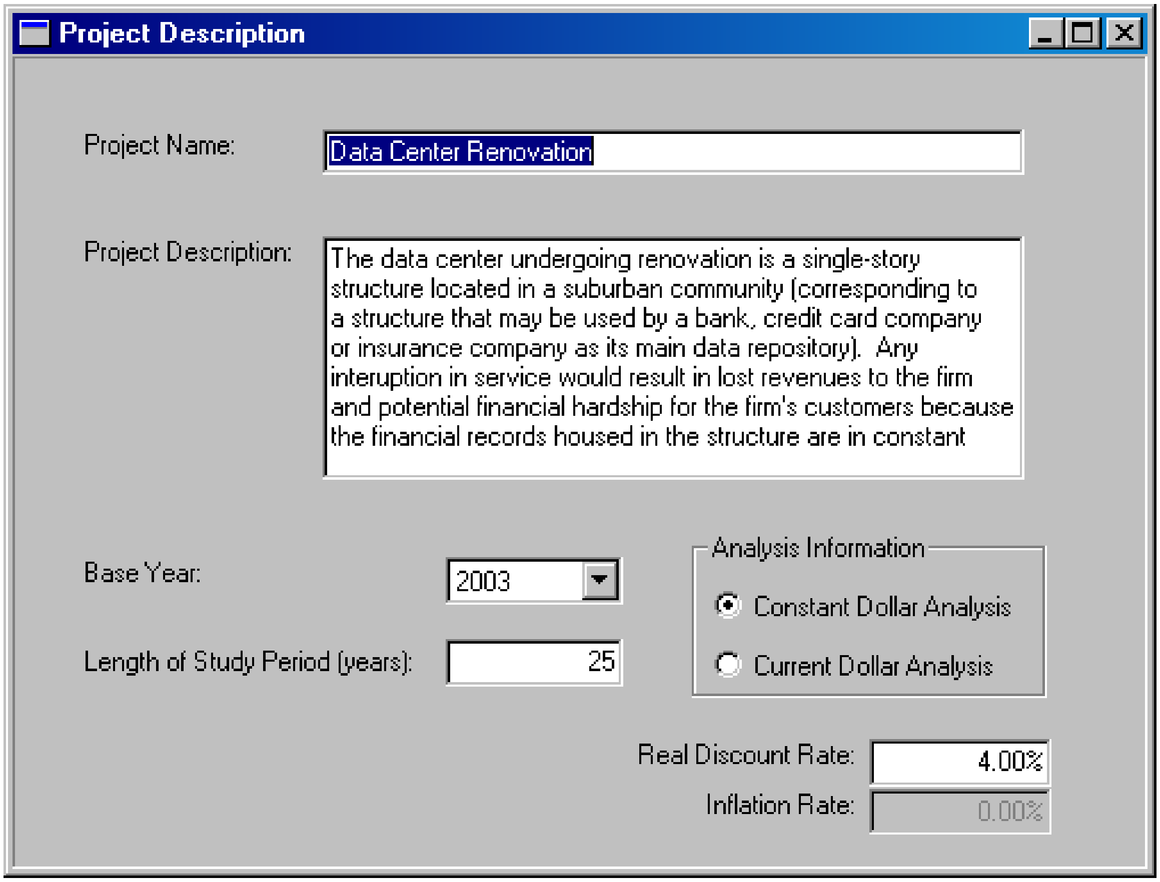
The software is designed to analyze up to four alternatives (see Figure 5-1). The Cost Summary window allows the user to specify both the cost types and the alternatives to be included in the economic evaluation. These "choices" are represented in Figure 5-1 by the "cost type" buttons and the "alternative" buttons.

A tree on the left-hand side of the Cost Summary window serves as the Main Menu to the software. The tree contains three top-level nodes: *Project, Analysis,* and *Reports*.[101]

5.3 Project Information

The items listed under the *Project* node allow the user to enter project information, define alternatives, and manage cost-related information. Clicking the *Description* option on the Main Menu opens the Project Description window. Here the user can enter project information such as name, description, base year, length of the study period, and the discount rate. Figure 5-2 displays the Project Description window for the data center case study. The *Alternatives* option allows the addition and deletion of project alternatives as well as entry of information about the alternatives.

Figure 5-2 Project Description Window for the Data Center Case Study



Project Description

Project Name: Data Center Renovation

Project Description: The data center undergoing renovation is a single-story structure located in a suburban community (corresponding to a structure that may be used by a bank, credit card company or insurance company as its main data repository). Any interuption in service would result in lost revenues to the firm and potential financial hardship for the firm's customers because the financial records housed in the structure are in constant

Base Year: 2003

Length of Study Period (years): 25

Analysis Information

● Constant Dollar Analysis

○ Current Dollar Analysis

Real Discount Rate: 4.00%

Inflation Rate: 0.00%

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[101] Software features are highlighted through the use of *italics* font.

Cost-related input screens for the software product are of two basic types: (1) input costs and (2) event-related costs. The user accesses these screens by selecting the *Costs* or *Events* options on the Main Menu.[102]

5.3.1 Input Costs

Clicking the *Costs* option opens the costs portion of the Edit Costs/Events window. The events portion of the Edit Cost/Events window is grayed out, indicating that it is inactive. This screen manages the creation, deletion, and editing of input costs. Upon entering the Edit Costs/Events window, the user selects the alternative for which cost information is to be reviewed or input. Once the alternative is selected, the Edit Costs/Events window displays all cost items associated with that alternative. Figure 5-3 is an example of the Edit Costs/Events window for the Base Case. Notice that the input costs are listed in alphabetical order according to their Budget Category—Investment, O&M, and Other. In this case, some costs are hidden, but can be viewed by scrolling down the list.

Highlighting and clicking the selected cost item opens the appropriate Cost Information window. This "edit" feature allows the user to review and, if desired, modify any previously recorded information for the cost item of interest. Figure 5-4 is an example of the Capital Investment Cost Information window for the data center case study. Figure 5-4 displays information on the Basic Renovation cost item, which is associated with the Base Case. Figure 5-5 is an example of the Other Cost Information window for the Change in Traffic Pattern cost item for the Proposed Alternative. Note that Figures 5-4 and 5-5 include a Classification Information group box which specifies how each cost item fits into the cost-accounting framework.

The Edit Costs/Events window is the means through which new cost items are created. The creation of a new cost item is accomplished by selecting the appropriate Budget Category cost type—Capital Investment, O&M, or Other—from the *Select Action* group box. The software then opens the Cost Information window associated with the selected cost type. The Cost Information windows allow the user to name the cost item, generate a cost estimate via separate entries for quantity and unit cost, and specify the timing of cash flows and any escalation rates that need to be applied (see Figures 5-4 and 5-5).

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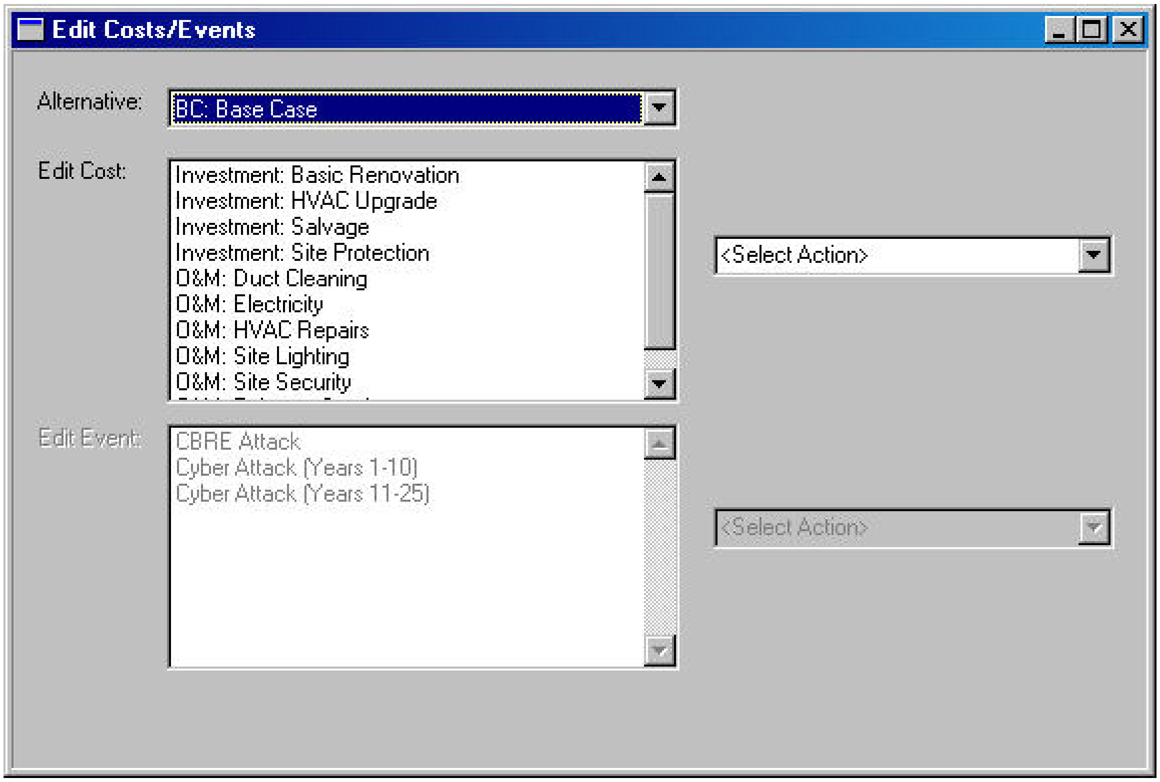
[102] Unless otherwise noted, all software features described in Sections 5.3 and 5.4 will be operational in the beta version scheduled for release in September 2004.

Figure 5-3 **Edit Costs/Events Window for the Data Center Case Study: Input Costs for the Base Case**



Alternative: BC: Base Case

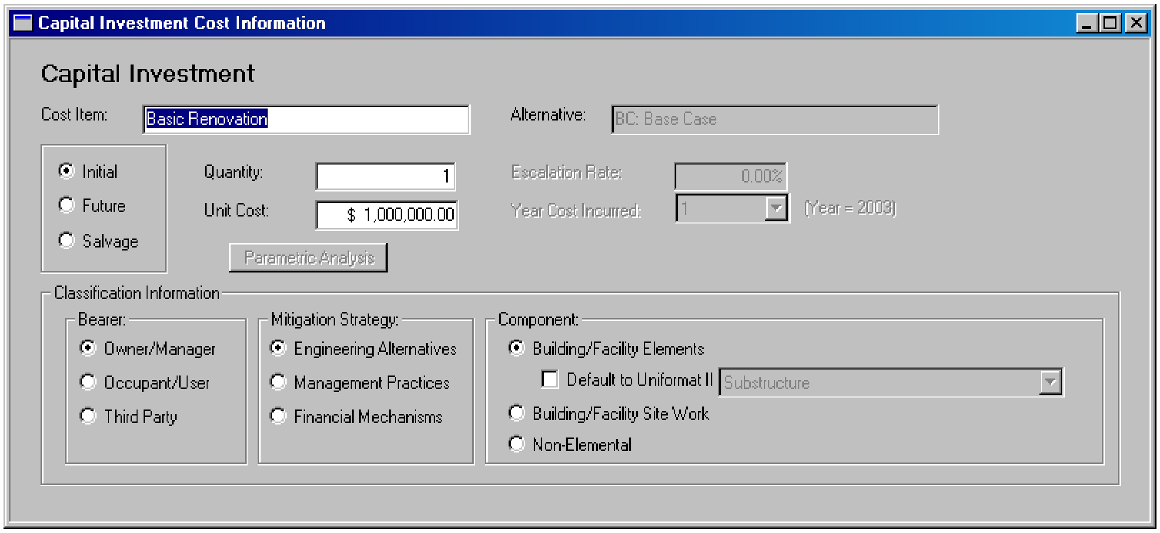
Edit Cost:
- Investment: Basic Renovation
- Investment: HVAC Upgrade
- Investment: Salvage
- Investment: Site Protection
- O&M: Duct Cleaning
- O&M: Electricity
- O&M: HVAC Repairs
- O&M: Site Lighting
- O&M: Site Security

<Select Action>

Edit Event:
- CBRE Attack
- Cyber Attack (Years 1-10)
- Cyber Attack (Years 11-25)

<Select Action>

Figure 5-4 **Capital Investment Cost Information Window for the Data Center Case Study: Basic Renovation**



Cost Item: Basic Renovation

Alternative: BC: Base Case

● Initial
○ Future
○ Salvage

Quantity: 1

Unit Cost: $ 1,000,000.00

Escalation Rate: 0.00%

Year Cost Incurred: 1 (Year = 2003)

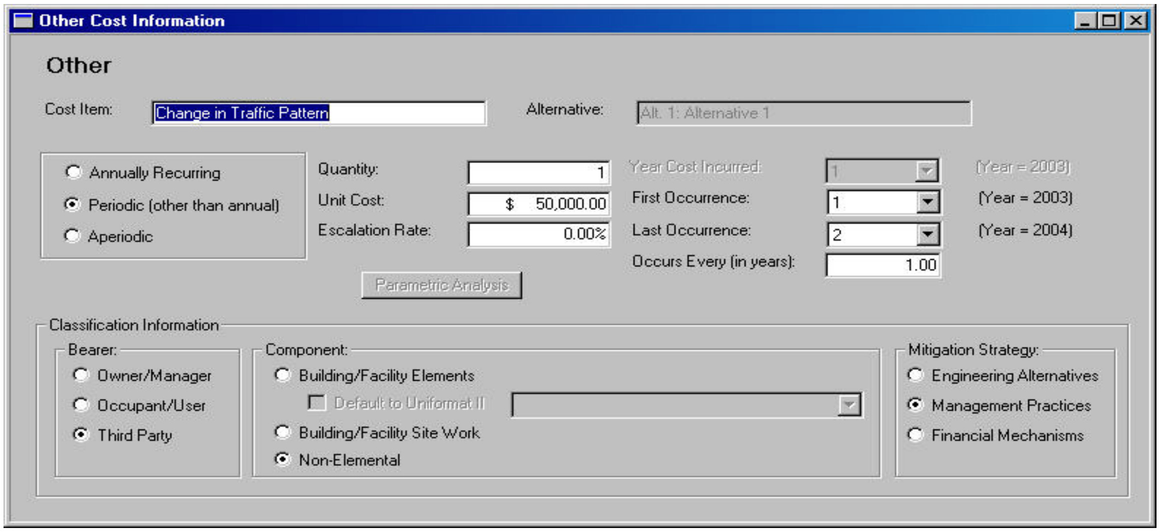
Classification Information

Bearer:
● Owner/Manager
○ Occupant/User
○ Third Party

Mitigation Strategy:
● Engineering Alternatives
○ Management Practices
○ Financial Mechanisms

Component:
● Building/Facility Elements
☐ Default to Uniformat II Substructure
○ Building/Facility Site Work
○ Non-Elemental

Figure 5-5 Other Cost Information Window for the Data Center Case Study: Change in Traffic Pattern for the Proposed Alternative



Other Cost Information

Other

Cost Item: Change in Traffic Pattern

Alternative: Alt. 1: Alternative 1

○ Annually Recurring
● Periodic (other than annual)
○ Aperiodic

Quantity: 1
Unit Cost: $ 50,000.00
Escalation Rate: 0.00%

Year Cost Incurred: 1 (Year = 2003)
First Occurrence: 1 (Year = 2003)
Last Occurrence: 2 (Year = 2004)
Occurs Every (in years): 1.00

Classification Information

Bearer:
○ Owner/Manager
○ Occupant/User
● Third Party

Component:
○ Building/Facility Elements
☐ Default to Uniformat II
○ Building/Facility Site Work
● Non-Elemental

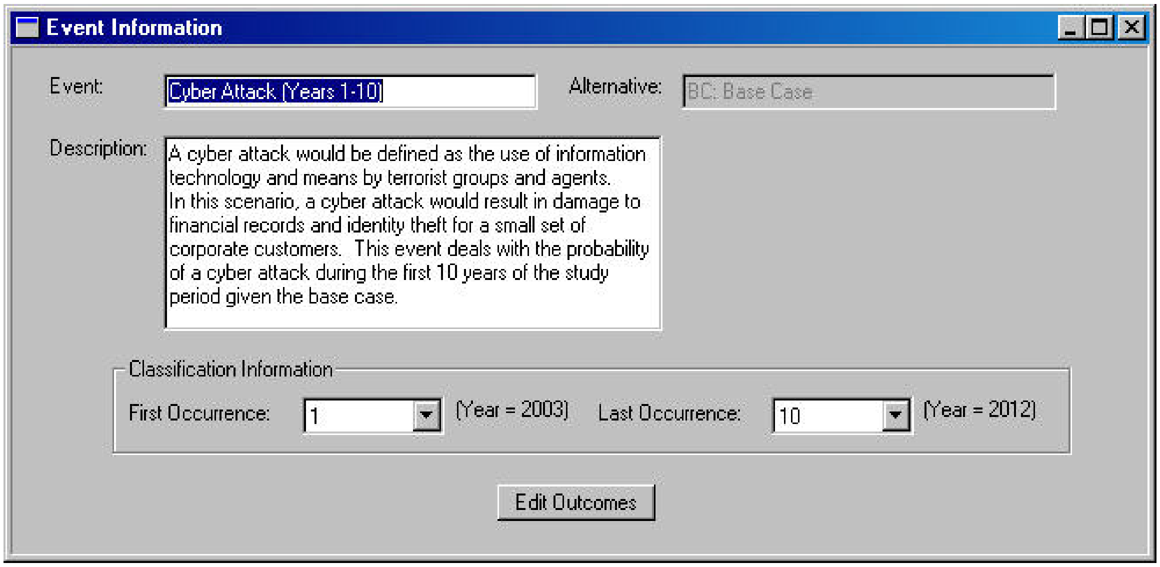
Mitigation Strategy:
○ Engineering Alternatives
● Management Practices
○ Financial Mechanisms

5.3.2 Event-Related Costs

Clicking the *Events* option opens the events portion of the Edit Costs/Events window. The costs portion of the Edit Costs/Events window is grayed out, indicating that it is inactive. Recall that in Figure 5-3, the costs portion of the Edit Costs/Events window was active and the events portion was grayed out. Clicking the *Events* option just switches the active and inactive portions of Figure 5-3. This screen manages the creation, deletion, and editing of event-related costs. Upon entering the Edit Costs/Events window, the user selects the alternative for which event-related information is to be reviewed or input. Once the alternative is selected, the screen displays all events associated with that alternative.

Highlighting and clicking the selected event opens the Event Information window. This feature allows the user to review and, if desired, modify any previously recorded information for the event of interest. The Edit Costs/Events window is the means through which new events are created. The creation of a new event is accomplished by selecting *Create New* from the *Select Action* group box. The software then opens the Event Information window. The Event Information window allows the user to name the event, provide a brief description of the event, enter the dates of first and last occurrence, and edit event-related outcomes. Figure 5-6 is an example of the Event Information window for the Cyber Attack scenario for the Base Case. Reference to Figure 5-6 shows that this Cyber Attack scenario covers the first 10 years of the study period. A second Cyber Attack scenario covers years 11 through 25. Two time periods are used because cyber crime is on the rise and although new countermeasures are being produced regularly, hackers are becoming more adept at finding and exploiting weaknesses in countermeasures software.

Figure 5-6 Event Information Window for the Data Center Case Study: Description of the Cyber Attack Scenario for the Base Case



Event: Cyber Attack (Years 1-10)

Alternative: BC: Base Case

Description: A cyber attack would be defined as the use of information technology and means by terrorist groups and agents. In this scenario, a cyber attack would result in damage to financial records and identity theft for a small set of corporate customers. This event deals with the probability of a cyber attack during the first 10 years of the study period given the base case.

Classification Information

First Occurrence: 1 (Year = 2003)

Last Occurrence: 10 (Year = 2012)

Associated with each event is a set of outcomes. Information on event-related outcomes is accessed via the Edit Outcomes/Outcome Costs window. This screen is reached by clicking the *Edit Outcomes* option in the Event Information window (see Figure 5-6). Clicking the *Edit Outcomes* option opens the outcomes portion of the Edit Outcomes/Outcome Costs window. Figure 5-7 is an example of the Edit Outcomes/Outcome Costs window for the first Cyber Attack scenario for the Base Case. This screen manages the creation, deletion, and editing of outcomes. The Edit Outcomes/Outcome Costs window displays all outcomes associated with the event of interest. The event/outcome costs portion of the Edit Outcomes/Outcome Costs window is grayed out, indicating that it is inactive.

Highlighting and clicking the selected outcome opens the appropriate Outcome Information window. This feature allows the user to review and, if desired, modify any previously recorded information for the outcome of interest. The Edit Outcomes window is the means through which new outcomes are created. The creation of a new outcome is accomplished by selecting *Create New* from the *Select Action* group box. The software then opens the Outcome Information window. The Outcome Information window allows the user to name the outcome, provide a brief description of the outcome, assign a probability of occurrence for the outcome,[103] update the sum of all outcome probabilities for the event of interest, and edit outcome-related cost items. Figure 5-8 is an example of the Outcome Information window; it provides a brief description of the outcome and an outcome probability for the first Cyber Attack scenario for the Base Case.

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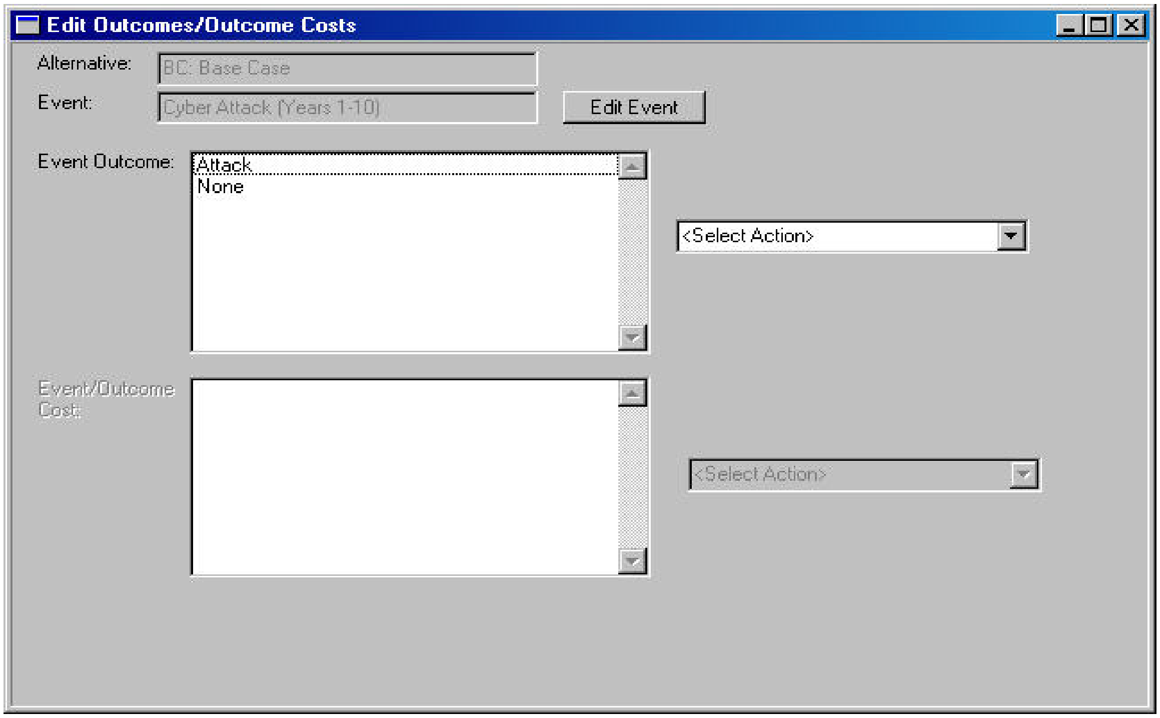
[103] Outcome probabilities are a byproduct of the risk assessment (see Section 3.1).

Figure 5-7 Edit Outcomes/Outcome Costs window for the Data Center Case Study: Base Case Cyber Attack Outcomes

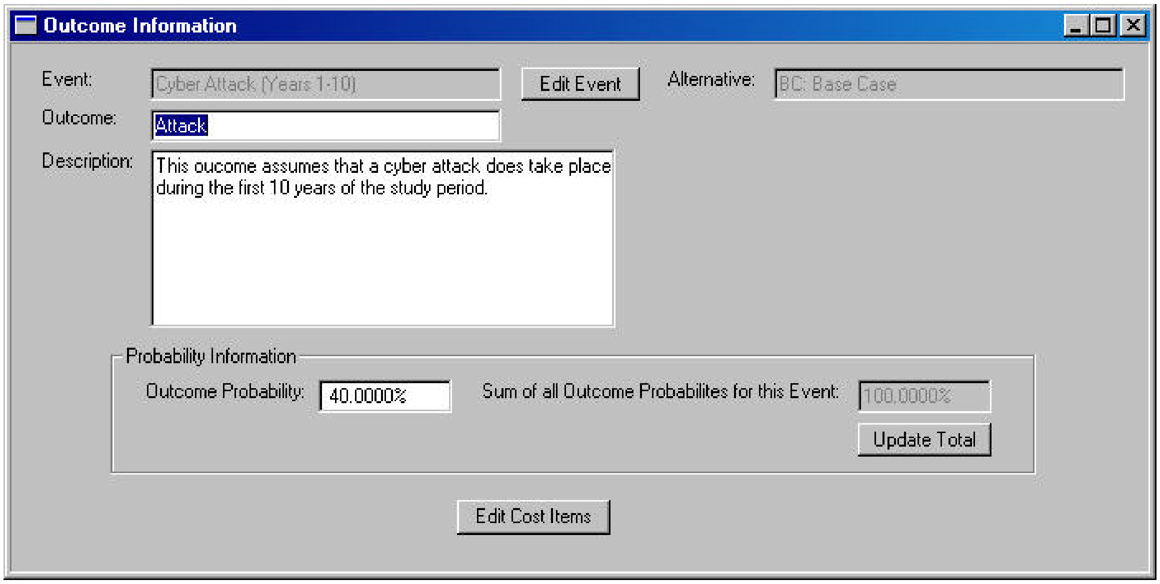


Alternative: BC: Base Case

Event: Cyber Attack (Years 1-10)

Event Outcome:
Attack
None

Figure 5-8 Outcome Information Window for the Data Center Case Study: Probability Information for the Base Case Cyber Attack Scenario



Event: Cyber Attack (Years 1-10)

Alternative: BC: Base Case

Outcome: Attack

Description: This oucome assumes that a cyber attack does take place during the first 10 years of the study period.

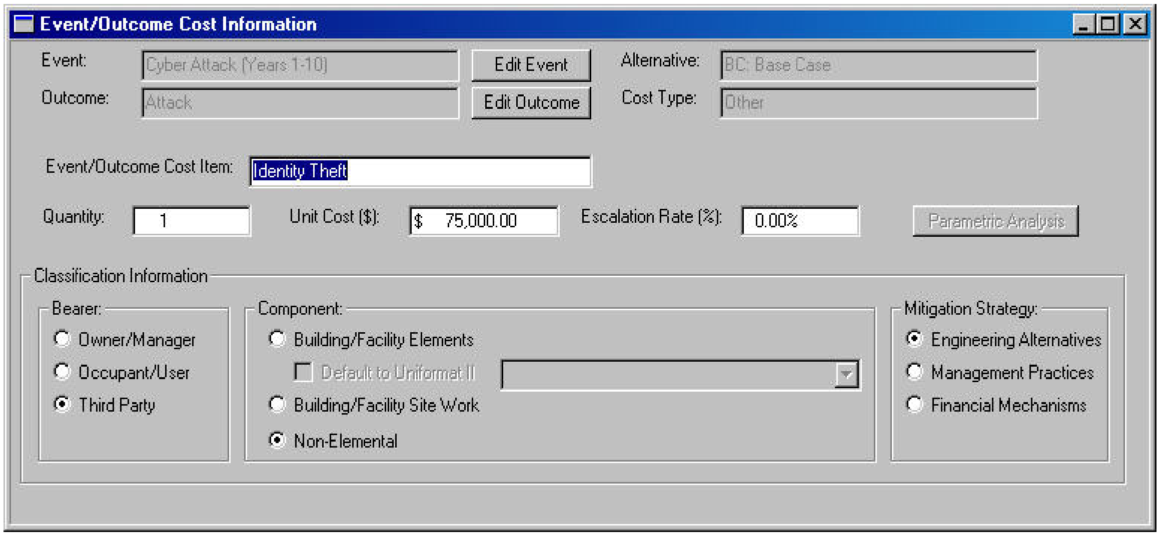
Outcome Probability: 40.0000%

Sum of all Outcome Probabilites for this Event: 100.0000%

Associated with each outcome is a set of event-related cost items. Information on event-related cost items is accessed by clicking the *Edit Cost Items* option of the Outcome Information Window (see Figure 5-8), which opens the event/outcome/cost portion of the Edit Outcomes/Outcome Costs window. The event/outcome portion of the Edit Outcomes/Outcome Costs window is grayed out, indicating that it is inactive. Recall that in Figure 5-7, the event/outcome/cost portion of the Edit Outcomes/Outcome Costs was grayed out. Clicking the *Edit Cost Items* option just switches the active and inactive portions of Figure 5-7. This screen manages the creation, deletion, and editing of event-related cost items. The Edit Outcomes/Outcome Costs window displays all event-related cost items associated with the outcome of interest.

Highlighting and clicking the selected event-related cost item opens the appropriate Event/Outcome Cost Information window. This feature allows the user to review and, if desired, modify any previously recorded information for the event-related cost item of interest. The Edit Outcomes/Outcome Costs window is the means through which new event-related cost items are created. The creation of a new event-related cost item is accomplished by selecting the appropriate Budget Category cost type—Capital Investment, O&M, or Other—from the *Select Action* group box. The software then opens the Event/Outcome Cost Information window. The Event/Outcome Cost Information window allows the user to name the event-related cost item, generate a cost estimate via separate entries for quantity and unit cost, and specify any escalation rates that need to be applied. Figure 5-9 is an example of the Event/Outcome Cost Information window for the Base Case. Figure 5-9 records information on the Identity Theft cost item for the first Cyber Attack scenario. Note that Figure 5-9 includes a Classification Information group box which specifies how each event-related cost item fits into the cost-accounting framework.

Figure 5-9 Event/Outcome Cost Information Window for the Data Center Case Study: Identity Theft Cost Item for the Base Case Cyber Attack Scenario



Event: Cyber Attack (Years 1-10)
Outcome: Attack
Alternative: BC: Base Case
Cost Type: Other

Event/Outcome Cost Item: Identity Theft

Quantity: 1
Unit Cost ($): $ 75,000.00
Escalation Rate (%): 0.00%

Classification Information

Bearer:
- ○ Owner/Manager
- ○ Occupant/User
- ● Third Party

Component:
- ○ Building/Facility Elements
  - ☐ Default to Uniformat II
- ○ Building/Facility Site Work
- ● Non-Elemental

Mitigation Strategy:
- ● Engineering Alternatives
- ○ Management Practices
- ○ Financial Mechanisms

5.3.3 Alternative-Specific Feature: The Edit Costs/Events Group Box

The software also enables the user to access the Edit Costs/Events window by clicking the *Edit* button in the Edit Costs/Events group box at the top of the Cost Summary window (see Figure 5-1). Since each alternative has a specific *Edit* button, when that button is clicked the Edit Costs/Events window opens with a display of all costs and all events associated with the alternative in the selected column of the Edit Costs/Events group box. This feature helps the user edit cost and event information very efficiently when the focus is on a single alternative.

5.4 Output Reports

The software product's output reports are designed to help the user "drill down" on how individual cost items are distributed across Bearer, Budget Category, Building Component, and Mitigation Strategy. The software product drills down according to the Budget Category. This approach gives users a snapshot of all of the costs entering the analysis, expressed in present value terms, which "roll up" into the life-cycle costs recorded in the Cost Summary window. Figure 4-1 and Table 4-2 are indicative of selected sets of output reports from the sensitivity analysis option that will be included in version 2.0 of the software product. Figure 4-1 is a standard output from the software product whenever a Monte Carlo simulation is performed. The user will also have the option to obtain additional graphical reports for economic measures other than life-cycle cost. Tabular summaries for Monte Carlo simulations (see Table 4-2) will also be available to the user of the software product. These summaries may be based on changes in a single variable, such as the discount rate, or a collection of variables varied in combination.

Figure 5-10 reproduces the Cost Summary window for the data center case study. Comparisons between Figure 5-10 and Table 4-3 highlight how the cost-accounting framework is implemented within the software product. With the exception of the Main Menu options, editing/screening options for the alternatives under analysis, and some descriptive information, Table 4-3 is identical to the Cost Summary window. Both Table 4-3 and the Cost Summary window of the software product employ the cost-accounting framework, express costs in present value terms, and support the calculation of additional economic measures. The software product is designed to help the user "drill down" on individual cost items. For example, whenever probabilistic sensitivity analyses are being performed, the software product drills down according to a probabilistic version of the Cost Summary window (see Table 4-3 and Figure 5-10). This feature involves a two-stage analysis. The first stage drills down from life-cycle cost (see Table 4-2) to the individual cost categories and cost types. The second stage drills down to the individual cost items to determine how they contribute to variations in life-cycle cost. This approach gives users a snapshot of all of the costs entering the analysis, expressed in present value terms, which "roll up" into the life-cycle costs recorded in the Cost Summary window.[104]

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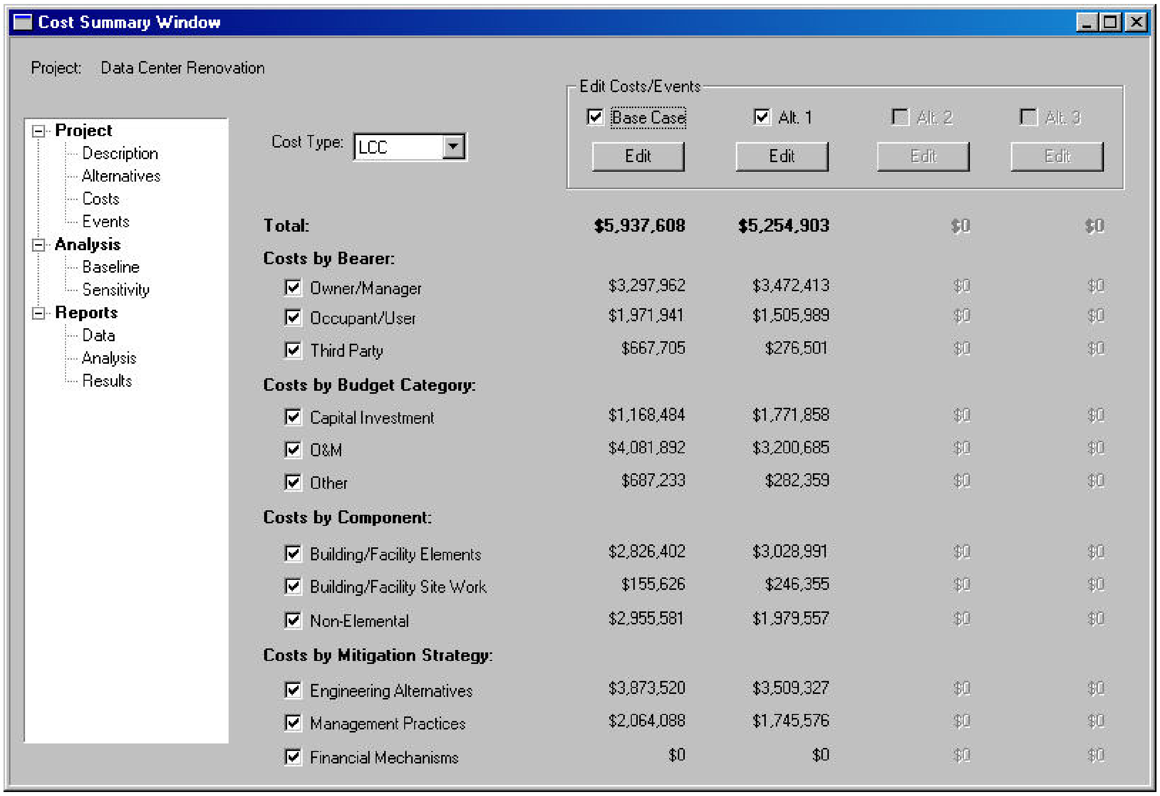
[104] For an in-depth discussion of this approach, see Chapman, *Applications of Life-Cycle Cost Analysis to Homeland Security Issues in Constructed Facilities,* pp. 60-68.

Figure 5-10 Cost Summary Window for the Data Center Case Study



Project: Data Center Renovation

Cost Type: LCC

	☑ Base Case	☑ Alt. 1	☐ Alt. 2	☐ Alt. 3
Total:	**$5,937,608**	**$5,254,903**	**$0**	**$0**
Costs by Bearer:				
☑ Owner/Manager	$3,297,962	$3,472,413	$0	$0
☑ Occupant/User	$1,971,941	$1,505,989	$0	$0
☑ Third Party	$667,705	$276,501	$0	$0
Costs by Budget Category:				
☑ Capital Investment	$1,168,484	$1,771,858	$0	$0
☑ O&M	$4,081,892	$3,200,685	$0	$0
☑ Other	$687,233	$282,359	$0	$0
Costs by Component:				
☑ Building/Facility Elements	$2,826,402	$3,028,991	$0	$0
☑ Building/Facility Site Work	$155,626	$246,355	$0	$0
☑ Non-Elemental	$2,955,581	$1,979,557	$0	$0
Costs by Mitigation Strategy:				
☑ Engineering Alternatives	$3,873,520	$3,509,327	$0	$0
☑ Management Practices	$2,064,088	$1,745,576	$0	$0
☑ Financial Mechanisms	$0	$0	$0	$0

5.5 Analysis Features and Software Rollout

The analysis features and the schedule for the software rollout are tightly coupled. Although the software product has two basic analysis features—baseline analysis and sensitivity analysis—they differ significantly in how they are implemented within the software.

Recall that in the baseline analysis all data elements (e.g., cost items) entering into the calculations are fixed (see Section 4.1.1). The baseline analysis includes both input costs and event-related costs. Thus, the baseline analysis is a complete analysis in all respects but one; it does not address the effects of uncertainty. For example, although the baseline analysis includes event-related costs, the probabilities of any event-related outcomes are fixed. Whereas these probabilities are estimated based on the best available data, there is uncertainty associated with these estimates. In summary, the baseline analysis produces a complete set of results, including expected values of losses stemming from event-related costs.

Given that all data elements are fixed in value, the baseline analysis is the more straightforward of the two analysis features. The alpha version of the software product will enable software evaluators to input the data needed to perform a comprehensive baseline analysis. The alpha version of the software will include the full range of project information options (see Section 5.3). The alpha version will also include a selected set of report options (see Section 5.4). The alpha version of the software product is not scheduled for public release. The alpha version will be tested as part of a collaborative effort between NIST and the Wharton Risk Management and Decision Processes Center. Production of the beta version will incorporate comments from Wharton and augment the alpha version by including a limited sensitivity analysis capability.

Sensitivity analysis measures the impact on project outcomes of changing the values of one or more key data elements about which there is uncertainty. Sensitivity analysis may be divided into two polar cases: (1) deterministic and (2) probabilistic.

Deterministic sensitivity analyses are the more straight forward of the two. In a deterministic sensitivity analysis, a small set of key data elements are varied either singly or in combination. Settings for the key data elements are designed to bracket the baseline value for that element. A common strategy is to posit minimum and maximum values which span the expected range of values for the data element. The beta version of the software product, scheduled for public release in September 2004, will include the ability to systematically vary any combination of data elements and measure their impact on economic measures of performance (e.g., life-cycle costs).

Version 1.0 of the software product is scheduled for public release in March 2005. Version 1.0 will draw on extensive testing of the beta version. The version 1.0 software product will produce the types of analysis results that provide decision makers with the basis for generating a risk mitigation plan. Version 1.0 of the software product will also include help files to assist users.

In a probabilistic sensitivity analysis, a small set of key input variables is varied either singly or in combination according to an experimental design. In most cases, probabilistic sensitivity analyses are based on Monte Carlo techniques, or some other form of simulation. The major advantage of probabilistic sensitivity analysis is that it permits the effects of uncertainty to be rigorously analyzed. For example, not only the expected value of each economic measure of performance can be computed but also the variability of that value. In addition, probabilistic levels of significance can be attached to the computed values of each economic measure of performance.

Version 2.0 of the software product is scheduled for public release in March 2006; it will enable users to conduct rigorous probabilistic sensitivity analyses under a wide variety of user-defined input scenarios. Version 2.0 will expand version 1.0 capabilities by including a financial risk module, which makes use of Monte Carlo techniques. This will enable users to conduct a rigorous, probabilistic financial risk assessment of alternative mitigation strategies. Version 2.0 will use Monte Carlo techniques to produce risk profiles for economic measures of performance. For example, a risk profile for the present value of net savings (PVNS) measure would record the probability of PVNS being less than zero or some other specified target value. Recall that PVNS greater than or equal to zero is a requirement for a risk mitigation plan to be cost-effective. Version 2.0 will draw on extensive testing of the version 1.0 software product and incorporate suggestions from version 1.0 users. Version 2.0 will include a users manual. Economists from OAE will also develop a training module for the software product.

To complement the previous chapter's discussion of life-cycle cost analysis' application to homeland security considerations and this chapter's description of the proposed software product, Chapter 6 outlines the theoretical foundations of the protective investment optimization problem. These foundations illustrate how the factors and costs affect the optimal level of investment in building protection.

6 Additional Considerations of Risk Mitigation Decisions

The previous two chapters describe the economic evaluation approaches to choosing among alternative risk mitigation plans to protect constructed facilities and the implementation of these approaches. The application of life-cycle costing and the related metrics are affected by different types of constructed facilities. The makeup of a constructed facility affects decisions about how much to spend on risk mitigation and the allocation of these expenditures within the constructed facility. In the sections that follow, several types of constructed facilities are presented, along with intuitive discussions of the basis for choosing the levels and allocations of protective expenditures, both among buildings and among the three risk mitigation strategies described in Chapter 2.

In the first section, we give an overview of decision making when the constructed facility is a single structure. In Section 6.2, we present the basis for organization-wide expenditure levels and allocations. Organization-wide decision-making applies to constructed facilities that are collocated, such as in campus settings. These collocated structures may be interconnected or independent. Organization-wide decision-making also applies to geographically distributed structures. In the third and final section, we discuss some social welfare implications of risk mitigation to protect constructed facilities.

6.1 Decision Making for a Single Building

For the case of a single building structure, decision makers must choose the total level of expenditures to protect the building, their allocation among engineering alternatives, management practices, and financial mechanisms, and their allocation in each period of the time frame of interest. Several theoretical treatments for allocating expenditures among the three risk mitigation strategies over time in the single-building case are presented in Appendix D. These analytical models produce optimality conditions for outlays for each of the three types of strategies based on marginal costs, marginal benefits, and budget constraints.

The first model assumes that only engineering alternatives requiring capital investments in the initial period are available. The second model adds the possibility of management practices to the mix of potential countermeasures. The third includes two financial mechanisms, insurance and subsidies, as potential strategies. The fourth and final model allows for capital investments in engineering alternatives in more than one period.

The approach briefly described in this section and elaborated on in Appendix D shares several commonalities with the life-cycle cost analysis presented in Chapter 4, but presents some key differences. First, the investments and expenditures in life-cycle cost analysis are variegated. Investments in HVAC equipment are distinct from investments in laminated safety glass. Management practices dollars spent to hire security personnel are differentiated from dollars spent to conduct periodic employee emergency evacuation drills. With life-cycle costing, it is possible to distinguish dollars expended for different financial mechanisms, such as premiums for insurance policies versus payment for a leasing option on an alternative commercial building. For each of these types of mitigation strategies, different levels of costs and expected reductions in losses are associated with each specific risk mitigation strategy. In the current approach, expanded on in Appendix D, there is no such distinction. Each dollar invested in engineering alternatives is homogeneous and not differentiated by type of investment. Each dollar spent to implement risk mitigation management practices is not distinguished by practice. Similarly, each dollar spent on financial mechanisms is treated as homogeneous, with no differentiation (with reference to the previous example) between a $50 000 annual insurance premium and a $50 000 lease option. The effect on costs and expected reduction in losses depends not on the nature and purpose of the investment or expenditure, but on the dollar amount of each. The simplification is necessary to ensure the models' tractability. In spite of the abstraction, the optimality conditions derived in Appendix D provide some insight into the question of how much to invest or spend on risk mitigation in each period.

A second difference between the life-cycle cost approach of Chapter 4 and this section (and Appendix D) is that the set of risk mitigation choices available to the building owner or manager in the life-cycle cost approach of Chapter 4 are discrete combinations of mitigation strategies: referring to Table 3-1, for example, a hypothetical Combination A could be the group of engineering alternatives, management practices, and financial mechanisms E2, E3, M2, and F3. A hypothetical Combination B could be the group including E1, E2, M5, F1, and F2. The life-cycle cost analysis helps the building owner or manager choose the most cost-effective combination of mitigation strategies from a finite, user-defined set. In this section and in Appendix D, the decision facing building owners and managers is not which combination of strategies is cost effective, but how much to invest. The simplification is one of the consequences of the removal of the dimension of type of investment in engineering alternatives.

In spite of these differences, the approaches described in Chapter 4 and in Appendix D are mutually consistent. They both break costs down by strategy: engineering alternative, management practice, and financial mechanism; and by category: capital investment, operations and maintenance, and other. They are both based on the minimization of life-cycle costs of investments and expenditures.

6.2 Organization-Wide Decision Making

An organization may own more than one structure or facility and require an approach to allocating protective resources among these facilities. These multiple buildings may be in a single location (such as in a campus-like setting) or they may be located throughout the country. For organizations with multiple structures, the model must be able to address both the question of how much to invest in each period as well as how much to allocate among the buildings and locations. Whether these structures are sited in close proximity to each other or scattered across several geographic areas affects this investment decision.

6.2.1 Collocated Structures or Campuses

Buildings in a campus-like setting or in close proximity to each other can, in some circumstances, be treated as a single building. In other situations, their differences require individualized assessment of and response to the threats, vulnerabilities, and risks that they face. The difference in treatment depends on the degree of interdependence among the collocated structures.

6.2.1.1 Collocated, Interconnected Structures

Buildings in a campus can be treated as a single building if they face similar probability of and vulnerability to attack. Such similarities may arise if the buildings share a common entrance and perimeter, for example. They may be physically connected through above-ground walkways or underground tunnels. Admission to one building may convey access to all other buildings. They may have interdependent electrical, telecommunications, HVAC, or other systems. For collocated structures, an attack on one building, for example, a conventional explosion, may damage nearby buildings, such as through the initial blast, shrapnel, or follow-on fires, simply due to physical proximity.[105]

For buildings that are interconnected and have no restrictions on access among them, the rational building owner or manager would allocate protective resources among them to maximize the lowest degree of invulnerability among the buildings. The decision rule is based on a constrained *maximin*-type optimization, where the objective is to maximize the minimum level of protection among the interconnected buildings within the given budgetary constraints. This optimization recognizes that all the buildings in the campus are only as secure as the weakest point among these buildings.[106] If building owners and managers were to ignore the accessibility issue and instead concentrate resources on a higher-occupancy building while leaving an interconnected, but unoccupied, building less protected, then potential terrorists could exploit the less protected building's vulnerability, nullifying the resources devoted to the high-occupancy structure. When there are interdependent outcomes among buildings, overprotecting one structure without commensurate allocations in others in the collection of buildings is inefficient.

6.2.1.2 Collocated, Independent Structures

Structures that are collocated, but not interconnected, may not all face the same probability, vulnerability, or consequences of a terrorist attack. A structure, for example, that houses critical units of the organization or facilities may experience a greater probability of attack. A building located on the perimeter of the campus rather than the interior may be more vulnerable to explosive attacks due to a smaller setback distance from a public road. A structure that houses hazardous contents, such as toxic chemicals or radioactive material, may be leveraged by potential terrorists into more widespread destruction. Some structures are more valuable to an organization, such as those with higher occupancy, house mission-critical elements or the leadership of the organization,

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[105] An example of collateral effects are the attacks on the twin towers of the World Trade Center, which destroyed seven buildings and one bridge, severely damaged seven additional buildings, and moderately damaged 15 other buildings (Hartwig, "The Long Shadow of September 11," p. 7).

[106] The concept is analogous to the notion that the degree of protection conveyed by a dike is determined by its lowest point.

or contain more costly physical contents, so that the consequences of their loss would be greater.

In these situations, protective resources should be allocated to equalize the marginal increase in benefits (i.e., the marginal reduction in costs and losses) across the buildings from each additional dollar of protective investment. The crucial difference is in the expected loss variable. The probability distribution of losses is now no longer solely based on the protected building. The value of neighboring buildings belonging to the same owner are included. The effect of including these buildings is to increase the marginal benefit from protecting one of the buildings. With the single building case, investment only reduced the expected losses to the owner from that one building. When the owner owns multiple buildings in close proximity to each other, investment reduces losses to the protected building as well as the owner's other nearby buildings. The proximity of the other buildings owned by the same group increases the life-cycle cost minimizing level of protective investment as a reduction in the expected loss.[107]

6.2.2 Geographically Distributed Structures

6.2.2.1 Geographically Distributed, Interconnected Structures

For some firms, buildings may exhibit interdependencies in spite of geographic separation. Telecommunications or data hubs are examples of such buildings. Physical damage or cyber terrorism at these facilities could adversely impact operations and business continuity at locations across a wider geographic space. In this case, the optimal allocation would be similar to the interconnected structures case. Cyber terrorism would be defended according to a *maximin* optimization. For protection against physical damage, building owners and managers should consider the consequences to all locations of damage to that particular facility when allocating protective resources.

6.2.2.2 Geographically Distributed, Independent Structures

For buildings that are located across a wider geographic area and not in close proximity to each other, the optimization principle is similar to the case of the collocated but not interconnected buildings. If the buildings belonging to an organization are sited throughout a region or country, so that their physical security and vulnerability are not interdependent,[108] then the organization should allocate its risk mitigation resources among its locations so that the marginal reduction in costs from each additional dollar of protective investment is equal across all facilities. More heavily occupied buildings or

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[107] In the single building case, protecting a building also reduces the expected losses (if an attack occurs) to other buildings whether they share an owner or not. This reduction in losses to other owners' buildings, however, was not included ("internalized") in the "benefits" of the protective investment that affect the single-building owner's decision about protection. The key difference in the case of collocated, but independent, structures is that the owner now considers the effects of other buildings, because his ownership of them means that he would bear the consequences of their destruction. The benefits of protecting one building includes the reduction in expected losses to the owner's other buildings in the cluster.

[108] Implicit in the assumption that spatial separation implies lack of interdependence is an abstraction from cyber threats, the consequences of which are not constrained by physical distance.

buildings in higher risk cities would receive more protective resources than low risk or low value facilities, because the marginal reduction in life-cycle cost due to each dollar of protective investment would be greater in these areas.

6.3 Social Welfare Considerations

The presumption in Sections 6.1 and 6.2 is that the building owner and manager consider only the benefits and costs that accrue to themselves when making risk mitigation decisions. These decisions, however, may convey benefits or costs to other parties and have broad social welfare implications.

The optimizing agent can be the building owner and manager, or it can be society. Some issues are more appropriately modeled according to one, and some according to the other. Insurance, for example, matters to the building owner and manager. For society, however, premiums and claims merely represent redistribution of assets between insurers and policyholders.

To take another example, economic spillovers of building protection to the owners of neighboring buildings do not enter into the building owner's problem, because the costs and benefits do not accrue to the decision maker. These spillovers, such as an increase or a decrease to the probability that they will be attacked, accrue to other parties, such as occupants and users, and neighbors. The presence of spillovers leads to distortions—the incentives of the decisions makers are not aligned with the costs and benefits that will accrue to society overall. There may be unintended consequences of deterrence if some buildings are protected, but other buildings are not. If terrorists avoid buildings that are observably protected in favor of nearby buildings that are not obviously protected, then the protection level of surrounding buildings increases the probability of a terrorist attack. These spillover effects are illustrated using a simple example in Appendix E.

There are several possible approaches to addressing societal aspects of risk mitigation decisions. Regulations, such as building codes and standards, play a key role in bringing social consequences into the choices of private decision makers. Trade associations and other coordinating agencies can also shape the way private decision makers consider the broader impacts of their actions.

7 Summary and Suggestions for Further Research

7.1 Summary

The September 11th attacks on the World Trade Center and the Pentagon and the subsequent dispersion of anthrax through the postal system have changed the way many in the United States approach security and safety. Future attacks could result in harm to the occupants of constructed facilities and bystanders; physical damage to constructed facilities; business interruptions; and financial losses. These realities have led to changes in the way key decision makers think about the design, location, construction, management, and renovation of constructed facilities. Owners and managers of constructed facilities are confronted with the challenge of responding in a financially responsible manner to the potential for future terrorist attacks. This report provides the economic foundations for producing a cost-effective risk mitigation plan which satisfies the objective of safeguarding assets in a financially responsible manner.

This report presents a three-step protocol for developing a cost-effective risk mitigation plan for constructed facilities. This protocol helps decision makers determine the vulnerability of their facility to damages from low-probability, high-consequence events; identifies engineering, management, and financial strategies for abating the risk of damages; and uses standardized economic evaluation methods to select the most cost-effective combination of risk mitigation strategies to protect their facility. By using these economic evaluation methods, the owners and managers of constructed facilities can reduce the life-cycle costs associated with low-probability, high-consequence events.

The development of a cost-effective risk mitigation plan is facilitated through the use of economic tools—evaluation methods and software for implementing these methods. This report addresses that need through the development of a decision methodology covering step three of the protocol—the economic evaluation of alternative risk mitigation strategies—and a proposed software product for implementing the decision methodology.

The decision methodology is based on the life-cycle cost method. The decision methodology covers how to apply the evaluation methods and interpret the results. This method is supported by a voluntary industry standard, ASTM E 917. Three other evaluation methods—present value of net savings, savings-to-investment ratio, and adjusted internal rate of return—are also supported by voluntary industry standards. The four evaluation methods are designed to cover a wide spectrum of investment decisions.

The decision methodology builds on the life-cycle cost method by employing two types of analysis—baseline analysis and sensitivity analysis—and a cost-accounting framework. The baseline analysis is designed to give a frame of reference for the sensitivity analysis. The baseline analysis results in a rank ordering of the alternative combinations of risk mitigation strategies in terms of their life-cycle costs. The sensitivity analysis augments the baseline analysis by assessing the impacts that uncertainty for selected sets of input data has on life-cycle costs. The sensitivity analysis enables the decision maker to generate risk profiles for each alternative combination of risk mitigation strategies. Together the baseline analysis and the sensitivity analysis provide the information needed to identify the most cost-effective risk mitigation plan. The cost-accounting framework complements the baseline and sensitivity analyses by identifying unambiguously who bears which costs, how costs are allocated among several widely-accepted budget categories, and how costs are allocated among key building components and the three types of risk mitigation strategies.

Implementation of the decision methodology, however, is accomplished through application of the proposed software product. Although the public release of the finalized version of the software product is scheduled for March 2006, a beta version will be released in September 2004. Version 1.0 is scheduled for public release in March 2005. The software product will significantly reduce the time and effort required for users to implement the third step of the protocol—evaluate the life-cycle cost implications of the alternative combinations of risk mitigation strategies. The software will guide the user through a structured set of input screens, so that complex investment alternatives can be systematically input, analyzed, and saved for purposes of documentation.

The report also includes discussions and descriptive materials on a variety of homeland security-related issues. These sections of the report provide guidance and insights for readers interested in learning more about ways in which economic analysis contributes to protecting constructed facilities against natural hazards and terrorist acts that occur infrequently, but result in devastating damages.

7.2 Suggestions for Further Research

The background work for this report uncovered additional areas of research that might be of value to government agencies and private-sector organizations concerned with homeland security-related issues. These areas of research are concerned with: (1) how decision makers process information associated with low-probability, high-consequence events; (2) the role of financial incentives in promoting the adoption of cost-effective risk mitigation plans; (3) the construction of scenarios for modeling sequential investment decisions; and (4) evaluations based on multiattribute decision analysis.

7.2.1 Decision-Making Under Uncertainty

Protecting against low-probability, high-consequence events such as terrorist acts and other natural and man-made hazards complicates the capital asset decision-making process. Additional research on decision-making under uncertainty is needed to provide a better understanding of how decision makers responsible for constructed facilities respond to the way information is provided to them, how they process this information, and how they perceive extremely low probabilities. Two additional research topics involving decision-making under uncertainty are how decision makers react to situations involving interdependent security (i.e., cases where one facility owner's actions serve to raise or lower the risks of another owner's constructed facility) and how they assess the merits of adopting new technologies (i.e., innovative products and services) as risk mitigation measures.

7.2.2 Financial Incentives

Financial incentives are a means for bringing about a socially desired outcome when there are externalities associated with investments in risk mitigation strategies.

Additional research is needed on the opportunities and challenges for utilizing financial incentives to encourage owners and managers to better protect their facilities from extreme events such as natural disasters, technological accidents, and terrorism. Such research could examine specific financial incentives that may have short-run and long-term benefits in reducing future losses from extreme events. For example, research summarizing the factors leading to the successful implementation of mitigation measures in recent years would be helpful in the design of any new incentive programs. Another priority for research is an investigation of the challenges and opportunities for implementing financial incentives through strategies that involve public-private partnerships.

7.2.3 Sequential Investment Decisions

Many investment decisions are sequential in nature. The data center case study summarized in Section 4.2.6 included sequential elements related to capital replacements.[109] However, additional research on scenario construction is needed to better capture the sequential nature of decision making in a life-cycle cost context. Because the sequence in which investment decisions are made impacts not only capital costs but O&M and other costs as well, research on scenario construction would help the users of the software product to identify those investment sequences which have the most favorable impact on life-cycle cost. Research on scenario construction would also help decision makers assess the merits of adopting new technologies. As a new technology enters the market place, there is a period during which potential adopters are learning about its true characteristics. Adoption decisions are especially challenging if the new technology is going through an improvement cycle. Improvement cycles tend to have a double-edged effect on adoption: a direct effect, stimulating greater use; and an indirect effect, whereby expectations of future advances lead to the postponement of adoption. Research on scenario construction would provide guidance to the decision maker on how to use the software product to assess the merits of the new technology. This guidance would enable the decision maker to keep their investment options open while collecting additional information on the performance characteristics of the new technology.

7.2.4 Multiattribute Decision Analysis

Many investment alternatives differ in characteristics that decision makers consider important but that are not readily expressed in monetary terms. Because the standardized evaluation methods employed in this report consider only monetary benefits and monetary costs associated with alternative investment choices, their application does not reflect the importance of these non-financial characteristics to the decision maker. When non-financial characteristics are important, decision makers need a method that accounts for these characteristics (also called attributes) when choosing among

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[109] For an in-depth description of the data center case study, see Chapman, *Applications of Life-Cycle Cost Analysis to Homeland Security Issues in Constructed Facilities*, pp. 21-68.

alternative investments. A class of methods that can accommodate non-monetary benefits and costs is multiattribute decision analysis.[110]

The analytical hierarchy process (AHP) is one of a set of multiattribute decision analysis methods that considers non-financial characteristics in addition to common economic evaluation measures when evaluating project alternatives. The AHP has several important strengths: (1) it is well-known and well-reviewed in the literature; (2) it includes an efficient attribute weighting process; (3) it incorporates hierarchical descriptions of attributes; (4) its use is facilitated by available software; and (5) it has been accepted by ASTM as a standard practice for investments related to buildings and building systems.[111]

The AHP and its associated software represent a powerful and versatile management tool. How to apply this management tool most productively to homeland security-related issues requires additional research on how decision makers view non-financial outcomes associated with low-probability, high-consequence events.

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[110] For more information on multiattribute decision analysis, see Norris, Gregory A., and Marshall, Harold E. *Multiattribute Decision Analysis Method for Evaluating Buildings and Building Systems.* NISTIR 5663 (Gaithersburg, MD: National Institute of Standards and Technology, 1995).

[111] ASTM International. "Standard Practice for Applying Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems," E 1765, *Annual Book of ASTM Standards: 2002*. Vol. 04.12. West Conshohocken, PA: ASTM International.

Appendix A: A Nation at Risk

Human losses from the events of September 11th were 2 749 fatalities at the World Trade Center site,[112] 189 fatalities at the Pentagon, and 44 passengers and crew fatalities at the Pennsylvania plane crash site. In addition, numerous individuals at these locations sustained serious injuries. In the weeks following the September 11th attacks, the spread of inhalation anthrax through the postal system caused the deaths of five individuals among the confirmed cases of the disease, as well as expenditures of almost $1 billion to test for, remediate, and prevent anthrax contamination.[113]

The total costs of the September 11th and anthrax dispersion events are difficult to quantify. In addition to the loss of life, these terrorist attacks strained public consciousness, disrupted the conduct of business and finance, destroyed infrastructure and property, undermined several industries (such as travel and tourism), and prompted military actions. Estimated insured property losses from the September 11th attacks exceed $20 billion, which is over 20 times greater than the second most costly terrorist attack, the 1993 IRA bombing near London's Natwest Tower. The insured property and infrastructure losses from September 11th are over 150 times those due to the 1995 bombing of the Alfred P. Murrah Building in Oklahoma City. If life, liability, and worker's compensation insurance are included, all insured losses from the September 11th attacks exceed $40.2 billion. This amount is twice the insured losses from Hurricane Andrew in 1992, the second most costly disaster in the world.[114]

A.1 Constructed Facilities at Risk

To appreciate the potential losses that could arise from terrorist attacks, we need an inventory of facilities that might be at risk. Constructed facilities at risk include infrastructure, non-residential buildings, and industrial facilities. Infrastructure includes transportation, water resource management, and energy delivery facilities. Example of nonresidential buildings are offices, education, and mercantile buildings. Industrial facilities include oil refining, chemical manufacturing, and power plants. Table A-1 presents a detailed classification of constructed facilities that could be considered at risk of terrorist attack.[115]

The value of these facilities can be measured by their replacement cost, their contents, or the value of the services and use that they provide. Other facilities have historic or symbolic value; loss or damage to these facilities may impose substantial cultural, psychic, or emotional costs on the populace.

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[112] Lipton, "New York Settles on a Number That Defines Tragedy," p. B7.

[113] Gugliotta and White, "Tests Clear Home, Mail of Anthrax Victim," p. A1.

[114] Hartwig, "The Long Shadow of September 11," pp. 13, 14, 17, 20 and 21.

[115] This report focuses on the building protection decisions facing owners and managers of non-residential facilities. Although they have not been targets in the United States, residential buildings, especially high-rise structures located in larger cities, could be potential targets. The analysis developed in this report can be applied to residential buildings.

Table A-1 Proposed Classification of Constructed Facilities

Infrastructure			
	Transportation		
		Bridges	
		Roads/Highways	
		Railroads	
		Canals/Waterways	
		Transshipment Facilities	
			Airports
			Rail Stations
			Marine Facilities
	Communications		
	Water Resources Management		
		Dams and Reservoirs	
		Levees and Locks	
		Water Treatment	
		Water and Waste Water Treatment	
		Potable Water Distribution	
	Energy Delivery		
		Electricity	
		Natural Gas	
		Oil	
Non-residential Buildings			
	Office		
	Education		
	Health Care		
	Mercantile and Service		
	Other		
Industrial Facilities			
	Oil Refining and Storage		
	Oil and Natural Gas Production		
	Chemical Manufacturing		
	Metals Refining/Manufacturing		
	Consumer Products Manufacturing		
	Pharmaceuticals Manufacturing		
	Electronics Manufacturing		
	Electricity Generating Power Plants		
		Coal-Fired	
		Hydroelectric	
		Nuclear	
		Other	
	Pulp and Paper Manufacturing		
	Other Manufacturing		
		Automotive	
		Aircraft	
		Miscellaneous Equipment and Components	

Table A-2 describes the stock of critical infrastructure and assets in the United States. Assets include the nation's telecommunications infrastructure, energy production and generation, and passenger and freight transportation networks. These assets provide services critical to the smooth functioning of the U.S. economy and society. Disruptions to the performance of these assets have the potential to quickly transmit from the site of disruption throughout the nation. Domestic energy production and raw materials processing facilities account for substantial capacity.

Table A-2 Critical Infrastructure and Assets in the United States: 2003

Infrastructure Type	Number	Units[116]
Electricity	2 800	Power plants
	130 million	Households and institutions served
	3.6 trillion	kWh consumed (2001)
Nuclear Power Plants	104	Commercial plants
	20 %	U.S. electrical generation capacity
Oil and Natural Gas	300 000	Producing sites
	4 000	Off-shore platforms
	Over 600	Natural gas processing plants
	153	Refineries
	Over 1 400	Product terminals
	7 500	Bulk stations
Chemical Industry & Hazardous Materials	66 000	Plants
Telecommunications	3.2 (2.0) billion	Kilometers (Miles) of cable
	20 000	Physical facilities
Aviation	5 000	Public airports
Passenger Rail and Railroads	193 080 (120 000)	Kilometers (Miles) of major railroads
	40 %	Of inner city freight
	20 million	Inner city resident use annually
	45 million	Passengers on trains and subways operated by local transit authorities
Highways, Trucking, and Busing	590 000	Highway bridges
Pipelines	3.2 (2.0) million	Kilometers (Miles) of pipelines
Maritime	300	Inland or coastal ports
Mass transit	500	Major urban public transit operators
Dams	80 000	Dams

Source: *The National Strategy for the Physical Protection of Critical Infrastructures and Key Assets*, White House, February 2003.

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[116] Common units in parentheses. All conversions based on Grimes, T. L., Suiter, R. C., and Williams, Juana. S. *Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices*. NIST Handbook 44 2003 ED (Gaithersburg, MD: National Institute of Standards and Technology, 2003), Appendix C.

The value of commercial real estate in the United States is an estimated $10.6 trillion. Of this amount, $5.5 trillion, or 52 %, represents the replacement cost of structures, $3.7 trillion (35 %) represents equipment and software, and $1.4 trillion (13 %) represents inventory.[117]

Table A-3 shows the stock of nonresidential buildings in the United States. In 1998 to 1999, non-residential buildings numbered almost 4.9 million, encompassing nearly 7.5 billion square meters (over 80 billion square feet).

Table A-3 Constructed Facilities at Risk: 1998, 1999[118]

Building Characteristics	Office	Education	Health Care	Mercantile /Service	Industrial	Other	All
Number of Buildings (thousands)	739	327	127	1 145	227	2 319	4 884
Building Floorspace (million m^2)	1 119	804	271	1 281	1 193	2 781	7 449
Building Floorspace (million ft^2)	12 044	8 651	2 918	13 786	12 836	29 939	80 174
Average Building Floorspace (m^2)	1 514	2 459	2 134	1 119	5 256	1 199	1 525
Average Building Floorspace (ft^2)	16 298	26 456	22 976	12 040	56 546	12 910	16 416

Sources: U.S. Department of Energy's CBECS (1999). Industrial building data from U.S. Department of Energy's MECS (1998).

Commercial real estate debt is another measure of the importance of the commercial building stock to the U.S. economy. At the end of 2000, this debt totaled $8.2 trillion, with 85 % in real estate and mortgage loans, 13 % industrial loans, and 2 % in lease receivables.[119] Commercial real estate debt links the real estate sector with the U.S. (and international) financial system. Any realized losses to financed real estate has the potential to be transmitted to the financial sector. Losses that are covered by insurance policies also potentially affect the financial system, such as in the aftermath of the September 11th attacks, the losses of which fell heavily on the insurance and reinsurance sectors. Commercial real estate debt is therefore a dimension by which the entire financial system is exposed to terrorism threats. Because of the pervasive influence of the financial sector on all other aspects of the economy, the potential for a disaster to transmit throughout the economy is considerable.

A.2 Risks, Hazards, and Consequences

The risks to the nation's homeland security can be decomposed into three elements: threat, vulnerability, and consequences. Threats refer to impending dangers. The threats to a nation's homeland security come from many sources and hazards. These threats may be realized both inside and outside the nation's borders. Threats may come

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[117] Hartwig, "The Long Shadow of September 11," p. 36.

[118] The number of office, education, health care, mercantile/service, and other buildings is based on 1999 data. The number of industrial buildings is based on 1998 data.

[119] Hartwig, "The Long Shadow of September 11," p. 37.

from physical attacks through the ground, the sky, or the air. The hazards which threaten a nation's constructed facilities may come in several forms: explosive, radiological, biological, or chemical.

Vulnerability refers to its susceptibility to experiencing such threats or suffering losses from attacks. The vulnerability of a constructed facility depends on several factors, as well. Among these factors are location, access, structural design, system components and configuration, construction materials, and surveillance and security measures. A facility's vulnerability may vary from threat to threat and hazard to hazard. Consequences are the negative outcomes due to realized threats. Potential damage from terrorist attacks may occur in the form of casualties, structural damage, loss of property and contents, and loss of use or business interruptions.

The risks facing different facilities will depend on several factors. Some researchers have attempted to develop psychological models to identify these factors, understand the decision process, and predict terrorist target selection.[120] Drake[121] examines the motives behind terrorist choices and actions. He also identifies the associated strategies and tactics that underlie the terrorist target selection process. Enders and Sandler[122] present an economic model of target selection, based on terrorist resources and the "relative prices" of different modes of attack. Plausible factors that they identify include location of a facility, its profile or symbolic significance, its occupants and tenants, and its vulnerability. Kunreuther and Heal[123] discuss the sets of challenges associated with interdependencies. They present a game theoretic model in which the interdependence of security between the two firms means that if one firm does not invest, then the payoffs from any investment that the other firm makes are completely negated. They show that the incentive for a firm to invest in mitigation and protection decreases if others who can contaminate it decide not to allocate funds for mitigation.

Terrorist threats can take many forms. While smaller-scale attack scenarios, such as abduction or assassination, are possible, the typical characterization of these terrorist threats is chemical, biological, radiological, and explosive (CBRE). Each of these four types of attacks are capable of indiscriminately inflicting massive casualties, physical damage, and psychological trauma among large populations and localities.

Building owners and managers may also recognize the dual effect that protecting buildings from terrorism hazards has on protection against other types of hazards. Some of the other types of hazards that can be considered include natural hazards (such as earthquakes, tornadoes, winter weather, wildfires, floods, hurricanes), industrial

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[120] Weaver, Ransom, Silverman, Barry, Shin, Hogeun, and Dubois, Rick. "Modeling and Simulating Terrorist Decision-making: A 'Performance Moderator Function' Approach to Generating Virtual Opponents," *Proceedings of the Tenth Conference on Computer Generated Forces and Behavioral Representation,* Norfolk, VA, May 15-17, 2001, pp. 39-44. Johns, Michael and Silverman, Barry. "How Emotions and Personality Effect the Utility of Alternative Decisions: A Terrorist Target Selection Case Study," *Proceedings of the Tenth Conference on Computer Generated Forces and Behavioral Representation,* Norfolk, VA, May 15-17, 2001, pp. 55-64.

[121] Drake, *Terrorists' Target Selection,* pp. 35-72 and pp. 175-182.

[122] Enders, Walter, Sandler, Todd, and Cauley, Jon. "UN Conventions, Technology and Retaliation in the Fight against Terrorism: An Econometric Evaluation," *Terrorism and Political Violence*, Vol. 2, No. 1, Spring 1990, pp. 83-105.

[123] Kunreuther, Howard and Heal, Geoffrey. "Interdependent Security," *Journal of Risk and Uncertainty,* Vol. 26, No. 2-3, March-May 2003, pp. 231-249.

accidents, sabotage (such as by disgruntled employees, protestors, or others), crimes such as theft or arson, espionage, cyber attack, and conventional war. Structural improvements, such as in design or materials, that fortify a building against high explosives, for example, may also protect the building from strong winds or other natural hazards.

A.2.1 A Classification of Hazards

When considering the effects of strategies designed to mitigate the risk of terrorist and other hazards to constructed facilities, the focus lies on reductions in losses if a building suffers a disaster. However, protective measures may also affect other aspects of a disaster in ways that ultimately affect its consequences for the building owner and manager, occupants, and other parties. A classification method based on the responsiveness of various aspects of hazardous events to protective measures helps illustrate and clarify the overall effectiveness of mitigation measures on hazards, beyond their direct effect on limiting damage.

This classification is determined by the degree to which three aspects of a hazard respond to the risk mitigation measures that the building owners and managers implement. Three dimensions of the hazardous event are: (1) the probability that a hazardous event will occur; (2) the type of hazardous event that may occur; and (3) the shift in the risk of the hazardous event to other parties.

A.2.2 Three Dimensions of Hazards

The responsiveness of the probability that an event will occur to risk mitigation measures is straightforward. The likelihood of an event ranges from completely unresponsive to building protection, such as natural hazards, to completely responsive, such as terrorism.

Similarly, for the second aspect of hazardous events, the responsiveness of the type of event that occurs can range from completely unresponsive to risk mitigation measures, such as severity of a hurricane or even type of natural hazard (earthquake vs. flooding vs. tornado), to completely responsive, such as terrorist choice of mode or scale of attack.

Finally, a building owner's risk mitigation choices may lead to a shift in risk to other parties. This third characteristic is partially related to the first aspect concerning the probability of a hazardous event's occurrence. For some hazardous events, a reduction or increase in the probability of a hazardous event in response to a facility's protection choices may lead to an increase or reduction, respectively, in the risk faced by other facilities that are similar or nearby. Shifts in risk toward other similar[124] facilities could occur if attackers, observing the protective measures taken at the facility, were to view these targets as substitutes for the protected facility. Shift in risk away from nearby facilities may occur if the attackers are deterred by protection in place. If an attack on a nearby target is deterred, the risk to neighboring facilities may be reduced because of the

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[124] Similarity of alternate targets implies that an attack on the alternate target would accomplish the same objectives as an attack on the initial target.

lower likelihood that they will suffer collateral damage.[125] The risk-shifting dimension of building protection is based on the potential deterrent effect of protective measures. Deterrence, in turn, depends in part on the availability of information about building protection to potential attackers. If protective measures are implemented without the knowledge of outsiders, then the deterrent effect, and the potential effect of risk shifting, may not be in play.

A.2.3 Examples and Illustrations

Table A-4 and Figure A-1 are two ways of illustrating this classification scheme. Table A-4 conveys a qualitative representation of the responsiveness that the different types of hazards have to mitigation, while Figure A-1 is a spatial representation. The hazards can be classified by the degree and extent of their responsiveness to building protection. The classification helps us predict what types of hazards will be affected by mitigation strategies and how they will be affected.

Table A-4 Responsiveness Classification of Hazards

Type of Hazard	Responsiveness of Characteristic to Mitigation			Purpose and Intent?
	Probability of an Event	Type of Event	Risk Shifting to Other Parties	
Natural Hazard	Low/None	Low/None	Low/None	No
Accident	Moderate (Prevention)	Moderate (Avoidance)	Low/None	No
Sabotage	High (Deterrence, detection)	High (Deterrence)	Low to Moderate	Yes
Terrorism	High (Deterrence, detection)	High (Deterrence)	High	Yes

In Figure A-1, hazards located in the nine rightmost cubes, for example, can be deterred by building protection. Hazards located in the nine cubes that make up the top layer of the figure will vary by type, depending on building protection choices. Several hazards are considered to demonstrate this classification scheme.

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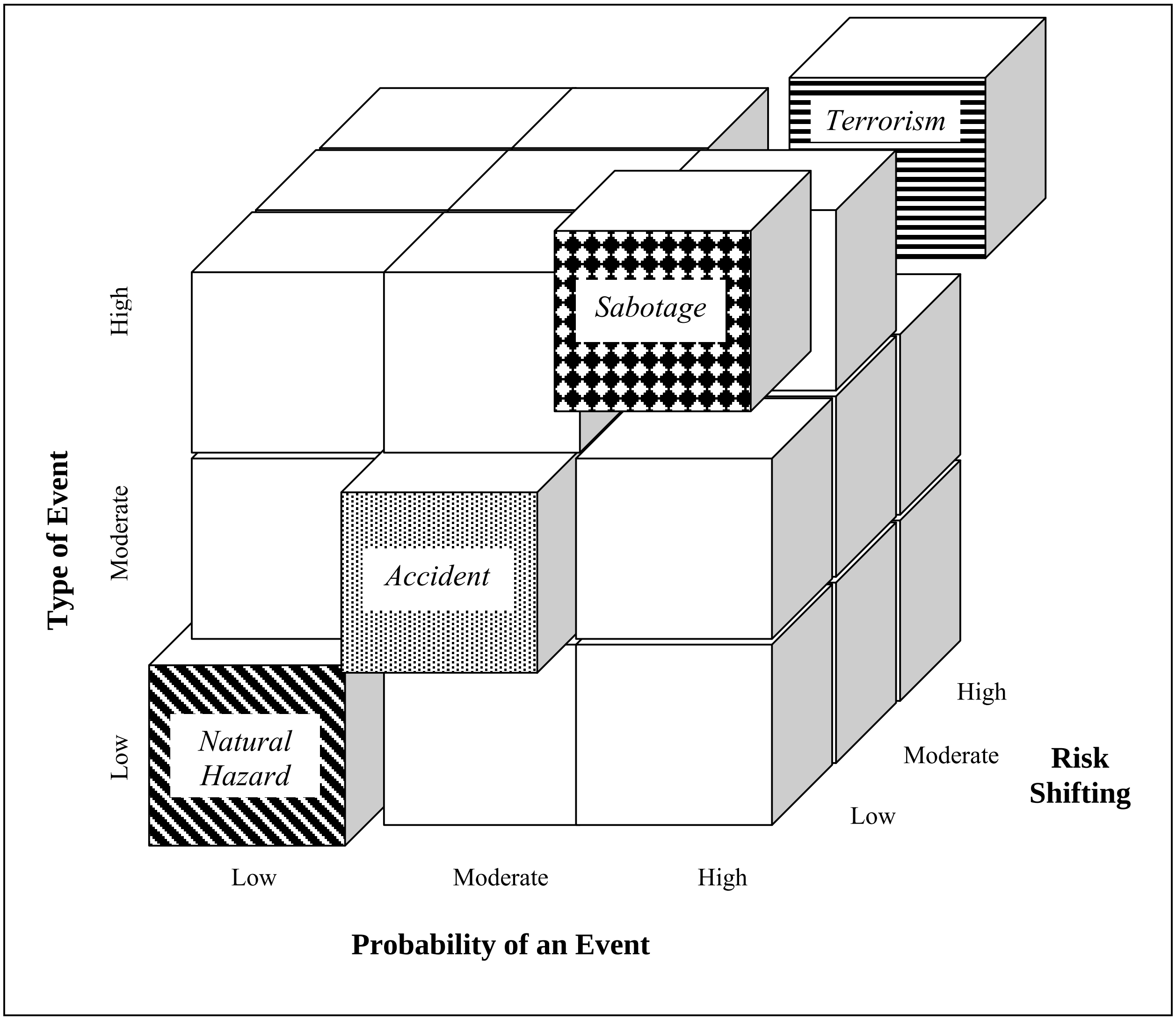
[125] The collapse of the twin towers of the World Trade Center from the September 11th attacks provides an example of the potential for extensive collateral damage. Although these two buildings were targeted and attacked, a total of seven buildings and one bridge were destroyed, seven more buildings suffered severe damage, and an additional 15 buildings suffered moderate damage (Hartwig, "The Long Shadow of September 11," p. 7).

Figure A-1 Classification of Hazards by Responsiveness to Mitigation



A.2.3.1 Natural Hazards

For natural hazards, the likelihood of an event is completely unresponsive to protection measures. Natural hazard events are not purposive. The probability of their occurrence is not affected by any mitigation measures that building owners and managers put in place. The type of event that occurs, such as earthquake vs. hurricane, or level 3 vs. level 5 hurricane, is also not affected by building protection. Furthermore, implementing effective mitigation reduces the building's risk and vulnerability to natural hazards, for both the building owner or manager and for society as a whole, so that no risk shifting occurs. Any reduction in risk due to a building owner or manager's choices about building protection does not lead to an increase in risk to other parties, and is therefore an absolute reduction of the social risk. Natural hazards are represented by the diagonally striped cube in Figure A-1. In general, this cube represents an event whose probability, variety, and shifts in risk are minimally affected by the building's mitigation measures. In the case of a hurricane, for example, mitigation measures at one facility do not affect the probability that a hurricane will hit it, nor will it affect the severity of the hurricane, nor will it cause the hurricane to move to an unprotected facility.

A.2.3.2 Accidents

Accidents, represented by the shaded cube, share some similarities with natural hazards. Accidents are not purposive, and mitigation can limit their negative consequences. In addition to reducing the severity of damage, preemptive mitigation measures or safeguards can prevent or reduce the likelihood of accidents. The likelihood of accidents is therefore classified as moderately responsive. Mitigation may affect the type of accident that can occur, if the safeguards are more focused on preventing one kind of accident (such as a chemical spill) than another. Therefore, the responsiveness of type of accident event to mitigation is also considered "moderate." Because accidents do not involve strategic behavior, in the sense that an accident does not "choose" the most vulnerable target, the reduction in probability of an accident occurring at one facility will not lead to an increased probability at another facility. The risk will not shift. As with natural hazards, a reduction in risk to the building owner is absolute and also represents a commensurate reduction in risk to society.

A.2.3.3 Sabotage

Sabotage, denoted by the checkerboard cube, is another type of hazard that owners of commercial office buildings, industrial facilities, and infrastructure face. Sabotage is purposive and can be prevented or deterred through mitigation, so the probability of sabotage is highly responsive to protective measures. The type of mischief that a saboteur chooses may also be affected by protective measures, if the saboteur identifies and exploits the weaknesses at a facility. To what extent the risk of sabotage shifts to other parties if a building owner implements protective measures depends on the motives of the saboteur. For sabotage by a disgruntled employee, for example, the risk may not shift if damaging another party would not satisfy the need of that employee (for revenge against the employer, for example). In the case of sabotage by protestors, however, the risk may shift to other, softer buildings or facilities possessing the attributes that the protesters find objectionable. For this reason, the responsiveness of risk shifting to other parties due to building protection is considered low to moderate, although it is represented as "low" in Figure A-1.

A.2.3.4 Terrorism

The case of terrorism, represented by the horizontally striped cube, is the extreme case, in which both the consequences and the probability of an event are affected by the mitigation choices of the building owner or manager. Effective mitigation may lower the probability of a terrorist event through increased deterrence and detection. Mitigation may also lead terrorists to abandon one mode of attack (such as a car bomb) for another (such as a rocket-propelled grenade). But unlike natural hazards and industrial accidents, terrorism involves the possibility of strategic behavior. Terrorists can make decisions about whether, where, when, and how to attack based on the mitigation decisions of building owners and managers. Terrorists who are intent on causing harm may observe mitigation and protection measures at the preferred target. The terrorists may look for a substitute target that is more vulnerable (i.e., a “softer” target) rather than attack its preferred target and accept a lower likelihood of causing damage, devote more resources to the attack, choose an alternate mode of attack, or face a higher chance of detection. With protective measures, the risk from the terrorist hazard shifts from the protected facility to less protected facilities. Although the building owner or manager who implements risk mitigation measures has reduced that building’s exposure to terrorist risk, these risk mitigation measures may leave overall terrorist risk unchanged, so that society as a whole is not necessarily safer from terrorist attack.

Appendix B: Process for Identifying and Classifying Benefits and Costs

This appendix outlines a three-step process for identifying and classifying benefits and costs. First, information was solicited from members of the Office of Applied Economics cost-effectiveness project team. This information was used to develop candidate lists of key stakeholder[126] classes (e.g., building owners) and general types of benefits and costs. Second, the lists were refined and organized into a suite of "classification" hierarchies. Third, the classification hierarchies were presented to the members of the Steering Committee, a cross section of subject matter experts from industry and government who provide advice and guidance to the cost-effectiveness project team. Following the Steering Committee meeting, additional comments on the hierarchies were solicited from both the Steering Committee and the project team. These interactions were used to finalize the classification hierarchies presented in this appendix and to outline a "priority setting" procedure that facilitates the collection of the types of data needed to generate the year-by-year estimates used as inputs to the economic evaluation methods presented in Chapter 4.

B.1 Identification of Key Stakeholders

Because individual stakeholders are affected in different ways by homeland security investment decisions, it is useful to first identify classes of individual stakeholders and then classify them into stakeholder groups. By developing a classification hierarchy of stakeholders, we are better able to *understand and identify* both potential opportunities (i.e., real or perceived benefits and cost savings accruing to that stakeholder) and potential barriers (i.e., real or perceived costs and benefit reductions borne by that stakeholder) to the use of the mitigation strategies described in this report.

Since individual stakeholder classes evaluate the benefits and costs of the mitigation strategies purely from their "stakeholder" viewpoint, it is important to reflect not only that viewpoint, but the viewpoints of aggregations of stakeholder classes (i.e., a single stakeholder group or a collection of stakeholder groups) and all stakeholder groups as well. The viewpoint of the individual stakeholder is important because they make the decision of whether or not to utilize a particular mitigation strategy. Examples of individual stakeholder classes are building owners, engineering consultants, and trade associations. A single stakeholder group is a special aggregation of individual stakeholders classified according to a common theme. An example of a stakeholder group is construction and associated support services. This stakeholder group contains five classes of individual stakeholders: construction workers, general contractors, specialty trade contractors, trade associations, and wholesale/retail trade/supply. A collection of stakeholder groups is important because an individual stakeholder class may be a key player in several stakeholder groups. The overall picture (i.e., all stakeholder groups) is important because it reflects the benefits and costs of the mitigation strategies to society. The government's approach to homeland security is undertaken from

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[126] Stakeholders are organizations or individuals directly affected by mitigation activities or disaster-related losses.

society's frame of reference. Thus, it includes all benefits and costs to whomsoever they accrue.

Table B-1 is a hierarchy of stakeholders; it lists stakeholder groups with their corresponding classes of individual stakeholders. It shows how the stakeholder groups are formed. The eight stakeholder groups are listed in a ***bold-italics*** typeface. The classes of individual stakeholders are listed in alphabetical order beneath each stakeholder group.

Table B-2 is a hierarchy of customers. Throughout this report, we make a distinction between stakeholders and customers. Customers are the intended users of the economic tools (i.e., economic evaluation methods and software for implementing those methods); they are either directly or indirectly empowered to decide which combination of mitigation strategies to employ. Therefore, customers are a subset of stakeholders. Table B-2 shows how customer groups are formed. In Table B-2, the eight customer groups are listed in a ***bold-italics*** typeface. The classes of individual customers are listed in alphabetical order beneath each customer group.

The methodology described in this report encompasses all stakeholder groups. However, if analyses from the perspective of a single stakeholder or stakeholder group were desired, Table B-1 could be used to structure these analyses (see Section B.4). In such cases, Table B-1 may be used to select which class (classes) of individual stakeholders is (are) appropriate.

B.2 Classification of Benefits and Cost Savings Derived from the Use of Mitigation Strategies

Stakeholders and customers of the software tool choose among alternative combinations of mitigation strategies because they anticipate receiving, in present value terms, benefits or cost savings in excess of the costs or benefit reductions associated with these choices. Table B-3 provides a framework for one side of the stakeholder/customer investment decision problem: namely, how to identify homeland security-related benefits and cost savings from society's frame of reference (i.e., across all stakeholder groups).

Table B-3 is organized as a three-tiered hierarchy. It is the culmination of the Office of Applied Economics cost-effectiveness project team's efforts to produce a consensus on a comprehensive list of homeland security-related benefits and cost savings.

The first tier of the hierarchy lists generic types of benefits and cost savings. The three first tier elements—financial incentives, cost savings, and other benefits—are in white font against a black background.

The second tier lists specific types of benefits and cost savings associated with its "parent" first tier element. Note that the first tier elements are subdivided into event related costs and non-event related costs. These first-tier subheadings are shown in *italics*. For example, for cost savings, its second tier event-related elements include reduced damages and fewer fatalities, illnesses, and injuries.

The third tier lists specific types of benefits and cost savings associated with its "parent" second tier element. For example, for tax advantages, its third tier elements include forgiveness of sales tax, investment tax credits, and reduced assessments.

Table B-1 Hierarchy of Stakeholders by Groups and Classes of Individual Stakeholders

Owners, Managers, and Developers
- Buildings (Private Sector, Public Sector Civilian, Public Sector Military)
- Industrial Facilities
- Infrastructure (Private Sector, Public Sector Civilian, Public Sector Military)

Construction and Associated Support Services
- Construction Workers
- General Contractors
- Specialty Trade Contractors
- Trade Associations
- Wholesale/Retail Trade/Supply

Codes, Standards, and Support Services
- Building/Industrial Facility/Infrastructure Owners
- Building/Industrial Facility/Infrastructure Permitting and Inspection
- Code Officials
- Code Organizations
- Construction Products/Equipment Manufacturers
- Professional Societies
- Product Certification Services
- Product Evaluation Services
- Research Organizations
- Standards Organizations
- Trade Associations

Manufacturing Interest Groups
- Construction Products/Equipment Manufacturers
- Customer Service Operations
- Product/Equipment/Software Designers
- Product/Equipment/Software Innovators
- Product/Equipment/Software Marketing, Sales, and Distribution Services
- Professional Societies
- Research Organizations
- Testing Laboratories
- Testing Services
- Trade Associations

Government Programs and Support Groups
- Elected Officials
- Disaster Assistance
- Emergency Preparedness
- Emergency Response
- Financial Planning
- Policy Makers
- Regulators: Nuclear Regulatory Commission, FAA, Office of Pipeline Safety
- Investigators: NTSB, National Construction Safety Team
- Specialized Federal, State, and Local Programs

Professional Services
- Architects
- Designers
- Engineering Consultants (Asset Evaluation, Cost and Value Engineers, Electrical Engineers, Fire Protection Engineers, HVAC/Mechanical Engineers, Security Consultants, Structural Engineers)
- Financial Institutions
- Insurance Companies: Direct and Reinsurance
- Real Estate Services
- Warranty Companies

Research and Policy Analysis Groups
- Financial Institutions
- Insurance Companies: Direct and Reinsurance
- Research Organizations

Other
- Customers/Users
- Occupants/Tenants/Employees/Visitors
- Special Interest Groups
- Third Parties

Table B-2 Hierarchy of Customers by Groups and Individual Customers

Civilian Government Operations

- Federal
    - Architect of the Capitol
    - DOD
    - DOE
    - Federal Facilities Council
    - GSA
    - Interagency Security Committee
    - Justice Department
    - State Department: Overseas Building Operations
    - Transportation Department
    - Treasury Department
- State and Local
    - Education: K-12, Colleges, Universities, and Vocational
    - Office
    - Public Assembly
    - Public Order and Safety: Courthouses, Fire Stations, Police Stations
    - State and Local Departments of Transportation

Military Installations

- Domestic and Overseas
- DTRA

Government Policy

- Department of Commerce
    - Economic Development Administration
    - Economics and Statistics Administration
- Department of Homeland Security
    - FEMA
    - National Infrastructure Protection Center
- Department of Justice: FBI
- White House: Executive Office of the President
    - Domestic Policy Council
    - Office of Homeland Security
    - Office of Science and Technology Policy

Private Sector Operations

- Owners
- Managers
- Developers

Professional Societies/Trade Associations

- AACE International
- ASME International
- CERF
- CII
- NIBS
- SAVE International
- TISP

Other Research Organizations

- ASME International
- ASTM International
- CERF
- CII
- ISO
- National Labs
- NIBS
- Universities with Construction Management Programs
- Wharton Risk Management and Decision Processes Center

Codes, Standards, and Support Services

- Code Organizations
- Standards Organizations

Professional Services

- Architects
- Designers
- Engineering Consultants (Asset Evaluation, Cost and Value Engineers, Electrical Engineers, Fire Protection Engineers, HVAC/Mechanical Engineers, Security Consultants, Structural Engineers)

Table B-3 Classification of Benefits and Cost Savings Derived from the Use of Mitigation Strategies

Financial Incentives		
Event Related		
	Lower Deductibles	
Non-Event Related		
	Cost-Sharing Arrangements	
	Federal Funding for Critical Assets	
	Reduced Insurance Premiums	
	Lower Financing Costs	
	Preferred Designation	
	Tax Advantages	
		Accelerated Depreciation
		Expensing Capital Investments
		Forgiveness of Sales Tax
		Investment Tax Credits
		Reduced Assessments
		Set Asides
		Tax Deductions
Cost Savings		
Event Related		
	Fewer Fatalities, Illnesses, and Injuries	
	Reduced Damages	
	Reduced Down Time	
Non-Event Related		
	More Efficient Systems	
		Energy Conservation
		Enhanced Control
		Improved Indoor Air Quality
		Reduced O&M Costs
Other Benefits		
Event Related		
	Potential for Addressing Multiple Hazards	
	Reduced Liability (Due to Use of Best Practices)	
	Less Likely Target: Building and Vicinity	
Non-Event Related		
	Better Able to Attract Tenants	
		Higher Occupancy Rate
		Increased Rental Income
		More Marketable
	Higher Employee Retention (Due to Reduced Labor Turnover)	
	Improved Public Relations (Due to Stewardship Issues)	
	Increased Productivity (Due to More Efficient Systems)	
	Increased Resale Value/Faster Property Turnover	
	Rental Premium	

It is important to recognize that the benefits and cost savings listed in Table B-3 might accrue to any individual stakeholder (i.e., they are aggregated according to society's frame of reference). Thus, Table B-3 is structured from "society's" frame of reference rather than from the perspective of a single stakeholder or stakeholder group. The main purpose of Table B-3 is to illustrate how the government approaches the social "benefits" side of the alternative mitigation strategies. Specifically, BFRL used this table to identify the data needed to measure these "broader" impacts. From the government's point of view, Table B-3 identifies the potential "benefits" data links. However, if the focus is on an individual stakeholder or stakeholder group, it will be necessary to develop a cross-reference between the generic types of benefits and cost savings listed in Table B-3 and the stakeholder groups listed in Table B-1. This cross-reference is the subject of Section B.4.

A potential benefit from building protection is economic spillovers. Some improvements, such as structural retrofits, modernized heating and ventilation systems, and increased perimeter security, may improve the performance of a building in ways other than reducing damage from terrorist threats. A building ventilation system with a larger fresh air shaft, more filtering and air circulation, and floor-by-floor air handling units, for example, may be intended to reduce vulnerability to chemical or biological contamination. However, it may lead to superior overall air quality, which has been linked to increased worker productivity.[127] Studies have also linked thermal controls to modest productivity improvement.[128] Government agencies have also reported anecdotal evidence of spillovers: tighter perimeter access following the September 11th attacks due to broad security concerns has had the additional effect of reducing the number of petty theft and vehicle vandalism incidents.

There is potential asymmetry, however, in the bearers of the upgrade costs and the beneficiaries of the economic spillovers. If the building owners provide the outlays for the improvements, but the spillover benefits accrue entirely to tenants and visitors, then financial incentive for improvements will not exist, and the level of investment in improvements would be sub-optimal. Benefits such as labor productivity improvements and crime reduction typically accrue to building tenants and occupants, rather than owners. In cases where the building owner and the building occupant are distinct from each other, these benefits are spillovers, which must be appropriable by building owners in order for these spillovers to be incentives. This linkage of incentives can occur through increased leasing rates to tenants. Another avenue of appropriation is in higher property value of fortified buildings. Whether or not the building owner is also the building occupant, a rise in the property value that reflects the investments in structural improvements is another financial incentive in its own right. Intuitively, property values would respond to risk mitigation that is embodied in the structure or system, such as hardening of the building shell, in contrast to un-embedded mitigation, such as security personnel-based patrolling measures.

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[127] Fisk, William J. "Health and Productivity Gains from Better Indoor Environments and Their Relationship with Building Energy Efficiency," *Annual Review of Energy and the Environment*, Vol. 25, 2000, pp. 537-566.

[128] Lomonaco, Carol and Miller, Dennis. "Comfort and Control in the Workplace," *ASHRAE Journal*, Vol. 39, No. 9, September 1997, pp. 50-56.

B.3 Classification of Costs and Benefit Reductions Associated with Risks or the Use of the Mitigation Strategies

Costs are at the heart of any decision to select among the key mitigation strategies. Costs are incurred at several points in the life cycle of a typical constructed facility. These costs and benefit reductions are summarized in Table B-4, which is organized as a three-tiered hierarchy.

Because Table B-3 and Table B-4 are used to measure the "benefits" and "costs" sides of the mitigation strategies, the end product of these classification hierarchies is a collection of economic data. In the case of homeland security-related costs and benefit reductions, the depth of the hierarchy (i.e., the number of tiers) is equal to three. In principle, the depth of these data-related classification hierarchies could be equal to one, to two, to three, or to some number greater than three. The rule governing the depth of the hierarchy is how far down in the hierarchy one must go until all lowest level elements in the hierarchy are indicative of economic data. For homeland security-related costs and benefit reductions, three tiers were considered adequate.

The first tier of the hierarchy in Table B-4 lists generic types of costs and benefit reductions. The three first tier elements—capital investment, operations, and maintenance, and other—are listed in white font against a black background.

The second tier lists specific types of costs and benefit reductions associated with its "parent" first-tier element. Note that the first-tier elements are subdivided into event-related costs and non-event related costs. These first-tier subheadings are shown in *italics*. For capital investment, its second-tier event related elements include expected damages; its second-tier, non-event related elements include first costs and new technology introduction costs.

New-technology introduction costs merit a closer examination. Ehlen and Marshall[129] define new-technology introduction costs as those costs covering the activities that bring the material/product from the research laboratory to full field implementation. New-technology introduction costs include the extra time and labor to design, test, monitor, and use the new technology. These costs are documented under the third tier of the classification hierarchy. Ehlen's and Marshall's research on new-technology introduction costs has a bearing on homeland security applications because they demonstrate that new-technology introduction costs disappear once the designer is satisfied with the technology's performance and service life, the technology enters full implementation, and its application has become routine.

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[129] Ehlen, Mark A., and Marshall, Harold E. *The Economics of New-Technology Materials: A Case Study of FRP Bridge Decking*. NISTIR 5864 (Gaithersburg, MD: National Institute of Standards and Technology, 1996).

Table B-4 Classification of Costs and Benefit Reductions Associated with Risks or the Use of Mitigation Strategies

Capital Investment		
Event Related		
	Expected Damages	
Non-Event Related		
	Conversion Costs	
	Decommissioning	
	First Costs	
	Future Upgrades	
	Major Replacements	
	New Technology Introduction Costs	
		Increased Costs of Adapting New Construction Technologies, Products, Equipment, and Practices to Industry Use
		Increased Risk Exposure and Uncertainty Due to Construction with New Technologies, Products, Equipment, or Practices
	R&D for Product Development and Testing	
	Site Protection	
	Special Security Features	
O&M		
Event Related		
	Business Interruptions	
Non-Event Related		
	Equipment Maintenance and Repair	
	Insurance Premiums	
	IT Security	
	Site Security	
	Site Utilities	
	Specialized Training	
Other		
Event Related		
	Denial of Service	
	Fatalities	
	Legal Liability	
	Non-Fatal Illnesses and Injuries	
Non-Event Related		
	Cost Burdens on Users/Producers/Customers	
	Costs of New Standards Development	
	Marketing, Advertising, and Distribution Costs for New Technologies, Products, Equipment, or Practices	
	Reduced Functionality	
	Transshipment Cost	

B.4 How Benefits and Costs Accrue to Stakeholders

In Sections B.2 and B.3, homeland security related benefits and costs were identified from society's frame of reference. Thus, it includes all benefits and costs to whomsoever they accrue. Although this is the traditional approach for public-sector economic studies, it is too broad for most stakeholder groups. This is because most stakeholder groups want to evaluate the benefits and costs accruing to them for choices among the key mitigation strategies. In addition, the traditional approach employed in public-sector studies complicates the data collection effort. Basically, the higher the level of abstraction, the more difficult it becomes to define data "categories" and collect the types of economic data that lead to meaningful results. To address this "complicating" factor, this study develops two cross-references between stakeholder groups and: (1) benefits and cost savings and (2) costs and benefit reductions. The two cross-references are presented as Table B-5 and Table B-6. Table B-5 lists key types of benefits and cost savings by stakeholder group; Table B-6 lists key types of costs and benefit reductions by stakeholder group.

The two cross-references serve three purposes. First, they define in an unambiguous manner all of the potential data categories from which to collect economic data. In fact, each data category may be specified as a unique combination of stakeholder group and type of benefit or type of cost. Second, the cross-references promote a priority-setting process for identifying what specific types of data to collect and where to collect them. For example, if we know that four stakeholder groups—building owners, managers, and developers, construction and associated support services, professional services, and other—are beneficiaries of increased resale value (see the cells beneath the "stakeholder group" column headings in Table B-5 with check marks (✓)), then we can focus our "resale value" data collection effort on these four stakeholder groups. Thus, the data collection strategy, stated in its simplest terms, is to limit the data collection effort to those cells of Table B-5 and Table B-6 with check marks (✓). This priority-setting approach to data collection is employed in this report. Finally, the cross-references provide the means through which an individual stakeholder/customer or stakeholder/customer group may evaluate the pros and cons of choosing among combinations of mitigation strategies. Thus, the cross-references both simplify the presentation of material in this report and provide the framework for identifying key data elements and for specifying a data collection strategy for individual customers/stakeholders.

An expanded discussion of the third purpose of the cross-references is used to illustrate how to apply the decision methodology presented in Chapter 4. This illustration is best understood by considering a specific stakeholder group, say building owners, managers, and developers. If building owners, managers, and developers are choosing among the key mitigation strategies, they need to know if the life-cycle cost over the proposed study period of a given combination of mitigation strategies is less than that of maintaining the *status quo*.

The first step in this "decision problem" is to identify the types of benefits and the types of costs. The "benefits" accruing to and the "costs" borne by building owners, managers, and developers are recorded in the first "stakeholder group" column of Tables B-5 and B-6, respectively. Reference to Table B-5 shows that building owners, managers, and developers benefit from all 19 types of benefits and cost savings. Examples of specific types of benefits and cost savings accruing to building owners, managers, and developers are lower financing costs, reduced damages, and increased resale value.

Reference to Table B-6 shows that building owners, managers, and developers bear 23 of the 26 types of costs. The costs not incurred by building owners, managers, and developers are associated with R&D for product development and testing, new standards development, and marketing, advertising, and distribution costs for new technologies.

The second step is to compile a list of the types of benefits and the types of costs for which data are available and are relevant. The goal of the second step is to identify those data that will allow meaningful comparisons—based on life-cycle cost considerations—between the combinations of mitigation strategies being considered.

The third step is to collect the economic data. The economic data collected in the third step are used to support a life-cycle cost analysis of the combinations of mitigation strategies being considered.

Finally, evaluate the economic performance of each combination of mitigation strategies being considered. This is done by calculating the life-cycle cost for each combination of mitigation strategies and selecting the one that minimizes the life-cycle cost over the proposed study period.

The same procedure can be used for an individual stakeholder/customer class. First, select the individual stakeholder class. Then, refer to Tables B-1 and B-2 to identify the appropriate stakeholder group(s). Finally, follow the procedure just described to determine how to choose among combinations of mitigation strategies.

Table B-5 Types of Benefits (or Cost Savings) Classified by Stakeholder Group

Type of Benefit or Cost Saving	Stakeholder Group							
	Owners, Managers, & Developers	Construction & Associated Support Services	Codes, Standards, & Support Services	Manufacturing Interest Group	Gov't. Programs & Support Groups	Professional Services	Research & Policy Analysis Groups	Other
Financial incentives								
Cost-Sharing Arrangements	✓	✓		✓	✓		✓	
Fed. Funding for Critical Assets	✓				✓		✓	✓
Insurance-Based Incentives[130]	✓				✓	✓	✓	✓
Lower Financing Costs	✓	✓		✓		✓	✓	✓
Preferred Designation	✓		✓		✓	✓	✓	
Tax Advantages	✓			✓	✓		✓	✓
Cost Savings								
Fewer Fatalities, Illnesses, & Injuries	✓				✓			✓
Reduced Damages	✓				✓			✓
Reduced Down Time	✓				✓			✓
More Efficient Systems	✓	✓		✓		✓		✓

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[130] Insurance-based incentives include reduced insurance premiums and lower deductibles.

Table B-5 Types of Benefits (or Cost Savings) Classified by Stakeholder Group (continued)

Type of Benefit or Cost Saving	**Stakeholder Group**							
	Owners, Managers,& Developers	**Construction & Associated Support Services**	**Codes, Standards, & Support Services**	**Manufacturing Interest Group**	**Gov't. Programs & Support Groups**	**Professional Services**	**Research & Policy Analysis Groups**	**Other**
Other Benefits								
Potential for Addressing Multiple Hazards	✓		✓		✓	✓	✓	✓
Reduced Liability	✓	✓		✓				✓
Better Able to Attract Tenants	✓					✓		✓
Higher Employee Retention	✓							✓
Improved Public Relations	✓							✓
Increased Productivity	✓							✓
Increased Resale Value/Faster Property	✓	✓				✓		✓
Less Attractive Target: Building & Vicinity	✓				✓		✓	✓
Rental Premium	✓					✓		✓

Table B-6 Types of Costs (or Benefit Reductions) Classified by Stakeholder Group

Type of Cost or Benefit Reduction	**Stakeholder Group**							
	Owners, Managers,& Developers	**Construction & Associated Support Services**	**Codes, Standards, & Support Services**	**Manufacturing Interest Group**	**Gov't. Programs & Support Groups**	**Professional Services**	**Research & Policy Analysis Groups**	**Other**
Capital Investment								
Expected Damages	✓	✓	✓	✓	✓	✓	✓	✓
Conversion Costs	✓	✓	✓			✓		
Decommissioning	✓	✓	✓			✓		
First Costs	✓	✓	✓	✓		✓		
Future Upgrades	✓	✓	✓	✓		✓		
Major Replacements	✓	✓		✓		✓		
New Technology Introduction Costs	✓	✓	✓	✓		✓		✓
R&D for Product Development & Testing			✓	✓				
Site Protection	✓					✓		
Special Security Features	✓			✓		✓		
O&M								
Business Interruptions	✓				✓	✓		✓
Equipment Maintenance & Repair	✓			✓				
IT Security	✓			✓		✓		✓
Site Security	✓					✓		✓
Site Utilities	✓							✓
Specialized Training	✓			✓		✓		

Table B-6 Types of Costs (or Benefit Reductions) Classified by Stakeholder Group (continued)

Type of Cost or Benefit Reduction	Stake Holder Group							
	Owners, Managers,& Developers	Construction & Associated Support Services	Codes, Standards, & Support Services	Manufacturing Interest Group	Gov't. Programs & Support Groups	Professional Services	Research & Policy Analysis Groups	Other
Other								
Denial of Service	✓				✓			✓
Fatalities	✓				✓			✓
Legal Liability	✓	✓	✓	✓		✓		
Insurance Premiums	✓					✓		
Non-Fatal Illnesses & Injuries	✓				✓			✓
Cost Burdens on Users / Producers / Customers	✓	✓	✓	✓		✓		✓
Costs of New Standards Development			✓	✓		✓	✓	
Marketing, Advertising, & Distribution Costs for New Technologies, Products, Equipment, or Practices				✓			✓	
Reduced Functionality	✓							✓
Transshipment Costs	✓	✓		✓				✓

Appendix C: A Note on Calculating the Savings-to-Investment Ratio

In Section 4.2.3, we noted that the use of the savings-to-investment ratio (SIR) is inappropriate whenever $PVI'_j \leq PVI'_0$, where the subscript j refers to alternative A_j, and the subscript 0 refers to the base case, and the apostrophe (') indicates that expected losses are included in all present value (PV) expressions. This appendix provides the mathematical foundations for calculating the SIR and interpreting the results of that calculation. All derivations presented in this appendix are based on the life-cycle cost (LCC) method. Section 4.2.1, where the LCC method was described, demonstrated that alternative A_j was economically preferred to the base case if, and only if, $LCC_j < LCC_0$. Alternatively, the derivations presented in this appendix could be based on the present value net savings (PVNS) method. Both the LCC and PVNS methods lead to the same conclusions because, by definition (see Equation (4.11)), if $PVNS_{j:0} > 0$, then $LCC_j < LCC_0$.

Given that alternative A_j is economically preferred to the base case, we derive conditions for calculating the SIR and a decision rule for interpreting the results. If

$$LCC_j < LCC_0 \tag{C.1}$$

then through reference to Equation (4.9), and upon simplification

$$PVC'_j + PVI'_j < PVC'_0 + PVI'_0 \tag{C.2}$$

which implies

$$PVI'_j - PVI'_0 < PVC'_0 - PVC'_j \tag{C.3}$$

which, through reference to Equations (4.12) and (4.13), yields

$$PVII_{j:0} < PVS_{j:0} \tag{C.4}$$

If

$$PVII_{j:0} > 0 \tag{C.5}$$

or, equivalently,

$$PVI'_j > PVI'_0, \tag{C.6}$$

then

$$1 < \frac{PVS_{j:0}}{PVII_{j:0}}, \tag{C.7}$$

which, through reference to Equation (4.14), produces the decision rule

$$SIR_{j:0} > 1 \tag{C.8}$$

Thus, whenever $PVII_{j:0} > 0$, a necessary condition for alternative A_j to be economically preferred to the base case is $SIR_{j:0} > 1$. This decision rule was stated in Section 4.2.3.

If

$$PVII_{j:0} \leq 0 \tag{C.9}$$

then three possibilities occur. These possibilities are analyzed as Case 1, Case 2, and Case 3.

Case 1: $PVII_{j:0} = 0$

In this case, $SIR_{j:0}$ is undefined because the denominator is zero.

Case 2: $PVII_{j:0} < 0$ and $PVS_{j:0} > 0$

Assume Expression (C.1) holds, then by virtue of Expression (C.4) the following inequality holds:

$$PVII_{j:0} < 0 < PVS_{j:0} \tag{C.10}$$

which implies

$$1 > 0 > \frac{PVS_{j:0}}{PVII_{j:0}} \tag{C.11}$$

or, equivalently

$$SIR_{j:0} < 0 \tag{C.12}$$

Although a negative SIR seems counter-intuitive, Case 2 is easily explained. Since $PVS_{j:0} > 0$ and $PVII_{j:0} < 0$, alternative A_j produces greater savings at a lower investment cost than the base case. Hence, alternative A_j is economically preferred to the base case.

Case 3: $PVII_{j:0} < 0$ and $PVS_{j:0} \leq 0$

Assume Expression (C.1) holds, then by virtue of Expression (C.4) the following inequality holds:

$$PVII_{j:0} < PVS_{j:0} \leq 0 \tag{C.13}$$

which implies

$$1 > \frac{PVS_{j:0}}{PVII_{j:0}} \geq 0 \qquad \text{(C.14)}$$

or, equivalently

$$0 \leq SIR_{j:0} < 1 \qquad \text{(C.15)}$$

An economic interpretation of Expression (C.15) is whenever both savings and the change in the present value of investment costs are negative, in order for A_j to be economically preferred to the base case, its reductions in *PVII* must be greater than the corresponding reductions in savings. Intuitively, negative values of *PVII* are a desirable outcome whereas negative savings are not.

The material presented in this appendix demonstrates that whenever Expression (C.1) holds (i.e. alternative A_j is economically preferred to the base case) any value of the SIR could result. Only if $PVII_{j:0} > 0$ does a concise decision rule result; namely, choose alternative A_j whenever $SIR_{j:0} > 1$.

The complications imposed by Cases 1, 2, and 3 provide a rationale for why it is inappropriate to use the SIR as a decision criterion whenever $PVII_{j:0} \leq 0$. Use instead, LCC and/or PVNS. Both LCC and PVNS produce unambiguous results for the three cases examined in this appendix.

If the value of the SIR is computed by hand, in a spreadsheet, or through the use of any software package, and if either Case 2 or Case 3 occurs, then values less than 1 will result for which alternative A_j is economically preferred to the base case (i.e. $PVNS_{j:0} > 0$). If Case 1 results, then a value for the SIR can not be calculated due to an attempted division by zero. Thus, if any type of software package is used to calculate the value of the SIR, some warning message needs to be generated whenever $PVII_{j:0} \leq 0$, to alert the software user that the values of LCC and PVNS are the relevant decision criteria, and not the value of the SIR.

Appendix D: Theoretical Foundations of Risk Mitigation Decisions

The decisions about how much to spend on protecting constructed facilities and their occupants from terrorist risks and natural hazards, and what types of measures are appropriate, are some issues facing building owners and managers. The life-cycle cost approach and the software implementation that were presented in Chapters 4 and 5 are tools to support this decision-making process. The question of how much to spend for the case of a single building described in Section 6.1, however, merits additional theoretical treatment.

The theoretical approach in this appendix breaks the expenditure decision into its components. It illustrates, through the use of four models, how the different factors that affect the choice of strategy interrelate, and how those interrelationships determine the level of expenditure associated with the lowest life-cycle cost. Although the four models are based on a life-cycle cost approach, this theoretical approach simplifies the life-cycle cost analysis in Chapter 4. The theoretical models here evaluate only the optimal level of investments in engineering alternatives, expenditures in management practices, and insurance coverage. The models in this appendix assume each dollar of investment in engineering alternatives is the same in terms of its effect on costs and losses, whether it is used, for example, to upgrade an HVAC system or to install laminated glass. In the analysis in Chapter 4, the different types of engineering alternatives are treated differently, so that even if their investment cost is the same, the effect on other costs (such as O&M) and expected losses may not be. The models in this appendix also include elaboration of the expected losses component of life-cycle cost.

In these models, building owners and managers choose investment and expenditure in risk mitigation based on constrained optimization. There is considerable empirical evidence that decision-makers have systematic biases and utilize simplified decision rules in making choices about investment in protective measures.[131] The challenge is to develop prescriptions so that they come closer to making decisions using normative models of choice such as constrained optimization. Subject to budget constraints, the objective is for building owners and managers to choose engineering alternatives, management practices, and financial mechanisms that minimize life-cycle costs, including expected losses from terror threats. Engineering alternatives involve both physical investment as well as non-investment expenditures, such as O&M and other costs. Protective investments are capital resources that building owners and managers allocate to mitigate the risk that terrorism or natural hazards pose to their facilities. Investments refer to durable, capital goods, such as building structural components, building systems and subsystems, land, and machinery and mechanical equipment. Examples include HVAC systems, structural retrofits, and closed-circuit television cameras and monitors.[132] Budgetary outlays to operate and maintain

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[131] Kunreuther, Howard. "Protective Decisions: Fear or Prudence," Chapter 15, *Wharton on Making Decisions,* edited by Stephen Hoch and Howard Kunreuther (New York: John Wiley & Sons, Inc., 2001), pp. 259-272.

[132] Protective investments do not include expenditures for protection. Unlike investments, protective expenditures do not retain value beyond the point when the expenditure is made. Examples of protective expenditures are additional security patrols hired, the value of employee labor hours devoted to training and drills, and resources devoted to developing emergency plans and procedures.

engineering alternatives and to implement management practices and financial mechanisms, on the other hand, are considered expenditures.

The models presented in this appendix examine the decisions that building owners and managers can make to protect a single building. The sections that follow include the descriptions, assumptions, and results of the models. Model 1, in Section D.1, is the case where building owners and managers choose the level of investment in engineering alternatives during the initial period. This model illustrates which factors affect the level of protective investment that results in the lowest life-cycle cost. Section D.2 presents Model 2, which extends Model 1 to include decisions about expenditures to implement management practices in each period. Model 3, in Section D.3, further extends Model 2 by adding financial mechanisms. Building owners and managers can choose how much insurance to purchase in every period and can receive a proportional subsidy for the investments in the engineering alternatives. Model 4, presented in Section D.4, generalizes Model 3 to allow for investments in engineering alternatives in more than one period. In all models, it is assumed that there are no interdependencies between individuals and the probabilities are not affected by the decisions of others.[133] Model 4 is a cumulation of Model 1, Model 2, and Model 3. Model 4 can be presented independently of the first three. But, each of the first three models is presented in order to highlight the factors which determine each type of mitigation strategy: engineering alternatives, management practices, and financial mechanisms.

D.1 Model 1: Choosing Engineering Alternatives for Risk Mitigation

The optimal level of investment in engineering alternatives will be based on minimization of life-cycle costs, taking into consideration the reductions in losses if terrorism or natural hazards occur. The costs include any increases in O&M or other costs. Even though the building owner or manager makes only one investment (here in period 0) to protect the building, the life-cycle cost approach is appropriate as the costs and benefits associated with the one-time investment accrue over the duration of the study period.

In Model 1, the building owner or manager chooses how much to invest in engineering alternatives to minimize the life-cycle cost. This decision is made in period 0, given the initial conditions and budget constraint. This level of investment in engineering alternatives is denoted I_0. Equations (D.1) through (D.4) describe the optimization problem for the basic model over the study period, which lasts from period 0 to period T:

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[133] Because they are optimizations for building owners and managers, rather than society as a whole, the models abstract from risk mitigation externalities associated with the probability of attack in each period. Negative externalities due to investments in risk mitigation arise from changes in the relative price that the terrorist "pays" to inflict a given level of damage to a target. Positive externalities from risk mitigation measures occur when terrorists do not observe the protection level of individual buildings but know the probability that buildings in a neighborhood (or other level of locality) are protected (Ayres and Levitt, "Measuring Positive Externalities from Unobservable Victim Precaution," pp. 47-59). Inclusion in an analytical model is left as an area of future research.

$$\min_{\{I_0\}}\left\{I_0+\sum_{t=0}^{T}\frac{OM_t+O_t+E(L_t)}{(1+d)^t}\right\} \qquad \text{(D.1)}^{134}$$

subject to:

$$K_{-1}\geq 0 \qquad \text{(D.2)}$$

$$K_0-K_{-1}=I_0 \qquad \text{(D.3)}^{135}$$

$$I_0\leq B_0^C \qquad \text{(D.4)}$$

where:

I_0 is the investment in engineering alternatives in period 0; the price of each unit of protection, P_I, is normalized to one dollar, so I_0 represents the gross flow (in dollars) of engineering alternatives in period 0. I_0 is the sum of expenditures across all three building cost components (building/facility elements, building/facility site work, and non-elemental components).

d is the (constant) discount rate, where $d\in[0,1]$.

K_{-1} is the initial or inherited stock of building protection, measured in dollars.

K_0 is the dollar value of cumulative building protection up to time 0: $K_0=I_0+K_{-1}$. For all periods beyond time 0, the level of the building protection capital stock equals K_0: $K_t=K_0$ for $t=1,\ldots,T$.

B_0^C is the period 0 capital budget allocation, in dollars, for investments in engineering alternatives.

OM_t is the dollar cost of operations and maintenance in period t for all building components. OM_t depends on the stock of building protection capital in each period. For generality, no assumption is made here about the exact relationship between the value of OM_t and the level of protective capital. This relationship between these costs and the level of protective investment is ambiguous. Actual O&M costs for specific protective measures depend on the nature of the measures themselves, rather than the amount of investment required to implement them. In other words, two different protection measures which require the same level of initial investment may incur O&M costs differently. One may consume energy

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[134] Assume for simplicity that each possible level of investment during period 0 is an unique alternative. The building owner or manager chooses I_0 from the set of $N+1$ alternatives $\{I_{j0}\}$, where $j=0,\ldots,N$ and the alternatives are sorted in increasing order of initial investment.

[135] This model abstracts from physical depreciation of the stock of protective capital in each period. Depreciation refers to physical depreciation of capital, not depreciation for tax purposes. Physical depreciation occurs when each unit of capital deteriorates and becomes less productive with use or over time. A constant rate of depreciation means that, during each period, a constant proportion of the capital stock wears out and cannot be used for protection. One example of this type of depreciation is the effect of weathering on a concrete bollard placed at the building's exterior. This weathering may gradually reduce the effectiveness of the bollard each period. The effect in each period would be very small.

resources daily but will not need to be maintained during the study period, while the other may require frequent maintenance. The actual cost of the maintenance, the frequency with which it must be incurred, and its timing will all depend on the type of system that is installed.

O_t represents other dollar costs in period t for all building components. This variable captures the direct costs of the investment other than initial investment and O&M costs. These other costs depend on the stock of protective physical capital, although, as with OM_t, the functional form of this relationship is not specified. Intuitively, other costs depend on cumulative net investment in protective measures from time 0 to time T. Examples of other costs include the cost of disposing the protective investment at the end of its expected life (positive cost) or salvage value (negative cost) of the protective equipment at the end of the study period.

$E(L_t)$ is the expected loss due to all hazards (terrorist attacks and natural disasters) in each period, measured in dollars.[136] A decomposition of this variable is below.

Equations (D.2) and (D.3) together describe the stock of capital invested in engineering alternatives during period 0. Equation (D.2) is the non-negativity condition for the initial stock of protective capital. Equation (D.3) shows that the change in the stock of protective capital during period 0 equals the level of protective investment made during period 0. Equation (D.4) is the budget constraint during period 0.

Equation (D.5) is an augmented expression for expected loss from both terrorist attacks and natural disasters:

$$
\begin{aligned}
E(L_t^h \mid h_t) &= \int_0^{\bar{L}} l f_t(l \mid h)\,dl \\
E(L_t^a \mid a_t) &= \int_0^{\bar{L}} l\, \mathrm{g}_t(l \mid a)\,dl \qquad \text{(D.5)} \\
E(L_t) &= p(h_t)E(L_t^h \mid h_t) + p(a_t)E(L_t^a \mid a_t) \\
&= E(L_t^h) + E(L_t^a)
\end{aligned}
$$

For the first equation in Equation (D.5), describing expected loss if a natural hazard occurs,

l is a random variable representing values that can be taken by L_t. l can range from 0 to $\bar{L}$, where $\bar{L}$ represents the total value of the buildings, including the property itself, occupants, contents, and use; and

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[136] It is assumed that the probability of natural hazards and terrorist events are independent, so that terrorists will not base decisions on when to implement an attack on disastrous weather conditions. It is also assumed that if more than one type of hazard occurs in each period, the damage and losses resulting from each are independent of the damage and losses from the others. Without this assumption, the aggregation of expected losses from each of the hazard types would double-count losses. That is, $p(a_t \mid h_t) = p(a_t)$ and $p(h_t \mid a_t) = p(h_t)$.

$f_t(l \mid h)$ is the probability distribution function of losses conditional on a natural hazard occurring during period t. The function is assumed to be continuous over the range $[0, \overline{L}]$ for all $t = 0,...,T$.

For the second equation in Equation (D.5), describing expected loss if a terrorist attack occurs,

$g_t(l \mid a)$ is the probability distribution function of losses conditional on a terrorist attack occurring during period t. The function is assumed to be continuous over the range $[0, \overline{L}]$ for all $t = 0,...,T$.

The final equation in Equation (D.5) describes $E\left(L_t^a\right)$, the expected loss from both natural and terrorist hazards during period t, where:

$p\left(h_t\right)$ is the probability of at least one incident involving a natural hazard occurring in the building's vicinity during period t; building owners and managers take this probability as given, based on historical geological and meteorological data; and

$p\left(a_t\right)$ is the probability of an attempted terrorist attack in the vicinity during period t.

Expected loss from an attack is determined by two components: (1) the probability that an attack will be attempted on the structure (or neighboring structures); and (2) the probability distribution of losses if an attack occurs. It is assumed that the effectiveness of protective measures increases with the level of investment in these measures. The deterrent effect of protective measures is captured as a reduction in the probability of an attack, $p(a_t)$. The reduction in damage due to a terrorist attack is captured as a reduction in the expected losses conditional on an attack, $E(L_t^a \mid a_t)$.

We assume that the probability of attack in each time period depends on the stock of protective capital in each period, K_0.[137] The stock of protective capital in a building lowers the probability of attack. The likelihood of an attack may fall due to improved detection of security breaches or measures that isolate the effects. Protective measures may deter terrorists from choosing a building as its target if the terrorists know of these measures. The deterrent and detection effects of protection are captured as a negative relationship between the total level of protection and the probability of an attack. Because K_0 is the sum of inherited protective capital and investment during period 0, there is a negative relationship between the level of investment in protection and the probability of an attack. Equation (D.6) characterizes these relationships:

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[137] In the absence of investment beyond period 0, the stock of protective capital in each period equals K_0: $K_t = K_0$ for $t = 0,...,T$.

$$\frac{\partial p(a_t)}{\partial K_0} < 0$$
$$\frac{\partial p(a_t)}{\partial I_0} < 0 \qquad \text{(D.6)}$$

The probability of attack is also affected by exogenous factors. Some factors are related to the ongoing war on terror. The more effectively the United States military and intelligence communities can detect terrorist personnel, movements, activities, and resources, for example, the lower the probability of an attack at any point in time. The war on terror may affect the integrity of terrorist organizational hierarchies and result in the capture of terrorist personnel. The geopolitical climate and the level of anti-United States sentiment abroad affect the probability that a building will be attacked. More pervasive anti-American sentiment abroad may contribute to terrorist recruitment and motivation. It may also contribute to the resources available to terrorists to plan and execute attacks. These factors do not depend on the level of protective capital in a constructed facility.

The level of protective capital affects $g_t(l \mid a)$, the probability distribution of losses, which in turn affects expected losses. The probability distribution of losses also depends on the total value of the building at the time of attack, which includes its occupants, the value of the structure, the value of its contents, and the value of its use and mission.[138]

The level of realized loss in period *t*, L_t^a, ranges in value from zero to $\overline{L}$, total loss. It is assumed that any attempted attack will be costly and some loss will occur.[139] Thus, the probability that the building will suffer losses in excess of 0 is 100 percent: $p(L_t^a > 0 \mid a_t) = 1$. This assumption does not imply that the probability of no damage is zero, however. No damage would occur if the building is not attacked, so the probability that the building suffers no damage, $1 - p(L_t^a > 0)$, equals the probability of no attack, $1 - p(a_t)$.

The maximum loss level, $\overline{L}$, is a function of the maximum occupancy (including visitors) and the value of the structure, contents, use, and mission. The conditional probability that an attack against the building occurs in period *t* and causes losses in excess of $\overline{L}$ is zero: $p(L_t^a > \overline{L} \mid a_t) = 0$.

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[138] By assumption, the value of the building structure, its use, and its mission are constant during each period. In other words, there is no seasonality during each period in these characteristics of a structure. This assumption represents an abstraction from visitor or occupancy fluctuations, such as might be found at tourism-related facilities.

[139] The attempt of a gunman to charge into the U.S. Capitol on July 24, 1998 is one example. Although no members of Congress were physically harmed, two Capitol police officers were killed and one bystander wounded. Note that the probability of different outcomes of an attack are not framed according to "success" or "failure." The success or failure of an attack is a judgment by the attackers of the outcome of the attack relative to their objectives. An attack deemed unsuccessful by the attackers may nevertheless inflict casualties or damage. From the perspective of the building owner or manager, the only relevant outcome is the actual damage sustained, not whether the attackers perceive the outcome as a success or a failure.

The exceedance probability curves in Figures D-1 and D-2 are the complements of cumulative distribution functions and are represented mathematically by $1-F(l)$[140]. For each level of loss, l, the exceedance probability at time t is the probability of realizing a loss greater than l: $p\left(L_t^a > l\right)$. The probability of suffering losses in excess of l conditional on an attack at time t is represented by $p\left(L_t^a > l \mid a_t\right)$. This conditional exceedance probability depends on several factors: the total value of the facility; the total level of investment in protection up to time t; the level of protection of nearby buildings; and the mode of attack.

Figure D-1 shows how the total value of a facility affects the exceedance probability of losses. If the total value of the facility increases from $\overline{L}^*$ to $\overline{L}'$, then the exceedance probability curve shifts out from $EP*$ to EP', since the probability of damage in excess of $\overline{L}^*$ is no longer zero. For a given level of loss, l, the probability of exceeding that level increases from $p*$ to p'. Figure D-2 shows how the level of protection affects the exceedance probability curve. When a building owner or manager invests in engineering alternatives in period *0* and increases the stock of protective capital from $K_{-1} = K_{low}$ to $K_0 = K_{high}$, the conditional probability of exceeding every level of loss will fall from EP_{-1} to EP_0. If an attack occurs, the probability that the facility will suffer losses of at least l falls from p_{-1} to p_0.While a higher level of protective investments reduces the expected level of losses, this reduction will be smaller with every dollar of spending on protection. The same relationships are true for the overall, accumulated level of protection, K_0. Equation (D.7) formalizes these relationships:

$$\begin{aligned}&\frac{\partial E(L_t^a)}{\partial I_0} < 0, \frac{\partial^2 E(L_t^a)}{\partial I_0^2} > 0\\&\frac{\partial E(L_t^a)}{\partial K_0} < 0, \frac{\partial^2 E(L_t^a)}{\partial K_0^2} > 0\end{aligned} \tag{D.7}$$

The conditional probability of realizing a given loss will also be affected by the level of protection in neighboring buildings, depending on the standoff distance and the delivery method of the terrorist attack. The more effectively a building can withstand a blast, for example, the less likely that occupants of adjacent buildings will suffer injuries due to flying glass and other debris.

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[140] For a brief discussion of exceedance probability curves, see Danzig, D. van. "Economic Decision Problems for Flood Prevention," *Econometrica*, Vol. 24 No. 3, July 1956, pp. 276-287.

Figure D-1 Change in Exceedance Probability in Response to Increase in Total Value of the Facility

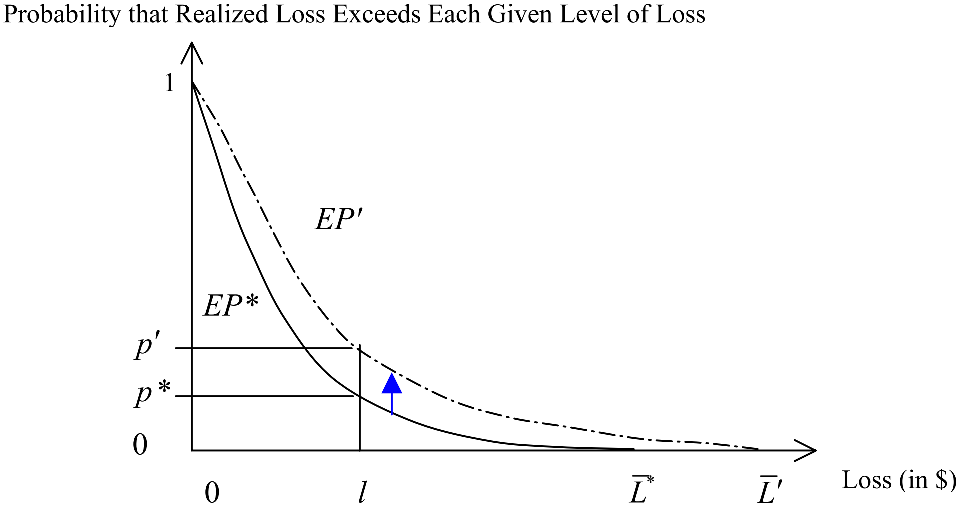
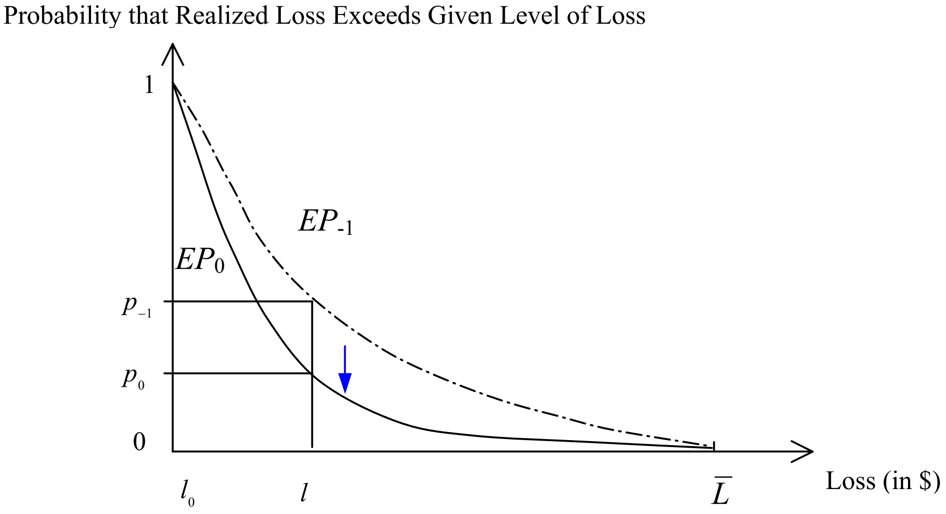


Figure D-2 Change in Exceedance Probability in Response to Increase in Level of Protective Capital



The optimal level of investment in engineering alternatives satisfies the condition in Equation (D.8)[141]:

$$-\sum_{t=0}^{T}\left\{\frac{\partial OM_t/\partial I_0+\partial O_t/\partial I_0+\partial E(L_t)/\partial I_0}{(1+d)^t}\right\}+\lambda_2+\lambda_3=1 \tag{D.8}$$

According to Equation (D.8), the optimal level of investment in engineering alternatives depends on the present discounted value of the marginal benefits over the study period from each additional dollar invested in engineering alternatives in period 0, the unit cost of that protection (i.e., one dollar), and the Lagrange multiplier, λ_3. λ_3 represents the marginal value, or "shadow price," of the resource. The building owner would be willing to pay up to λ_3 for each additional dollar increase in the budget for engineering alternatives. If the budget constraint does not bind, then this willingness to pay for each dollar increase in the budget would be 0, and investment in engineering alternatives would proceed until the present discounted value of the life-cycle marginal benefits from each additional dollar of investment equals 1. Note the negative sign in Equation (D.8). Because OM_t, $E(L_t)$, and O_t are measured as costs, marginal benefits are represented as marginal reductions in those costs. Note that Equation (D.8) is the optimization condition only from the perspective of the owner or manager of a specific building. It does not address interdependencies with other buildings or include externalities associated with investments and expenditures on engineering alternatives. Social considerations of risk mitigation are discussed briefly in Chapter 6 and in greater detail in Appendix E.

If the budget constraint is binding (i.e., the level of investment that would satisfy the optimization without the budget constraint exceeds the constrained optimum), then the building owner and manager should invest until the present discounted value of life-cycle marginal benefits from each additional dollar of investment equals the marginal cost of investment (one dollar) net of the unit cost of increasing the budget, λ_3.

D.2 Model 2: Choosing Engineering Alternatives and Management Practices for Risk Mitigation

A second type of risk mitigation strategy, discussed in Chapter 2, is based on management practices. Model 2 combines management practices with Model 1, so that building owners and managers can both invest in engineering alternatives in period 0 and adopt management practices in all periods to reduce losses from terrorism. The optimization illustrates the conditions that affect the levels of expenditures on

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[141] This condition is derived by setting up the Model 1 Lagrangian, $\mathscr{L}_1$, as: $\mathscr{L}_1 = I_0 + \sum_{t=0}^{T}\frac{OM_t+O_t+E(L_t)}{(1+d)^t} + \lambda_1 K_{-1} + \lambda_2[K_0 - K_{-1} - I_0] + \lambda_3[B_0^C - I_0]$ and deriving first-order conditions. Equation (D.8) and all other first-order conditions are denominated in dollar currency units.

management practices and investment in engineering alternatives that result in the lowest life-cycle cost. Model 2 addresses the interaction effects between these two types of risk mitigation strategies. The interaction effects may be synergistic, compensating, or negating.

Equation (D.9) is the objective function of the engineering alternative-management practice model:

$$\min_{\{I_0, M_0, \ldots, M_T\}} \left\{ I_0 + \sum_{t=0}^{T} \frac{OM_t + O_t + E(L_t) + M_t}{(1+d)^t} \right\} \tag{D.9}$$

subject to the conditions given in Equations (D.2) and (D.3). Two additional constraints apply:

$$I_0 \leq B_0^C \tag{D.10}$$

and

$$M_t \leq B_t^{Op} \text{ for all } t = 0, \ldots, T. \tag{D.11}$$

The variables I_0, OM_t, O_t, $E(L_t)$, B_0^C, d, and t are interpreted as they were in Model 1. M_t represents the level of expenditure (in dollars) to implement management practices to reduce terrorist risk in period t. B_t^{Op} is the operating budget allocation for period t. Equation (D.10) describes the capital budget constraint for the initial period, when the building owner and manager make their decisions about how much to invest in engineering alternatives. Equation (D.11) describes the operating budget constraint during each period. This budget constraint affects the allocation of resources to the implementation of management practices in each period.

The optimal levels of investment in engineering alternatives and expenditures to implement management practices satisfy the conditions in Equations (D.12) and (D.13)[142]:

$$-\sum_{t=0}^{T} \left\{ \frac{\partial OM_t / \partial I_0 + \partial O_t / \partial I_0 + \partial E(L_t) / \partial I_0}{(1+d)^t} \right\} + \mu_2 + \mu_3 = 1 \tag{D.12}$$

and

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[142] This condition is derived by setting up the Model 2 Lagrangian, $\mathscr{L}_2$, as:

$$\mathscr{L}_2 = I_0 + \sum_{t=0}^{T} \frac{OM_t + O_t + E(L_t) + M_t}{(1+d)^t} + \mu_1 K_{-1} + \mu_2 [K_0 - K_{-1} - I_0] + \mu_3 [B_0^C - I_0] + \sum_{t=0}^{T} \mu_{4t} [B_t^{Op} - M_t],$$

and deriving first-order conditions.

$$-\frac{\partial OM_t/\partial M_t + \partial O_t/\partial M_t + \partial E(L_t)/\partial M_t}{(1+d)^t} + \mu_{4t} = \frac{1}{(1+d)^t} \text{ for } t=0,\dots,T. \tag{D.13}$$

Equation (D.12) describes the conditions for the optimal level of investment in engineering alternatives in period 0. The benefits and costs of investment in engineering alternatives during period 0 last throughout the study period due to the assumption of no depreciation. Therefore, Equation (D.12) is a summation of these effects over the entire study period. Its interpretation mirrors that for Equation (D.8).

Equation (D.13) describes the optimization conditions for expenditures on management practices. The optimal level of expenditure on management practices in each period is the level where the (present discounted value) of marginal expenditure in that period exactly equals the (present discounted value) of marginal benefit (negative marginal cost) of that expenditure, in addition to the shadow price of the operating budget. Unlike engineering alternatives, expenditures on management practices in each period only affect the costs and benefits during that same period.

D.3 Model 3: Choosing Engineering Alternatives, Management Practices, and Financial Mechanisms for Risk Mitigation

Model 3 includes the final type of risk mitigation measure available to building owners and managers: financial mechanisms. These mechanisms include insurance and participation in government cost sharing arrangements. It builds on Model 2, so that building owners and managers choose the optimal combination of investment in engineering alternatives, expenditures on management practices, and reliance on financial mechanisms in an overall risk mitigation plan to minimize life-cycle costs of terrorism and other hazards. The financial mechanisms considered in Model 3 are proportional subsidies for investments in engineering alternatives and the purchase of insurance.

Building owners and managers choose how much to invest in engineering alternatives in period 0 in light of the subsidy, how much to spend on management practices in each period, and how much insurance to purchase in each period. Equation (D.14) is the objective function for Model 3:

$$\min_{\{I_0;M_0,\dots,M_T;C_0,\dots,C_T\}} \left\{(1-\alpha)I_0 + \sum_{t=0}^{T} \frac{OM_t + O_t + E(L_t) + M_t - E(C_t) + q_t C_t}{(1+d)^t}\right\} \tag{D.14}$$

subject to Equations (D.2) and (D.3). Two additional constraints are:

$$(1-\alpha)I_0 \le B_0^C \tag{D.15}$$

and

$$M_t + q_t C_t \le B_t^{Op} \text{ for all } t = 0,\dots,T. \tag{D.16}$$

The familiar variables are interpreted as before. In addition,

α is the proportion of the investment in protective measures borne by the government through an investment subsidy, i.e., $\alpha \in [0,1]$.

$E(C_t)$ is the expected insurance claim paid to building owners for insured losses from all hazards during period t.

C_t is the number of units of insurance for all hazards that the building owner purchases in each period.[143]

q_t is the insurance premium rate per monetary unit of insurance paid in each period, and $q_t \in [0,1]$. The total insurance premium payment in period t is q_tC_t.[144] In theory, actuarially fair insurance is priced according to risk: the price of each dollar of insurance equals the probability of losing that dollar. This price is a function of the risk mitigation adopted to protect the insured assets.[145]

Equation (D.15) is the period 0 budget constraint for investment. The building owner's share of investment in engineering alternatives cannot exceed B_0^c. Equation (D.16) is the budget constraint for each period in the study period for management practices and financial mechanisms. Expenditures to implement management practices and to maintain insurance policies must not exceed each period's operating budget, B_t^{Op}.

If the building owner purchases actuarially fair insurance, then the insurance premium in each period will equal the expected value of losses. Protective investment affects insurance in two ways. It reduces the insurance premium per dollar of coverage, q_t, by deterring or detecting breaches, thereby lowering the probability of attack. Because the premium is assumed to be actuarially fair, the insurance premium will fall with higher protective investment (assuming no interdependencies). Because insurance is actuarially fair, however, the net effect of protection on insurance premium payments and on expected claims is zero—any reduction in one will be exactly offset by a reduction in the other. The second way protective investment affects insurance is through the reduction in (conditional) expected losses due to their protective function. This reduction in losses would reduce the amount of coverage purchased in models where the amount of insurance is a choice variable.

Model 3 includes a proportional government subsidy for investment in engineering alternatives. A government may provide a subsidy if it believes that the marketplace does not adequately value the social benefits of disaster mitigation measures

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[143] It would be straightforward to show that, if the building owner were risk averse and the price per unit of insurance were actuarially fair, then the building owner would fully insure. Model 3 assumes the deductible is zero. In the presence of a deductible greater than zero, the analysis would require specification of a functional form for the owner's utility.

[144] Actuarially fair insurance is priced so that the insurance premium rate, q_t, equals the probability of losing each insured dollar in period t. That is, if a person faces a 20 % probability of losing \$100, then the actuarially fair insurance premium amount against that loss is (0.20)(100)=\$20, where q_t, the price per dollar of insurance in each period, is 20 cents. The probability of loss in each period is a composite of the probabilities of terrorist and natural hazards. If q_t is the probability that the building owner or manager will suffer a loss of C_t during period t, then the expected claim, $E(C_t)$, will exactly equal the total premium payment, q_tC_t.

[145] In reality, insurance is priced higher than the actuarial premium to reflect administrative costs.

for constructed facilities. The fixed proportion, $\alpha \in [0,1]$, represents the percentage of the total amount of investment in engineering alternatives that the government will bear.

The optimality condition for choosing investment I_0 in Model 3 is similar to Equation (D.12) for Model 2. Written as Equation (D.17), the condition takes the form[146]:

$$-\sum_{t=0}^{T}\left\{\frac{\partial OM_t/\partial I_0 + \partial O_t/\partial I_0 + \partial E(L_t)/\partial I_0}{(1+d)^t}\right\} + \nu_2 + (1-\alpha)\nu_3 = 1-\alpha \tag{D.17}$$

and

$$-\frac{\partial OM_t/\partial M_t + \partial O_t/\partial M_t + \partial E(L_t)/\partial M_t}{(1+d)^t} + \nu_{4t} = \frac{1}{(1+d)^t} \text{ for } t=0,\dots,T. \tag{D.18}$$

The allocation of the period 0 budget for investment in engineering alternatives must satisfy Equation (D.17). The left-hand side of Equation (D.17) is the marginal benefit of each additional dollar of investment in engineering alternatives over the life cycle. With the negative sign, it is written as the marginal reduction in cost. The reduction in costs could be in the form of lower maintenance or disposal costs, a lower probability of attack, or less severe consequences from an attack. The right-hand side of the equation is the cost of each dollar of investment in period 0 that the building owner or manager bears. $1-\alpha$ represents the cost of each unit of investment in engineering alternatives paid for by the building owner, since government cost-sharing defrays a fixed proportion α of the investment. The life-cycle cost minimizing level of investment must satisfy this equality.

Equation (D.18) is the condition for optimal expenditure on management practices. It says that the present discounted value of the marginal cost (negative benefit) in each period must equal the difference between the (present discounted) price of each dollar of expenditure on management practices, and the shadow price of each dollar increase in the budget for management practices.

Insurance drops out of the optimization. This result is a consequence of the risk neutrality of building owners and managers implicit in optimizing based on cost, rather than utility, and the actuarially fair pricing of the insurance. Because the expected claim, $E(C_t)$, is exactly offset by the premium payment, q_tC_t, and because premium payments

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[146] This condition is derived by setting up the Model 3 Lagrangian, $\mathscr{L}_3$, as:

$$\mathscr{L}_3 = (1-\alpha)I_0 + \sum_{t=0}^{T}\frac{OM_t+O_t+E(L_t)}{(1+d)^t} + \sum_{t=0}^{T}\frac{M_t-E(C_t)+q_tC_t}{(1+d)^t} + \nu_1 K_{-1} + \nu_2[K_0-K_{-1}-I_0]$$

$$+\nu_3[B_0^C-(1-\alpha)I_0] + \sum_{t=0}^{T}\nu_{4t}[B_t^{Op}-M_t-q_tC_t],$$

deriving first-order conditions, and simplifying.

are paid from the same budget as management practices, insurance falls out of the model. The building owner and manager would produce more savings by devoting the operating budget, B_t^{Op}, to management practices, which directly affect the expected losses from hazardous events. This result is driven by key assumptions of the model: the building owner's risk neutrality, actuarially fair pricing of the insurance, and the financial ability of the owner organization to survive the costs of an extreme event. In reality, these assumptions generally do not hold in the private sector, and building owners and managers generally choose to purchase insurance.

D.4 Model 4: Choosing Multi-period Engineering Alternatives, Management Practices, and Financial Mechanisms for Risk Mitigation

Models 1, 2, and 3 assume that investments in engineering alternatives are only undertaken during the initial period. Limited annual capital facilities budgets, however, may drive decisions to introduce investments in engineering alternatives over multiple periods. The level of building protection achieved through a one-time investment is constrained by period 0 budgetary resources, which may not be sufficient to address all of the vulnerabilities identified during the risk assessment process. Model 4 extends Model 3 to allow for investments in periods of the study other than the initial period.

The objective function for Model 4 is represented as Equation (D.19):

$$\min_{\{I_0,\ldots,I_T;M_0,\ldots,M_T;C_0,\ldots,C_T\}} \sum_{t=0}^{T} \left\{ \frac{(1-\alpha)I_t + OM_t + O_t + E(L_t) + M_t - E(C_t) + q_t C_t}{(1+d)^t} \right\} \tag{D.19}$$

subject to the following constraints (in addition to Equation (D.2)):

$$K_t - K_{t-1} = I_t \text{ for } t = 0,\ldots,T \tag{D.20}$$

$$(1-\alpha)I_t \le B_t^C \text{ for } t = 0,\ldots,T \tag{D.21}$$

$$M_t + q_t C_t \le B_t^{Op} \text{ for } t = 0,\ldots,T \tag{D.22}$$

The interpretations of all but a few of the variables are the same as they were in Model 3. In addition,

I_t	is the investment spent on engineering alternatives in period t for $t=0,\ldots,T$.
K_t	is the accumulated capital investment in engineering alternatives up to period t: $K_t = K_{-1} + \sum_{s=0}^{t} I_s$.

Equations (D.20), (D.21), and (D.22) are similar to Equations (D.3), (D.15), and (D.16). They are the multi-period analogues to the capital accumulation, capital budget constraints, and operating budget constraints.

Building owners and managers will choose the life-cycle cost-minimizing combination of investment in engineering alternatives, expenditures to implement management practices, and insurance coverage in each period of the study period.[147]

The optimization conditions for investment in each period are:

$$-\sum_{t=t^*}^{T}\left\{\frac{\partial OM_t/\partial I_{t^*}+\partial O_t/\partial I_{t^*}+\partial E(L_t)/\partial I_{t^*}}{(1+d)^t}\right\}+o_{2t^*}+(1-\alpha)o_{3t^*}=\frac{1-\alpha}{(1+d)^{t^*}}\text{ for }t^*=0,\ldots,T \qquad \text{(D.23)}$$

and

$$-\frac{\partial OM_t/\partial M_t+\partial O_t/\partial M_t+\partial E(L_t)/\partial M_t}{(1+d)^t}+o_{4t}=\frac{1}{(1+d)^t}\text{ for }t=0,\ldots,T. \qquad \text{(D.24)}$$

Equation (D.24) and the insurance result are as they were in Model 3. Equation (D.23), the condition for investment in engineering alternatives, however, differs. The modified optimization condition for investment says that the present value of investment outlays in year t^* must equal the present value of the marginal increase in benefits over the remaining years of the study period plus $(1-\alpha)$ times the shadow value of an incremental increase in the capital budget plus the change per period in the shadow value of each additional unit of investment.

The approaches captured in Models 1 through 4 are intended to illustrate the determinants of optimal allocation of investment and expenditure resources on engineering alternatives, management practices, and financial mechanisms over time. We present them to offer some insight into the bases for these allocations while recognizing that these models are difficult to execute in practice. In addition, the simplifications of homogenous engineering alternatives and homogenous management practices in these models limit their applicability for building owners and managers who seek specific guidance about such allocations. But, the methodology described in Chapter 4 and the software implementation described in Chapter 5, offer more tangible guidance for these decisions.

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[147] The Lagrangian for Model 4, $\mathscr{L}_4$, is:

$$\mathscr{L}_4=\sum_{t=0}^{T}\frac{(1-\alpha)I_t+OM_t+O_t+E(L_t)+M_t-E(C_t)+q_tC_t}{(1+d)^t}+o_1K_{-1}+\sum_{t=0}^{T}o_{2t}[K_t-K_{t-1}-I_t]$$
$$+\sum_{t=0}^{T}o_{3t}[B_t^C-(1-\alpha)I_t]+\sum_{t=0}^{T}o_{4t}[B_t^{Op}-M_t-q_tC_t].$$

Appendix E: Substitution Implications of Risk Mitigation Activities

In Section 6.3, we briefly described the social welfare considerations of a building owner's risk mitigation decisions. This appendix illustrates one specific aspect of the social welfare implications of such decisions.

Mitigation measures may carry a negative externality if protection in one building leads to an increase in likelihood of an attack on other (less protected) targets. Under certain conditions, unobservable protective measures could reduce the probability of an attempt, both on the protected building and nearby buildings as well. Ayres and Levitt have shown that, in contrast to observed risk mitigation, unobserved protection may have positive externalities.[148] However, these protections may not be adopted voluntarily by individuals unless there is a concern for social welfare.

One consequence of observable defensive measures is to increase the perceived relative costs to terrorists of some modes of attack compared to others. Hardening structures and enforcing access restrictions may make buildings more difficult to penetrate, causing terrorists to forgo bombing, for example, in favor of abduction or assassination, when human targets are outside the fortified structure. Enders and Sandler[149] show that the fortifications and enhanced security measures at U.S embassies in 1976, 1985, and 1986 led to a reduction in the number of attacks against U.S. and U.K. interests, for example, but led to an increase in assassinations, threats, and skyjackings. They also show that the introduction of metal detectors at airports reduced skyjackings and threats, but these reductions were accompanied by an increase in the incidence of assassinations and kidnappings, from which metal detectors provided no protection.

Drake[150] identifies another type of substitution as a consequence of risk mitigation. Observable risk mitigation practices may also lead to substitution away from the protected structure to a less protected, "softer," target. In the case of a building with security and fortification measures that are observable, a potential terrorist may believe that attacking the building carries a higher probability of detection or lower likely level of damage. Observable precautions may therefore reduce the desirability of a target and the probability of attack. But the effect of these protective measures may spill over in a negative way onto less fortified buildings if the risk of terrorist attack is shifted to these other buildings. If these other buildings are not owned by the same party, this shift in probability of attack represents a negative externality to the original building's fortification measures.

While the decision problem is examined here from the perspective of the building owner rather than society as a whole, terrorist behavior and building owners' incentives may lead to deviations from optimal social outcomes.[151] Whether these deviations are positive or negative depends on the ability of potential attackers to discern the levels of fortification and protection of each possible target.

Figure E-1 illustrates the case of two targets, Building X and Building Y, which the terrorists see as perfect substitutes for each other. Each axis in Figure E-1 measures

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[148] Ayres and Levitt, "Measuring Positive Externalities from Unobservable Victim Precaution," pp. 47-59.

[149] Enders and Sandler, "The Effectiveness of Antiterrorism Policies," pp. 834-842.

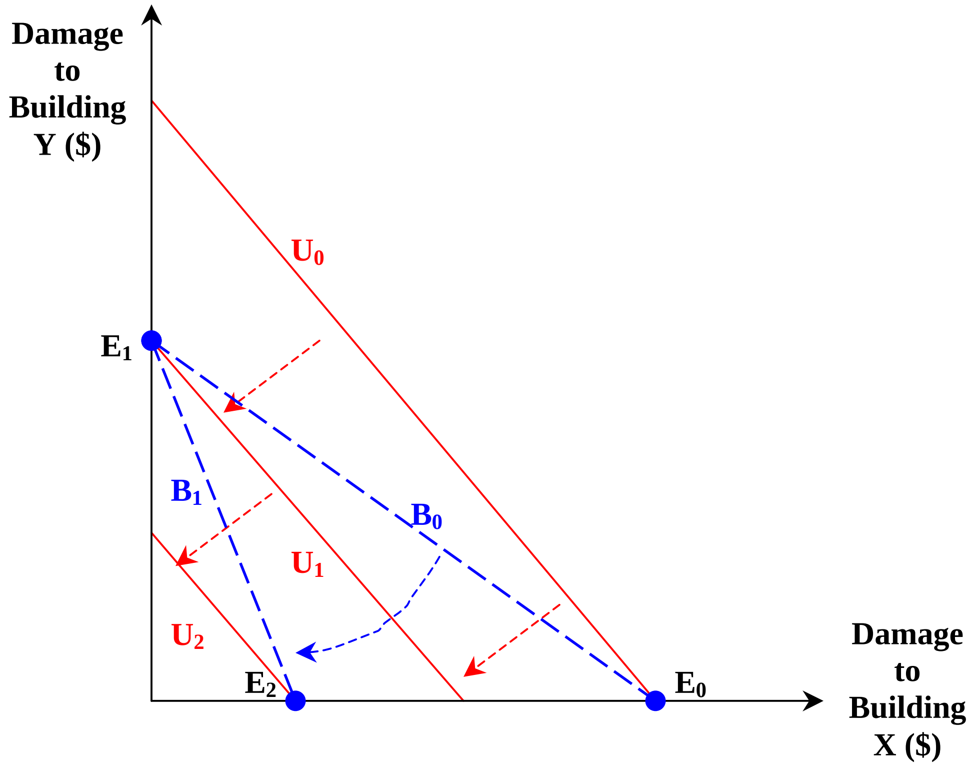
[150] Drake, *Terrorists' Target Selection,* pp. 116-118.

[151] In all discussions of the social welfare implications of protecting constructed facilities from attack, it is assumed that the benefits, or costs to terrorists, are not included in social welfare.

the dollar amount of damage to each building. Suppose further that the satisfaction that the terrorist would derive from causing damage to one target versus the other is traded off at a constant rate. This assumption is represented in Figure E-1 by the linear and parallel indifference curves, U_0, U_1, and U_2. Each indifference curve represents the combination of damage to Building X and Building Y that yields a constant level of satisfaction to the terrorist. Because terrorists are more satisfied with more damage to the targets, moving away from the origin represents increases in satisfaction. U_0, therefore, represents a higher level of satisfaction to the terrorist than U_1, which, in turn, represents a higher level of satisfaction than U_2.

Attacking each target is costly to the terrorist. Costs may include resources for advanced surveillance, logistical preparations, manpower, and materials. The probability and disutility of capture, if measured in dollars, can also be considered a cost to the terrorist. These costs represent the price that must be paid in an attack on each target. These prices of attacking Building X and Building Y, P_X and P_Y, respectively, combined with the finite resources that the terrorist can devote to an attack, yields an initial budget constraint, B_0. The slope of this constraint, $-P_X/P_Y$, represents the amount of damage to Building Y that the terrorist must trade off to cause one unit of damage to Building X. As it is drawn, B_0 represents the combinations of damage to Buildings X and Y that the terrorist can "afford" to inflict. If the terrorist devotes all of the resources to attacking Building X, then it can inflict the amount of damage associated with point E_0. If, on the other hand, the terrorist devotes all of the resources to attacking Building Y, then it can inflict the amount of damage associated with point E_1.

Figure E-1 Building Protection and Substitution Toward Soft Targets



When B_0 is the terrorist budget constraint and the terrorist views Building X and Building Y as substitutable targets according to the indifference curves in Figure E-1, the terrorist will choose to devote all resources to attacking Building X. At this equilibrium, represented by point E_0, the terrorist would experience U_0, the maximum attainable level of satisfaction for the available budget. If the terrorist devoted all resources to attacking Building Y, the most satisfaction that could be attained would be U_1, which is less than U_0. The terrorist can afford any intermediate combination of damage to Buildings X and Y along B_0, but these combinations all bring less satisfaction to the terrorist than U_0, the level from using all resources to attack Building X. Allocating terrorist resources to attacking Building X therefore results in the greatest satisfaction that the terrorist can achieve with his available budget, B_0. For the terrorist to achieve any higher level of satisfaction would require additional resources.

Suppose that the owners and managers of Building X were to implement protective measures. Now, the terrorist would have to devote more resources to attacking Building X to achieve a given level of damage. The increase in resources may be necessary, for example, to pursue additional reconnaissance to circumvent the protective measures. They may also represent an increased probability of detection and capture. The protective measures have the effect of increasing the price that terrorists would have to "pay" to cause a given level of damage to Building X. If Building Y does not change its level of protection and if the terrorist's resources do not change, then this increase in price of damaging Building X causes a rotation in the budget constraint from B_0 to B_1. After Building X installs protection, if the terrorist were to use all his resources to attack Building X, the maximum damage that he could inflict is represented by point E_2 and the maximum satisfaction that he could attain is U_2. If the terrorist instead used the resources to attack Building Y, on the other hand, then he would be able to inflict damage corresponding to point E_1, and derive higher satisfaction, because $U_1 > U_2$. If the owners and managers of Building Y do not increase its protection, the terrorist will perceive it as a softer target than Building X, and switch its attack accordingly.

Table E-1 describes the outcomes and consequences for Building X, Building Y, and social welfare in the cases with and without fortification of Building X for the prices and preferences illustrated in Figure E-1. If Building X is not protected, then the terrorist will target it and inflict damage of E_0. If Building X is fortified, then the owners and managers of Building X achieve their goal of protecting Building X: it avoids an attack and suffers no damage. If Building X is unprotected, Building Y will not be targeted for attack. With Building X better protected, however, Building Y will be attacked and suffer damage of E_1. The fortunes of the building's respective owners shift dramatically between the two scenarios. For society as a whole, however, the change in consequences is less dramatic. With $E_1 < E_0$, society is better off with the protective measures for Building X.

Table E-1 Level of Damage Due to Terrorist Attack

	Without Building X Fortification	With Building X Fortification
Building X	E_0	0
Building Y	0	E_1
Society	E_0	E_1

This simple example illustrates the consequences that the fortification of one facility can have on other facilities. In this example, society as a whole is better off with Building X's protective measures, because society has avoided E_0 worth of damage and instead lost a lesser amount, E_1. There is, however, a transfer within society, as Building Y bears the risk that Building X did before the latter implemented its protective measures.

There is a tipping point in the relative prices of attacking one building over the other, beyond which the terrorist will switch targets. If the owners and managers of Building X implement mitigation measures that increase the relative price of an attack on Building X, but not sufficiently to increase the relative price past the tipping point, then the terrorist will still prefer to attack Building X. The higher price, while not sufficient to change terrorist choice of target, may still lead to a lower level of damage, but it will not lead to a complete transfer of risk within society to Building Y. At the tipping point, the terrorist will be indifferent between attacking either building, or both. That is, the tipping point in relative prices occurs when the slope of the budget constraint just equals the slope of the indifference curve at a given utility level so that the budget constraint and the indifference curve are coincident. If the relative prices are at the tipping point, then the terrorists would be as satisfied to attack one as the other, or some combination of both. Therefore, not all protective measures will lead to a complete shift in terrorism risk to another building. The shift in risk will be complete only when the budget constraint rotates past the indifference curve.

Appendix F: Glossary of Terms

Most of the economic terms listed herein are taken form ASTM Standard E 833.[152] ASTM E 833 covers terminology related to the economic evaluation of building construction. The definitions contained in ASTM E 833 are under the jurisdiction of ASTM Committee E06 on Performance of Building Constructions.

This glossary contains a number of terms that are not contained in ASTM E 833. These terms were either defined through reference to a source document or were defined by the authors. If the term is derived via a source document, then a reference is given. If the authors defined the term, it is designated with an obelisk in bold font (**†**). Unless otherwise noted, all remaining terms are taken from ASTM E 833.

adjusted internal rate of return (**AIRR**)—the compound rate of interest that, when used to discount the terminal value of costs and benefits of a project over a given study period, will make the costs equal the benefits when cash flows are reinvested at a specified rate (Syn. *financial management rate of return (FMRR)*).

annual value—a uniform annual amount equivalent to the project costs or benefits taking into account the time value of money throughout the study period (Syn. *annual worth*, *equivalent uniform annual value*).

annual worth—See **annual value**.

arithmetic mean[153]—in statistics, of a finite set of n numbers is defined as their sum divided by n (Syn. *mean*).

base date—See **base time**.

base time—the date to which all future and past benefits and costs are converted when a present value method is used (usually the beginning of the study period) (Syn. *base date*).

benefit-cost analysis—a method of evaluating projects or investments by comparing the present value or annual value of expected benefits to the present value or annual value of expected costs.

benefit-cost ratio—See **benefit-to-cost ratio.**

benefit-to-cost ratio (**BCR**)—benefits divided by costs, where both are discounted to a present value or equivalent uniform annual value (Syn. *benefit-cost ratio*).

building decision—a decision regarding the design, financing, engineering, construction, management, or operation of a building.

building economics—the application of economic analysis to the design, financing, engineering, construction, management, operation, ownership, or disposition of buildings.

building system—an aggregation or assemblage of items joined in regular interaction or interdependence in buildings or building construction.

capital cost—the costs of acquiring, substantially improving, expanding, changing the functional use of, or replacing a building or building system.

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[152] ASTM International. "Standard Terminology of Building Economics," E 833, Annual Book of ASTM Standards: 2002. Vol. 04.11. West Conshohocken, PA: ASTM International.

[153] *Encyclopedia Britannica*. 15th Edition. Vol. VI, p. 735 (Chicago, IL: Encyclopedia Britannica Inc., 1974).

cash flow—the stream of monetary (dollar) values—costs and benefits—resulting from a project investment.

constant dollars—dollars of uniform purchasing power exclusive of general inflation or deflation (Syn. *real dollars*).

Discussion—Constant dollars are tied to a reference year.

constructed facilities (†)—permanent structures, including infrastructure, buildings, and industrial facilities (see Table A-1).

cost analysis—subdividing the project estimate into component parts to find and compare their relationship to previously established historical costs.

cost effective—the condition whereby the present value benefits (savings) of an investment exceeds its present value costs.

current dollars—dollars of purchasing power in which actual prices are stated, including inflation or deflation.

Discussion—In the absence of inflation or deflation, current dollars equal constant dollars.

decision analysis—a technique for making economic decisions in an uncertain environment that allows a decision maker to include alternative outcomes, risk attitudes, or subjective impressions about uncertain events in an evaluation of investments.

disaster mitigation (†)—measures, procedures, and strategies designed to reduce either the likelihood or consequences of a disaster.

discounting—a technique for converting cash flows that occur over time to equivalent amounts at a common time.

discount rate—the rate of interest reflecting the investor's time value of money, used to determine discount factors for converting benefits and costs occurring at different times to a base time.

Discussion—The discount rate may be expressed as nominal or real.

discount factor—a multiplicative number (calculated from a discount formula for a given discount rate and interest period) that is used to convert costs and benefits occurring at different times to a common time.

discounted payback period—the time required for the cumulative benefits from an investment to pay back the investment cost and other accrued costs considering the time value of money.

economic evaluation methods—a set of economic analysis techniques that consider all relevant costs associated with a project investment during its study period, comprising such techniques as life-cycle cost, benefit-to-cost ratio, savings-to-investment ratio, internal rate of return, and net savings.

endogenous (†)—the state of a variable whose value in a system or model is determined simultaneously with other variables within the system or model.

engineering alternatives (†)—technical options in the construction or renovation of constructed facilities, their systems, or their subsystems to reduce the likelihood or consequences of disasters; types of engineering alternatives include designs, materials, components.

equivalent uniform annual value—See **annual value**.

exogenous (†)—the state of a variable whose value in a system or model is fixed, taken as given, or determined outside of the system or model.

financial incentives (†)—monetary rewards or penalties for disaster mitigation choices; rewards or penalties may arise from market responses or government policies.

externality[154]—the discrepancy between private and social costs or private and social benefits.

> Discussion—The key aspect of externalities is interdependence without compensation. Some individual or firm benefits without paying, or it causes others to have higher costs without compensation.

financial management rate of return (*FMRR*)—See **adjusted internal rate of return**.

first cost—costs incurred in placing a building or building subsystem into service, including, but not limited to, costs of planning, design, engineering, site acquisition and preparation, construction, purchase, installation, property taxes and interest during the construction period, and construction-related fees (Syn. *initial investment cost*, *initial cost*).

future value—the value of a benefit or cost at some point in the future, considering the time value of money (Syn. *future worth*).

future worth—see **future value.**

geometric mean[155]—in statistics, of a finite set of values, the n^{th} root of the product of the values, in which n is the number of values.

incremental cost (benefit)—the additional cost (benefit) resulting from an increase in the investment in a building project (Syn. *marginal cost (benefit)*)

inflation—a rise in the general price level, usually expressed as a percentage rate.

initial cost—See **first cost**.

initial investment cost—See **first cost**.

internal rate of return (**IRR**)—the compound rate of interest that, when used to discount study period costs and benefits of a project, will make the two equal.

investment cost—first cost and later expenditures which have substantial and enduring value (generally more than one year) for upgrading, expanding, or changing the functional use of a building or building subsystem.

life cycle—See **study period**.

life-cycle cost (**LCC**) **method**—a technique of economic evaluation that sums over a given study period the costs of initial investment (less resale value), replacements, operation (including energy use) and maintenance of an investment decision (expressed in present or annual value terms).

maintenance cost (†)—the total labor, material, and other related costs incurred in conducting corrective and preventative maintenance on a building, or on its systems and components, or on both.

management practices (†)—organizational or workforce-related procedures or policies intended to reduce the likelihood or consequences of disasters.

marginal cost (*benefit*)—See **incremental cost** (**benefit**).

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[154] Greenwald, Douglas. *The McGraw-Hill Dictionary of Modern Economics: A Handbook of Terms and Organizations* (New York, NY: McGraw-Hill Book Company, 1973).

[155] *Encyclopedia Britannica*. 15th Edition. Vol. IV, p. 479.

market discount rate—See **nominal discount rate**.

minimum acceptable rate of return (**MARR**)—the minimum percentage return required for an investment to be economically acceptable.

mean—See **arithmetic mean**.

median[156]—in statistics, a value in an ordered set of quantities above and below which falls an equal number of quantities.

net benefits (**savings**)—the difference between the benefits and the costs—where both are discounted to present or annual value dollars.

nominal discount rate—the rate of interest reflecting the time value of money stemming both from inflation and the real earning power of money over time (Syn. *market discount rate*).

Discussion—This is the discount rate used in discount formulas or in selecting discount factors when future benefits and costs are expressed in current dollars.

operating cost—the expenses incurred during the normal operation of a building or a building system or component, including labor, materials, utilities, and other related costs.

opportunity cost of capital—the rate of return available on the next best available investment of comparable risk.

optimization[157]—the process of searching for the best value that can be realized or attained.

present value—the value of a benefit or cost found by discounting future cash flows to the base time (Syn. *present worth*).

present worth—See **present value**.

rate of return—the percentage yield on an investment per unit time.

real discount rate—the rate of interest reflecting that portion of the time value of money related to the real earning power of money over time.

Discussion—This is the discount rate used in discount formulas or in selecting discount factors when future benefits and costs are expressed in constant dollars.

real dollars—See **constant dollars**.

replacement cost—building component replacement and related costs, included in the capital budget, that are expected to be incurred during the study period.

resale value—the monetary sum expected from the disposal of an asset at the end of its economic life, its useful life, or at the end of the study period.

retrofit—the modification of an existing building or facility to include new systems or components.

risk analysis—the body of theory and practice that has evolved to help decision makers assess their risk exposures and risk attitudes so that the investment that is *best for them* is selected.

Discussion—This definition is restricted to the types of analyses described in ASTM Building Economics Standards, and is not necessarily consistent with how the term is used in reference to analyses in such areas as environment or health.

risk attitude—the willingness of decision makers to take chances or gamble on investments of uncertain outcome.

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[156] *Encyclopedia Britannica*. 15th Edition. Vol. VI, p. 744.

[157] Gass, Saul I., and Harris, Carl M. *Encyclopedia of Operations Research and Management Science* (Boston, MA: Kluwer Academic Publishers, 2001).

Discussion—Risk attitudes are generally classified as risk averse, risk neutral, or risk taking. Risk averse decision makers would prefer a sure cash payment to a risky venture with known expected value greater than the sure cash payment. Risk neutral decision makers act on the basis of expected monetary value. They would be indifferent between a sure cash payment and a risky venture with expected value equal to the sure cash payment, and would therefore accept a fair gamble. Risk takers prefer a risky venture with known expected value to a sure cash payment equal to the expected value.

risk averse (RA)—See **risk attitude**.

risk exposure—the probability of investing in a project whose economic outcome is different from what is desired (the target) or what is expected.

risk mitigation (†)—the actions or decisions designed to reduce the financial and nonpecuniary risk from uncertain events.

risk neutral (RN)—See **risk attitude**.

risk taking (RT)—See **risk attitude**.

salvage value—the value of an asset, assigned for tax computation purposes, that is expected to remain at the end of the depreciation period.

savings-to-investment ratio (**SIR**)—either the ratio of present value savings to present value investment costs, or the ratio of annual value savings to annual value investment costs.

sensitivity analysis—a test of the outcome of an analysis by altering one or more parameters from (an) initially assumed value(s).

study period—the length of time over which an investment is analyzed (Syn. *life cycle*, *time horizon*).

sunk cost—a cost that has already been incurred and which should not be considered in making a new investment decision.

terrorism (†)—intentional actions of an individual or group of individuals designed to instill widespread fear and anxiety among a population through the use of violence and destruction of property.

time horizon—See **study period**.

time value of money—the time-dependent value of money stemming both from changes in the purchasing power of money (that is, inflation or deflation), and from the real earning potential of alternative investments over time.

uncertainty—lack of certain, deterministic, values for the variable inputs used in an economic analysis of a building or building system.

useful life—the period of time over which an investment is considered to meet its original objective.

References

ASTM International. "Standard Classification for Building Elements and Related Site Work—UNIFORMAT II," E 1557, *Annual Book of ASTM Standards: 2002*. Vol. 04.11. West Conshohocken, PA: ASTM International.

ASTM International. "Standard Guide for Selecting Economic Methods for Evaluating Investments in Buildings and Building Systems," E 1185, *Annual Book of ASTM Standards: 2002*. Vol. 04.11. West Conshohocken, PA: ASTM International.

ASTM International. "Standard Guide for Summarizing the Economic Impacts of Building Related Projects," E2204, *Annual Book of ASTM Standards: 2002*. Vol. 4.12. West Conshohocken, PA: ASTM International.

ASTM International. "Standard Practice for Applying Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems," E 1765, *Annual Book of ASTM Standards: 2002*. Vol. 04.12. West Conshohocken, PA: ASTM International.

ASTM International. "Standard Practice for Measuring Benefit-to-Cost and Savings-to-Investment Ratios for Investments in Buildings and Building Systems," E 964, *Annual Book of ASTM Standards: 2002*. Vol. 04.11. West Conshohocken, PA: ASTM International.

ASTM International. "Standard Practice for Measuring Internal Rate of Return and Adjusted Internal Rate of Return for Investments in Buildings and Building Systems," E 1057, *Annual Book of ASTM Standards: 2002*. Vol. 04.11. West Conshohocken, PA: ASTM International.

ASTM International. "Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems," E 917, *Annual Book of ASTM Standards: 2002*. Vol. 04.11. West Conshohocken, PA: ASTM International.

ASTM International. "Standard Practice for Measuring Net Benefits for Investments in Buildings and Building Systems," E 1074, *Annual Book of ASTM Standards: 2002*. Vol. 04.11. West Conshohocken, PA: ASTM International.

ASTM International. "Standard Terminology of Building Economics," E 833, *Annual Book of ASTM Standards: 2002*. Vol. 04.11. West Conshohocken, PA: ASTM International.

ASTM International. *ASTM Standards on Building Economics* (West Conshohocken, PA: ASTM International, 1999).

Ayres, Ian, and Levitt, Steven D. “Measuring Positive Externalities from Unobservable Victim Precaution: An Empirical Analysis of Lojack,” *Quarterly Journal of Economics*, Vol. 113, No. 2, February 1998, pp. 43-77.

Betterley, Richard S. “The Terrorism Coverage Market: Hope for Coverage in a Difficult Market,” *The Betterley Report,* April 2002.

Bouabid, Jawhar. “HAZUS-MH and Technological Hazards,” November 2002, http://www.fema.gov/hazus/zip/dl_tech.zip.

Bradshaw, III, Joel C. “Protecting Personnel at Risk: DOD Writes Anti-Terrorism Standards to Protect People in Buildings,” *AMPTIAC Quarterly*, Vol. 6, No. 4, February 2003, pp. 11-15.

Chapman, Robert E. *Applications of Life-Cycle Cost Analysis to Homeland Security Issues in Constructed Facilities: A Case Study*. NISTIR 7025 (Gaithersburg, MD: National Institute of Standards and Technology, 2003).

Chapman, Robert E. and Fuller, Sieglinde K. *Benefits and Costs of Research: Two Case Studies in Building Technology*. NISTIR 5840 (Gaithersburg, MD: National Institute of Standards and Technology, 1996).

Chapman, Robert E., Gass, Saul I., Filliben, James J., and Harris, Carl M. *Evaluating Emergency Management Models and Data Bases: A Suggested Approach*. NISTIR 88-3826 (Gaithersburg, MD: National Institute of Standards and Technology, 1989).

Danzig, D. van. “Economic Decision Problems for Flood Prevention,” *Econometrica*, Vol. 24, No. 3, July 1956, pp. 276-287.

Drake, C.J.M. *Terrorists’ Target Selection* (London: Macmillan Press, Ltd, 1998).

Ehlen, Mark A. and Marshall, Harold E. *The Economics of New-Technology Materials: A Case Study of FRP Bridge Decking*. NISTIR 5864 (Gaithersburg, MD: National Institute of Standards and Technology, 1996).

Encyclopedia Britannica. 15th Edition. Vol. VI, p. 735 (Chicago, IL: Encyclopedia Britannica Inc., 1974).

Enders, Walter and Sandler, Todd. “The Effectiveness of Antiterrorism Policies: A Vector-Autoregression-Intervention Analysis,” *American Political Science Review*, Vol. 87, No. 4, December 1993, pp. 829-844.

Enders, Walter, Sandler, Todd, and Cauley, Jon. “UN Conventions, Technology and Retaliation in the Fight against Terrorism: An Econometric Evaluation,” *Terrorism and Political Violence*, Vol. 2, No. 1, Spring 1990, pp. 83-105.

Executive Office of the President. *The National Strategy for the Physical Protection of Critical Infrastructures and Key Assets* (Washington, DC: The White House, 2003).

Executive Office of the President. *OMB Circular A-94* (Washington, DC: Office of Management and Budget, 1992).

Federal Emergency Management Agency. *Bringing the Plan to Life: Implementing the Hazard Mitigation Plan*. FEMA 386-4. (Washington, DC: Federal Emergency Management Agency, August 2003).

Federal Emergency Management Agency. *Developing The Mitigation Plan; Identifying Mitigation Actions and Implementing Strategies*. FEMA 386-3. (Washington, DC: Federal Emergency Management Agency, April 2003).

Federal Emergency Management Agency. *Insurance, Finance, and Regulation Primer for Terrorism Risk Management in Buildings*. FEMA 429 (Washington, DC: Federal Emergency Management Agency, December 2003).

Federal Emergency Management Agency. *Integrating Human-Caused Hazards Into Mitigation Planning*. FEMA 386-7 (Washington, DC: Federal Emergency Management Agency, September 2003).

Federal Emergency Management Agency. *Primer for Design of Commercial Buildings to Mitigate Terrorist Attacks*. FEMA 427 (Washington, DC: Federal Emergency Management Agency, December 2003).

Federal Emergency Management Agency. *Primer to Design Safe School Projects in Case of Terrorist Attacks*. FEMA 428 (Washington, DC: Federal Emergency Management Agency, December 2003).

Federal Emergency Management Agency. *Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings*. FEMA 426 (Washington, DC: Federal Emergency Management Agency, December 2003).

Federal Emergency Management Agency. *Understanding Your Risks: Identifying Hazards And Estimating Losses*. FEMA 386-2 (Washington, DC: Federal Emergency Management Agency, August 2001).

Federal Employees News Digest, “Employees Fighting Transfer to New Building,” Vol. 53, No. 14, October 27, 2003, p. 5.

Fisk, William J. “Health and Productivity Gains from Better Indoor Environments and Their Relationship with Building Energy Efficiency,” *Annual Review of Energy and the Environment*, Vol. 25, 2000, pp. 537-566.

Fuller, Sieglinde K. and Petersen, Stephen R. *Life-Cycle Costing Manual for the Federal Energy Management Program*. NIST Handbook 135 (Gaithersburg, MD: National Institute of Standards and Technology, 1996).

Gass, Saul I. and Harris, Carl M. *Encyclopedia of Operations Research and Management Science* (Boston, MA: Kluwer Academic Publishers, 2001).

Greenwald, Douglas. *The McGraw-Hill Dictionary of Modern Economics: A Handbook of Terms and Organizations* (New York, NY: McGraw-Hill Book Company, 1973).

Grimes, T. L., Suiter, R. C., and Williams, Juana. S. *Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices*. NIST Handbook 44 2003 ED (Gaithersburg, MD: National Institute of Standards and Technology, 2003).

Gugliotta, Guy and White, Ben. "Tests Clear Home, Mail of Anthrax Victim," *Washington Post*, November 24, 2001, p. A1.

Hartwig, Robert. "The Long Shadow of September 11: Terrorism and Its Impacts on Insurance and Reinsurance Markets," July 2002, http://server.iii.org/yy_obj_data/binary/687221_1_0/sept11.pdf.

Hays, Constance L. "As Important as the Corporate Disaster Plan Is How Fast the Employees Carry It Out," *New York Times*, September 12, 2001, p. C10.

Hunter, Regina L. "Risk Assessment Method—Property Analysis and Ranking Tool: Risk Analysis Software for the GSA Property Manager," *mimeo*, Sandia National Laboratories, 2001.

Jaffee, Dwight and Russell, Thomas. "Extreme Events and the Market for Terrorism Insurance," Fisher Center for Real Estate and Urban Economics, Working Paper 02-282, April 2002.

Johns, Michael and Silverman, Barry. "How Emotions and Personality Effect the Utility of Alternative Decisions: A Terrorist Target Selection Case Study," *Proceedings of the Tenth Conference on Computer Generated Forces and Behavioral Representation,* Norfolk, VA, May 15-17, 2001, pp. 55-64.

Keohane, Nathaniel and Zeckhauser, Richard. "The Ecology of Terror Defense," *Journal of Risk and Uncertainty,* Vol. 26, Nos. 2-3, March-May 2003, pp. 201-229.

Kollar, John J. "Terrorism Insurance Coverage in the Aftermath of September 11th," *A Public Statement by the Extreme Events Committee of the American Academy of Actuaries,* April 17, 2002.

Koprowski, Gene. "Soft Targets," *Homeland Defense Journal*, Vol. 1, No. 1, April 2003, pp. 34-37.

Kowalski, Wlayslaw Jan. *Immune Building Systems Technology* (New York: McGraw-Hill, 2003).

Kunreuther, Howard. "Protective Decisions: Fear or Prudence," Chapter 15, *Wharton on Making Decisions,* edited by Stephen Hoch and Howard Kunreuther (New York: John Wiley & Sons, Inc., 2001), pp. 259-272.

Kunreuther, Howard and Heal, Geoffrey. "Interdependent Security," *Journal of Risk and Uncertainty,* Vol. 26, Nos. 2-3, March-May 2003, pp. 231-249.

Kunreuther, Howard, Meszaros, Jacqueline, Hogarth, Robin, and Spranca, Mark. "Ambiguity and Underwriter Decision Processes," *Journal of Economic Behavior & Organization*, Vol. 26, No. 3, May 1995, pp. 337-352.

Kunreuther, Howard, Michel-Kerjan, Erwann, and Porter, Beverly. "Assessing, Managing and Financing Extreme Events: Dealing with Terrorism," *NBER Working Paper,* No. 10179*,* December 2003.

Lewis, Bernard T. and Payant, Richard P. *The Facility Manager's Emergency Preparedness Handbook* (New York: AMACOM Books, 2003).

Lipton, Eric. "New York Settles on a Number That Defines Tragedy: 2,749 Dead in Trade Center Attack," *New York Times,* January 23, 2004, p. B7.

Lomonaco, Carol and Miller, Dennis. "Comfort and Control in the Workplace," *ASHRAE Journal*, Vol. 39, No. 9, September 1997, pp. 50-56.

Marshall, Harold E. *Choosing Economic Evaluation Methods—Part III in the Audiovisual Series on Least-Cost Energy Decisions for Buildings* (Gaithersburg, MD: National Institute of Standards and Technology, 1995).

Marshall, Harold E. *Least-Cost Energy Decisions for Buildings—Part II: Uncertainty and Risk Video Training Workbook.* NISTIR 5178 (Gaithersburg, MD: National Institute of Standards and Technology, 1993).

Marshall, Harold E. *Least-Cost Energy Decisions for Buildings—Part III: Choosing Economic Evaluation Methods Video Training Workbook.* NISTIR 5604 (Gaithersburg, MD: National Institute of Standards and Technology, 1995).

Marshall, Harold E. *Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Building Investments*. NIST Special Publication 757 (Gaithersburg, MD: National Institute of Standards and Technology, 1988).

Marshall, Harold E. *Uncertainty and Risk—Part II in the Audiovisual Series on Least-Cost Energy Decisions for Buildings* (Gaithersburg, MD: National Institute of Standards and Technology, 1992).

Moss, Michael and Bagli, Charles V. "Instincts to Flee Competed with Instructions to Remain," *New York Times,* September 13, 2001, p. A6.

National Institute of Justice. *Crisis Information Management Software (CIMS) Feature Comparison Report*, NCJ 197065, October 2002, Special Report, http://www.ojp.usdoj.gov/nij/pubs-sum/197065.htm.

Norris, Gregory A. and Marshall, Harold E. *Multiattribute Decision Analysis Method for Evaluating Buildings and Building Systems*. NISTIR 5663 (Gaithersburg, MD: National Institute of Standards and Technology, 1995).

Owen, David D. and R.S. Means Engineering Staff. *Building Security: Strategies & Costs* (Kingston, MA: Construction Publishers & Consultants, 2003).

Paté-Cornell, Elisabeth and Guikema, Seth. "Probabilistic Modeling of Terrorist Threats: A Systems Approach to Setting Priorities Among Countermeasures," *Military Operations Research*, Vol. 7, No. 4, 2002, pp. 5-23.

Ruegg, Rosalie T. and Marshall, Harold E. *Building Economics: Theory and Practice*, (New York: Chapman and Hall, 1990).

Schaad, Werner. "Terrorism—dealing with the new spectre," *Swiss Re Focus Report,* 2002.

Tobin, L. Thomas. "California Case Study: Examples of Incentives to Encourage Earthquake Resistant Communities," presented at the Wharton School, Economic Incentives for Building Safer Communities Wharton Risk Management and Decision Processes Center Roundtable, June 11, 2002.

U.S. Census Bureau. *Value of Construction Put in Place*, Series C30, http://www.census.gov/const/c30/tab102.txt.

U.S. Department of Defense. *DoD Minimum Antiterrorism Standards for Buildings*, UFC 4-010-01, July 31, 2002.

U.S. Department of Energy. *Commercial Buildings Energy Consumption Survey,* 1999.

U.S. Department of Energy. *Manufacturing Energy Consumption Survey,* 1998.

U.S. General Accounting Office. "Terrorism Insurance: Rising Uninsured Exposure to Attacks Heightens Potential Economic Vulnerabilities," Testimony of Richard J.

Hillman Before the Subcommittee on Oversight and Investigations, Committee on Financial Services, House of Representatives, February 27, 2002.

U.S. Postal Service. *2001 Comprehensive Statement on Postal Operations*, 2001.

Von Neumann, John and Morgenstern, Oskar. *Theory of Games and Economic Behavior* (Princeton, New Jersey: Princeton University Press, 1953).

Weaver, Ransom, Silverman, Barry, Shin, Hogeun, and Dubois, Rick. “Modeling and Simulating Terrorist Decision-making: A ‘Performance Moderator Function’ Approach to Generating Virtual Opponents,” *Proceedings of the Tenth Conference on Computer Generated Forces and Behavioral Representation,* Norfolk, VA, May 15-17, 2001, pp. 39-44.

Zilinskas, Raymond A. *Biological Warfare* (Boulder, CO: Lynne Rienner Publishers, Inc., 2000).