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Standard Guide for Developing a Cost-Effective Risk Mitigation Plan for New and Existing Constructed Facilities[1]

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INTRODUCTION

Protecting constructed facilities from damages from natural and man-made hazards in a cost-effective manner is a challenging task. Several measures of economic performance are available for evaluating building-related investments. These measures include, but are not limited to, life-cycle cost, present value net savings, savings-to-investment ratio, and adjusted internal rate of return. This guide provides a generic framework for assessing the risks associated with natural and man-made hazards, formulating combinations of risk mitigation strategies for constructed facilities exposed to those hazards, and using measures of economic performance to identify the most cost-effective combination of strategies.

1. Scope

1.1 This guide describes a generic framework for developing a cost-effective risk mitigation plan for new and existing constructed facilities—buildings, industrial facilities, and other critical infrastructure. This guide provides owners and managers of constructed facilities, architects, engineers, constructors, other providers of professional services for constructed facilities, and researchers an approach for formulating and evaluating combinations of risk mitigation strategies.

1.2 This guide insures that the combinations of mitigation strategies are formulated so that they can be rigorously analyzed with economic tools. Economic tools include evaluation methods, standards that support and guide the application of those methods, and software for implementing the evaluation methods.

1.3 The generic framework described in this guide helps decision makers assess the likelihood that their facility and its contents will be damaged from natural and man-made hazards; 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.

1.4 The purpose of the risk mitigation plan is to provide the most cost-effective reduction in personal injuries, financial losses, and damages to new and existing constructed facilities. Thus, the risk mitigation plan incorporates perspectives from multiple stakeholders—owners and managers, occupants and users, and other affected parties—in addressing natural and man-made hazards.

1.5 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

- E631 Terminology of Building Constructions
- E833 Terminology of Building Economics
- E917 Practice for Measuring Life-Cycle Costs of Buildings and Building Systems
- E964 Practice for Measuring Benefit-to-Cost and Savings-to-Investment Ratios for Buildings and Building Systems
- E1057 Practice for Measuring Internal Rate of Return and Adjusted Internal Rate of Return for Investments in Buildings and Building Systems
- E1074 Practice for Measuring Net Benefits and Net Savings for Investments in Buildings and Building Systems
- E1121 Practice for Measuring Payback for Investments in Buildings and Building Systems
- E1185 Guide for Selecting Economic Methods for Evaluating Investments in Buildings and Building Systems
- E1369 Guide for Selecting Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Buildings

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

and Building Systems
E1557 Classification for Building Elements and Related Sitework—UNIFORMAT II
E1765 Practice for Applying Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems
E1946 Practice for Measuring Cost Risk of Buildings and Building Systems
E2103 Classification for Bridge Elements and Related Approach Work
E2166 Practice for Organizing and Managing Building Data
E2204 Guide for Summarizing the Economic Impacts of Building-Related Projects

2.2 *Adjuncts:*

Discount Factor Tables Adjunct to Practices E917, E964, E1057, E1074, and E1121[3]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide, refer to Terminologies E631 and E833.

4. Summary of Guide

4.1 This guide presents a generic framework for developing a cost-effective risk mitigation plan for constructed facilities exposed to natural and man-made hazards. The generic framework consists of three interrelated components. The three components are: *(1)* perform risk assessment; *(2)* specify combinations of risk mitigation strategies; and *(3)* perform economic evaluation. The generic framework builds on an approach presented in Chapman and Leng **(1)**.[4]

4.2 This guide identifies related ASTM standards and adjuncts and describes why measuring uncertainty and risk is critical in the development of cost-effective protective strategies for constructed facilities. In addition to ASTM standards and adjuncts, this guide identifies technical documents and software that support the generic framework. These documents and software are summarized in Appendix X1.

4.3 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, indicate which areas are more prone to these specific hazards in the future. Many analysts refer to past incidences of man-made hazards, such as crime, as predictors of future occurrences. Sources of hazards data are presented in Appendix X2.

5. Significance and Use

5.1 Standard practices for measuring the economic performance of investments in buildings and building systems have been published by ASTM. A computer program that produces economic measures consistent with these practices is available.[5] The computer program is described in Appendix X3. Discount Factor Tables has been published by ASTM to facilitate computing measures of economic performance for most of the practices.

5.2 Investments in long-lived projects, such as the erection of new constructed facilities or additions and alterations to existing constructed facilities, are characterized by uncertainties regarding project life, operation and maintenance costs, revenues, and other factors that affect project economics. Since future values of these variable factors are generally unknown, it is difficult to make reliable economic evaluations.

5.3 The traditional approach to uncertainty in project investment analysis is to apply economic methods of project evaluation to best-guess estimates of project input variables, as if they were certain estimates, and then to present results in a single-value, deterministic fashion. When projects are evaluated without regard to uncertainty of inputs to the analysis, decision makers may have insufficient information to measure and evaluate the financial risk of investing in a project having a different outcome from what is expected.

5.4 To make reliable economic evaluations, treatment of uncertainty and risk is particularly important for projects affected by natural and man-made hazards that occur infrequently, but have significant consequences.

5.5 Following this guide when performing an economic evaluation assures the user that relevant economic information, including information regarding uncertain input variables, is considered for projects affected by natural and man-made hazards.

5.6 Use this guide in the project initiation and planning phases of the project delivery process. Consideration of alternative combinations of risk mitigation strategies early in the project delivery process allows both greater flexibility in addressing specific hazards and lower costs associated with their implementation.

5.7 Use this guide for economic evaluations based on Practices E917 (life-cycle costs), E964 (benefit-to-cost and savings-to-investment ratios), E1057 (internal rate of return and adjusted internal rate of return), E1074 (net benefits and net savings), and E1765 (analytical hierarchy process for multiattribute decision analysis).

5.8 Use this guide in conjunction with Guide E2204 to summarize the results of economic evaluations involving natural and man-made hazards.

6. Procedures

6.1 The recommended steps in developing a cost-effective risk mitigation plan are as follows:

6.1.1 Establish risk mitigation objectives and constraints.

6.1.2 Conduct assessment and document findings.

6.1.3 Review alternative risk mitigation strategies.

6.1.4 Select candidate combinations of risk mitigation strategies.

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[3] Available from ASTM International Headquarters. Order Adjunct No. ADJE091703.

[4] The boldface numbers in parentheses refer to a list of references at the end of this standard.

[5] The NIST Cost-Effectiveness Tool for Capital Asset Protection helps users calculate measures of economic performance for buildings and building systems that are consistent with ASTM standards. The program is downloadable from http://www.nist.gov/el/economics/CETSoftware.cfm.

6.1.5 Develop cost estimates and sequence of cash flows for each candidate combination.

6.1.6 Select appropriate economic method(s) for evaluating the candidate combinations of risk mitigation strategies (see Guide E1185).

6.1.7 Compute measures of economic performance for each candidate combination.

6.1.8 Recompute measures of economic performance taking into consideration uncertainty and risk (see Guide E1369 and Practice E1946).

6.1.9 Analyze results and recommend the most cost-effective combination of risk mitigation strategies.

6.1.10 Prepare report with documentation supporting recommended risk mitigation plan.

7. Perform Risk Assessment

7.1 *Establish Risk Mitigation Objectives and Constraints*:

7.1.1 Specify the decision-maker's objectives. This is crucial in defining the problem and determining the suitability of the economic evaluation method(s).

7.1.2 Identify the constructed facility or set of facilities to be evaluated. Identify the types of hazards to be evaluated.

7.1.3 Specify the design or system objective that is to be accomplished. Identify any constraints that limit the available options to be considered.

7.2 *Conduct Assessment and Document Findings*:

7.2.1 Form an assessment team composed of individuals familiar with the type of facility or set of facilities to be evaluated, individuals familiar with assessment tools and techniques, and individuals who have breadth and depth of experience and understand other disciplines and system interdependencies. Refer to the risk assessment guidance documents and software tools summarized in Appendix X1 to gain assessment insights on specific hazards or classes of hazards. Supplement your data sources with those described in Appendix X2 to compile information on the likelihood and severity of specific hazards or classes of hazards.

7.2.2 Use information from the documents and software summarized in Appendix X1 to produce an assessment plan. Provide the assessment team with the tools, such as laptop computers and electronic forms/data collection sheets, needed to implement the assessment plan.

7.2.3 Make assignments and deploy the assessment team. Collect and compile information on specific hazard types, their likelihood, and consequences.

7.2.4 Use an agreed upon format, such as Classifications E1557 or E2103 or Practice E2166, to create a compiled set of information collected from the assessment team that documents the findings of the risk assessment. Transmit the compiled set of information to a central repository to insure that access to sensitive information can be limited to those with a legitimate need to know.

8. Specify Combinations of Risk Mitigation Strategies for Evaluation

8.1 *Review Alternative Risk Mitigation Strategies*—This section describes three risk mitigation strategies—engineering, management, and financial. Each strategy is composed of multiple approaches for addressing hazards identified in the risk assessment. These approaches focus on hazard mitigation for a specific system or collection of systems and components, as well as facility and site-related elements. Strategies may be used either singly or in combination. Past research indicates that combinations of risk mitigation strategies offer flexibility in dealing with both a single hazard and multiple hazards.

8.1.1 *Engineering*:

8.1.1.1 Engineering strategies are technical options in the construction or renovation of constructed facilities, their systems, or their subsystems designed to reduce the likelihood or consequences of disasters. Engineering strategies provide protection against both natural and man-made hazards. Engineering strategies also help defend against man-made hazards, where their ability to detect or deter may reduce the likelihood or consequences of such hazards.

8.1.1.2 Protective engineering strategies are intended to reduce harm to occupants, damage to the structure, and disruption of business if a disaster occurs. Protective engineering strategies may improve the structural integrity of a building, facilitate evacuation of occupants, or circumvent compromised systems.

8.1.1.3 There is some overlap among engineering strategies that deter, detect, and protect against terrorist attacks and other criminal acts. Detection and protective engineering strategies that are observable to potential terrorists may deter them from attacking. Closed-circuit television (CCTV), for example, is designed to detect unauthorized activities, but its visibility may deter these activities.

8.1.1.4 Risk mitigation strategies may also be hazard-specific. Reinforced building shell, shatter-resistant glass, and use of barriers and bollards to achieve increased setback distances for existing buildings are examples of engineering strategies that protect against blast.

8.1.2 *Management*:

8.1.2.1 Management strategies can be procedural or technical. Some management strategies relate to security, training, and communications. Others relate to decisions on where to locate the building and who should have access to its systems and subsystems. Some management strategies complement engineering strategies, while others substitute for them.

8.1.2.2 Security practices are the use of security personnel and procedures to prevent terrorist or criminal 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.

8.1.2.3 Training practices are used primarily to prepare responses to disaster. 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. 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.

8.1.2.4 Building owners and managers may also use 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. 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.

8.1.2.5 Another management practice available to building owners and managers relates to the building's location and ease of access. Decisions concerning location come into play for new construction and for acquisitions of existing buildings. Setback distances, which have effects that are interdependent with some engineering strategies, are a component of the management decision about location. 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, mailrooms, loading docks, side entrances, connected buildings, driveways, and rooftops. Sensitive areas include rooms housing HVAC equipment and controls; servers, network connections, and other information technology (IT) assets; and CCTV monitoring equipment.

8.1.3 *Financial*:

8.1.3.1 Building owners and managers can explore financial strategies to reduce their pecuniary risks from natural and man-made hazards. There are two types of financial strategies to address risk mitigation: insurance and financial incentives. Both topics are explored in detail in Grossi and Kunreuther **(2)** and in Kunreuther, Meyer, and Van den Bulte **(3)**.

8.1.3.2 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.

8.1.3.3 Financial incentives fall into two categories: government incentives and private incentives. Government incentives are explicitly designed public policy instruments that encourage decision makers to make certain choices over others. Private incentives reward decision makers for making some choices over others through private transactions. In the case of risk mitigation, government and private incentives are policies, measures, or characteristics that motivate building owners and managers to implement risk mitigation measures in their buildings.

8.1.3.4 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.

8.1.3.5 Financial incentives for risk mitigation in constructed facilities may also be offered by the private sector. Building owners have commercial relationships with insurers, tenants, employees, potential buyers, and lenders. These parties may each benefit from a building's reduced vulnerability.

8.1.3.6 Insurance companies benefit from the adoption of either engineering or management strategies through smaller claims if a disaster 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 obtain more favorable insurance policies, such as those that are longer term, have lower deductibles, or have fewer exclusions.

8.1.3.7 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.

8.1.3.8 Potential buyers are another party from which a building owner can extract rewards for the building's risk mitigation measures. The installation of protective measures 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 sold.

8.1.3.9 Building owners 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 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.

8.2 *Select Candidate Combinations of Risk Mitigation Strategies*:

8.2.1 Form a project team empowered to select combinations of risk mitigation strategies. The project team will include some of the individuals from the assessment team as well as additional individuals with specific knowledge about the facility or subject matter expertise. Provide the project team with access to the compiled set of information produced by the risk assessment team (see 7.2).

8.2.2 Review the findings of the assessment team on how individual building elements are affected by each hazard type. Use information from the documents and software summarized in Appendix X1 to identify mitigation strategies for building elements and hazard types. Employ a combination of mitigation strategies rather than focusing only on engineering-based approaches.

8.2.3 Form each combination of risk mitigation strategies into a well-defined alternative, which addresses one of more of the hazards identified in the risk assessment. Prepare a brief narrative statement for each alternative in the set, describing what it does and how it accomplishes it.

8.3 *Develop Cost Estimates and Sequence of Cash Flows for Each Candidate Combination*:

8.3.1 Consult with senior management to establish a first cost budget constraint for the project. Compile information on the amount and timing of investment costs, operating costs, and maintenance and repair costs for each alternative combination of risk mitigation strategies. Eliminate from further consideration those alternatives whose initial investment costs exceed the first cost budget constraint for the project.

8.3.2 Compile information on the likelihood and consequences of each hazard type (see Section 7) for each alternative. Develop estimated costs for each consequence.

8.3.3 Identify areas where information is impacted by uncertainty.

8.3.4 Identify any significant effects that remain unquantified.

9. Perform Economic Evaluation

9.1 *Select Appropriate Economic Method(s) for Evaluating the Candidate Combinations of Risk Mitigation Strategies*:

9.1.1 Numerous methods are available for measuring the economic performance of investments in buildings and building systems. Use Guide E1185 to identify types of building design and system decisions that require economic evaluation and to match the technically appropriate economic methods with the decisions.

9.1.2 Four economic evaluation methods addressed in Guide E1185 apply to the development of a cost-effective risk mitigation plan for dealing with natural and man-made hazards: *(1)* life-cycle costs (Practice E917); *(2)* present value net savings (Practice E1074); *(3)* savings-to-investment ratio (Practice E964); and *(4)* adjusted internal rate of return (Practice E1057). The computer program described in Appendix X3 produces calculated values for each of the four economic evaluation methods.

9.1.3 More than one method can be technically appropriate for many design and system decisions. If more than one method is technically appropriate, use all that apply, since many decision makers need information on measures of magnitude (life-cycle costs and present value net savings) and of return (savings-to-investment ratio and adjusted internal rate of return) to assess economic performance.

9.2 *Compute Measures of Economic Performance for Each Candidate Combination*:

9.2.1 Follow the instructions given in the selected evaluation method(s) for computing the measure(s) of economic performance (see 9.1). Perform these computations with fixed parameter values. Cases where parameter values are allowed to vary are treated in 9.3.

9.2.2 Use the computed values of the measure(s) of economic performance (outcomes) to rank order the alternatives (combinations of risk mitigation strategies). Refer to the selected evaluation method(s) to determine the criterion for ranking alternatives.

9.2.3 Designate the alternative with the best outcome (measure of economic performance) as the most cost-effective risk mitigation plan. For example, if the life-cycle cost method is used, the alternative with the lowest life-cycle cost has the best outcome. Consequently, it qualifies as the most cost-effective risk mitigation plan.

9.2.4 Examine any significant effects that remain unquantified. Note how these effects differ across alternatives.

9.3 *Recompute Measures of Economic Performance Taking into Consideration Uncertainty and Risk*—Decision makers typically experience uncertainty about the correct values to use in establishing basic assumptions and in estimating future costs. Guide E1369 recommends techniques for treating uncertainty in parameter values in an economic evaluation. It also recommends techniques for evaluating the risk that a project will have a less favorable economic outcome than what is desired or expected. Practice E1946 establishes a procedure for measuring cost risk for buildings and building systems, using the Monte Carlo simulation technique as described in Guide E1369. The computer program described in Appendix X3 incorporates the treatment of risk and uncertainty to produce a set of calculated values for each of the four economic evaluation methods referenced in 9.1.2 that are consistent with Guide E1369.

9.3.1 *Perform Sensitivity Analysis* (see Guide E1369)

9.3.1.1 Sensitivity analysis is a test of the outcome of an economic evaluation to changing values of one or more parameters about which there is uncertainty. It shows decision makers how the economic viability of a project changes as the discount rate, key unit costs, escalation rates, and other critical parameters vary.

9.3.1.2 A sensitivity analysis might use as inputs a pessimistic value, a value based on a measure of central tendency (mean or median), and an optimistic value for the parameter of interest. Then an analysis could be performed to see how each outcome (for example, savings-to-investment ratio) changes as each of the three chosen values for the selected input is considered in turn, while all other parameters are held constant. A sensitivity analysis can also be performed on different combinations of parameters. That is, several parameters are altered at once and then an outcome measure is computed.

9.3.1.3 The key advantage of sensitivity analyses is that they are easily constructed and computed and the results are easy to explain and understand. Their disadvantage is that they do not produce results that can be tied to probabilistic levels of significance (for example, the probability that the savings-to-investment ratio is less than 1.0).

9.3.2 *Perform Monte Carlo Simulation* (see Guide E1369 and Practices E917 and E1946)

9.3.2.1 Monte Carlo simulation varies a small set of key parameters either singly or in combination according to an experimental design. Associated with each key parameter is a probability distribution function from which values are randomly sampled. The major advantage of the Monte Carlo simulation technique is that it permits the effects of uncertainty to be rigorously analyzed through reference to a derived distribution of project outcome values. Their disadvantage is that they require a computer program to implement.

9.3.2.2 In a Monte Carlo simulation, not only the expected value of the outcome can be computed but also the variability of that value. In addition, probabilistic levels of significance can be attached to the computed outcome value for each alternative under consideration.

9.3.2.3 Key elements of Guide E1369 and Practice E1946 have been incorporated into the calculation of life-cycle costs (Practice E917). Practice E917 provides direction on how to apply Monte Carlo simulation when performing economic evaluations of alternatives designed to mitigate the effects of natural and man-made hazards that occur infrequently but have significant consequences. Practice E917 contains a comprehensive example on the application of Monte Carlo simulation in evaluating the merits of alternative risk mitigation strategies for a prototypical data center.

9.4 *Analyze Results and Recommend the Most Cost-Effective Combination of Risk Mitigation Strategies*—Choosing among alternatives designed to reduce the impacts of natural and man-made hazards is more complicated than most building investment decisions. Consequently, guidance is provided to help identify key characteristics and the level of effort that will promote a better-informed decision. This guidance draws on information presented in 9.2 and 9.3.

9.4.1 Review the calculated values of each alternative's measures of performance. Include the outcomes computed for each of the three types of analysis: *(1)* fixed parameter values (see 9.2); *(2)* sensitivity analyses (see 9.3.1); and *(3)* Monte Carlo simulations (see 9.3.2).

9.4.2 Use the performance criterion from each selected evaluation method to rank order alternatives for each type of analysis (fixed parameter values, sensitivity analyses, and Monte Carlo simulations). Document differences in alternative rankings among the three types of analysis. Focus on circumstances under which the most cost-effective risk mitigation plan identified in the fixed parameter values analysis is replaced by (an)other alternative(s) when the effects of uncertainty are considered. Use the results of the Monte Carlo simulations to identify the characteristics associated with ranking changes for those alternatives under consideration.

9.4.3 Recommend an alternative as the most cost-effective risk mitigation plan. Provide a rationale for the recommendation. Include as part of the rationale, findings from each of the three types of analysis. Include a discussion of circumstances under which the recommended alternative did not have the best measure of economic performance.

9.4.4 Describe any significant effects that remain unquantified. Explain how these effects impact the recommended alternative. Refer to Practice E1765 and its adjunct for guidance on how to present unquantified effects along with the computed values of the measures of economic performance.

10. Prepare Report with Documentation Supporting Recommended Risk Mitigation Plan

10.1 In a report of an economic evaluation, state the objective, the constraints, the alternatives considered, the key assumptions and data, and the computed value for each outcome (measure of economic performance) of each alternative. Make explicit the discount rate; the study period; the main categories of cost data, including initial costs, recurring and nonrecurring costs, and resale values; and grants and incentives if integral to the decision-making process. State the method of treating inflation. Specify the assumptions or costs that have a high degree of uncertainty and are likely to have a significant impact on the results of the evaluation. Document the sensitivity of the results to these assumptions or data. Describe any significant effects that remain unquantified in the report.

10.2 Use the generic format for reporting the results of an economic evaluation described in Guide E2204. It provides technical persons, analysts, and researchers a tool for communicating results in a condensed format to management and non-technical persons. The generic format calls for a description of the significance of the project, the analysis strategy, a listing of data and assumptions, and a presentation of the computed values of any measures of economic performance. Guide E2204 contains a comprehensive example evaluating the merits of alternative risk mitigation strategies for a prototypical data center summarized using the generic format.

10.3 To complete the report, include as supporting documentation information compiled from the risk assessment and a description of the process by which combinations of risk mitigation strategies were assembled.

10.4 Appendix X4 provides a comprehensive, illustrative application of the three-step protocol in the development of a risk mitigation plan against intentionally-set fires in at-risk Michigan communities.

11. Keywords

11.1 adjusted internal rate of return; analytical hierarchy process; building condition assessment; building economics; building systems; cost analysis; economic evaluation methods; economic impacts; engineering economics; homeland security; impact assessment; life-cycle costs; man-made hazards; measures of economic performance; Monte Carlo simulation; multiattribute decision analysis; natural hazards; net savings; present-value analysis; project management; risk assessment; risk mitigation strategies; savings-to-investment ratio; sensitivity analysis

APPENDIXES

(Nonmandatory Information)

X1. RISK ASSESSMENT GUIDANCE AND SOFTWARE TOOLS

X1.1 Risk Assessment Guidance Documents

X1.1.1 Multiple guidance documents are available to help building owners and managers assess the risks facing their structures. These documents vary considerably in their technical sophistication and focus on individual hazards and classes of hazards. Eighteen guidance documents are described in this section. The first three guidance documents are rigorous theoretical treatments; they provide a framework for analysis that is applicable to a broad cross section of natural and man-made hazards. The remaining 15 guidance documents are applications oriented; they strike a balance between rigor and ability to implement.

X1.1.2 Stewart's and Melchers' **(4)** *Probabilistic Risk Assessment of Engineering Systems* is a rigorous treatment of the subject. They describe ways in which hazardous situations might arise by drawing on examples from a wide range of industries. They discuss issues that engineers and other stakeholders face in design, construction, and management of projects which could have serious cost impacts. The way risk analysts tend to examine the system with which they have to deal is introduced through a series of industry-specific examples. A number of approaches are then outlined, from simple but powerful techniques to more detailed analyses required for complex systems having major impacts should failure occur.

X1.1.3 The American Society of Mechanical Engineers (ASME) Innovative Technologies Institute (ITI), through funding from the Department of Homeland Security (DHS), has launched the Risk Analysis and Management for Critical Asset Protection (RAMCAP) project.[6] In 2005, ASME-ITI published a guidance document **(5)** on assessing the risk associated with terrorist threats. The goal of this document is to inform resource allocation decisions for the protection of critical infrastructure. Although the focus is on terrorist threats, the ASME-ITI guidance document provides a framework suitable for addressing other types of man-made hazards as well as natural hazards. Specifically, the document provides a review of the existing approaches to assessing risk, highlights the common terminology and basis for reporting results, and presents recommended methodology and best practices. ASME-ITI's RAMCAP project focuses on three key issues. First, it defines a common framework that can be used by the owners and operators of the nation's critical infrastructure to assess terrorist risk to their own assets and systems. Second, it provides guidance on methods that can be used to assess and estimate risk information defined by the common framework. Third, this common risk framework provides an efficient and consistent mechanism for both the private and public sectors to report essential risk information to DHS. The technical content of the RAMCAP guidance document is divided into three parts. Section I, The RAMCAP Framework, provides an overview of how a risk analysis methodology can be applied to assessing the risk associated with terrorist threats. How the results of the risk analysis should be communicated to key stakeholders so the value of the information is optimized and security is insured is also described. Section II, RAMCAP Implementation, contains a step-by-step procedure for determining the individual parameters necessary for assessing risk from terrorism events. Topics covered include: how to perform screening; the definition of threats, vulnerability analysis, consequence assessment, and threat assessment; and how these elements are combined to estimate terrorism risk. Section II also covers risk assessment and contains an introduction into risk management considerations. Section III, RAMCAP Appendices and References, contains a lexicon of terms used in risk analysis, abbreviations and acronyms, and a list of requirements for compliance with RAMCAP.

X1.1.4 Grossi and Kunreuther's **(2)** *Catastrophe Modeling: A New Approach to Managing Risk* provides an in-depth treatment of recent developments in the nature and application of catastrophe models used to manage risk from natural disasters. It describes current and potential future uses of such models. The book emphasizes natural disasters, but also discusses application of the models to the terrorist attacks of September 11, 2001. The book is divided into four parts. Part I provides an introduction to risk management and catastrophe models and develops a framework for integrating risk assessment with risk management strategies via catastrophe modeling. Part II explores the complex process of linking the science of natural hazards to the output of catastrophe models. Part III examines how catastrophe modeling aids insurers and other stakeholders in managing the risks from natural hazards. Part IV focuses on the use of catastrophe models (see X1.2.4).

NOTE X1.1—Many of the documents described in the remainder of this section include guidance on the selection and use of mitigation strategies as well as guidance on performing a risk assessment.

X1.1.5 The Federal Emergency Management Agency (FEMA) has developed a series of guidance manuals to assist state and local communities in planning for risk mitigation. These manuals address the need for risk assessment for a variety of hazards. They describe the processes of identifying hazards, identifying and developing mitigation strategies, implementing risk mitigation plans, and applying these processes to man-made hazards. *Understanding Your Risks* **(6)** 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* **(7)** provides state and local decision makers with the tools to identify mitigation objectives and strategies.

[6] Available from ASME Innovative Technologies Institute, 1828 L Street, NW, Suite 906, Washington, DC 20036-5104, http://www.asme-iti.org.

Bringing the Plan to Life **(8)** 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* **(9)** 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 a coordinated fashion with local emergency responders.

X1.1.6 FEMA's Risk Management Series of publications is 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 **(10)**, 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 **(11)**, is a primer. FEMA 427 introduces a series of 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 **(12)**, 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 **(13)**, 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. FEMA 452 **(14)**, *Risk Assessment: A How-To Guide to Mitigate Potential Terrorist Attacks Against Buildings*, provides a clear, flexible, and comprehensive methodology for preparing a risk assessment. FEMA 452 outlines methods for identifying the critical assets and functions within buildings, determining the threats to those assets, and assessing the vulnerabilities associated with those threats. The *Guide* presents five steps and multiple tasks within each step that define a process for conducting a risk assessment and for selecting risk mitigation strategies. FEMA has also created a course, E155, *Building Design for Homeland Security*, that draws on FEMA 426 and FEMA 452.[7] The course familiarizes students with assessment methodologies available to identify the relative level of risk for a variety of threats, including blast and chemical, biological, and radiological agents.

X1.1.7 In 2002, the Department of Defense (DoD) published a Uniform Facilities Criteria (UFC), "DoD Minimum Antiterrorism Standards for Buildings" **(15)**. The objective of these criteria is to improve the survival of DoD personnel from terrorist attacks. Although the UFC system applies to the military departments, DoD agencies, and DoD field activities, the criteria 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 FY 2004, 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 the General Services Administration (GSA) and the Department of State, which, according to Bradshaw **(16)**, place more emphasis on building hardening.

X1.1.8 On February 5, 2004, the National Fire Protection Association issued the 2004 edition of NFPA 1600, *Standard on Disaster/Emergency Management and Business Continuity Programs* **(17)**. NFPA 1600 establishes a common set of criteria for disaster management, emergency management, and business continuity programs. The standard provides those individuals with the responsibility for disaster and emergency management and business continuity programs the criteria to assess current programs or develop, implement, and maintain a program to mitigate, prepare for, respond to, and recover from disasters and emergencies.

X1.1.9 In 2003, the American Management Association (AMA) published *The Facility Manager's Emergency Preparedness Handbook* **(18)**. 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.

X1.1.10 In 2003, R. S. Means published *Building Security: Strategies & Costs* **(19)** to assist building owners and managers to assess risk and vulnerability to their buildings, 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.

X1.1.11 In 2005, the Institute for Business & Home Safety (IBHS) published *Open for Business* **(20)**. The IBHS document notes that the threat of a disaster-related closure is especially

[7] Additional information on Course E 155 is provided at http://www.fema.gov/fima/rmsp.shtm.

great for small and mid-sized businesses because they lack the financial resources for recovery, the ability to spread their risk across several geographical locations, ready access to alternative suppliers, and other advantages that most large organizations posses. The IBHS document focuses on business continuity planning. It includes a series of forms and checklists designed to produce a rapid risk assessment for a broad class of hazards and recommended strategies to address each type of hazard.

X1.2 Software-Based Risk Assessment

X1.2.1 Researchers have developed a number of software-based risk assessment tools to model terrorist decision processes as well as risks from natural hazards and other man-made hazards. One such tool is the Risk Assessment Method—Property Analysis and Ranking Tool (RAMPART) software, developed at Sandia National Laboratories with funding from the General Services Administration **(21)**. 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) **(22)**.

X1.2.2 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). HAZUS is a natural hazard loss estimation methodology developed by the National Institute of Building Sciences (NIBS) with funding from FEMA. HAZUS allows users to compute estimates of damage and losses from natural hazards using geographical information systems (GIS) technology. Originally designed to address earthquake hazards, HAZUS has been 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.[8] NIBS maintains committees of wind, flood, earthquake, and software experts to provide technical oversight and guidance to HAZUS-MH development. HAZUS-MH uses GIS software to map and display hazard data and the results of damage and economic loss estimates for buildings and infrastructure. Three data input tools have been developed to support data collection. The Inventory Collection Tool helps users collect and manage local building data for more refined analyses than are possible with the national level data sets that come with HAZUS. The Building Inventory Tool allows users to import building data from large datasets, such as tax assessor records. The Flood Information Tool helps users manipulate flood data into the format required by the HAZUS flood model. FEMA has also developed a companion software tool called the HAZUS-MH Risk Assessment Tool to produce risk assessment outputs for earthquakes, floods, and hurricanes. The Risk Assessment Tool pulls natural hazard data, inventory data, and loss estimate data into pre-formatted summary tables and text. These summaries are designed to support the presentation of data to decision-makers and other stakeholders. HAZUS-MH also contains a third party model integration capability that provides access and operational capability to a wide range of natural and man-made hazard models that supplements the natural hazard loss estimation capability in HAZUS-MH.

X1.2.3 FEMA developed a Risk Assessment Database application to support the building assessment process described in FEMA 452 (see X1.1.6). The Risk Assessment Database is a standalone application that is both a collection tool and a management tool. Assessors can use the tool to assist in the systematic collection, storage, and reporting of assessment data. It has functions, folders, and displays to import and display threat matrices, digital photos, cost data, emergency plans, and certain GIS products as part of the record of assessment. Managers can use the application to store, search, and analyze data collected from multiple assessments. The Risk Assessment Database is initially installed at an organization's headquarters. This database, referred to as the Manager's Database, becomes the main access and storage point for future assessment data. When an organization wants to conduct an assessment, a database administrator uses the tool to produce a small temporary database, called the Assessor's Database. Into this Assessor's Database are placed references, site plans, GIS portfolios, and other site-specific data that are known about the assessment site or are developed during the pre-assessment phase. This Assessor's Database is given to the Assessment Team and is loaded on one of more of their assessment computers. The Assessment Team then conducts their assessment and records information in the Assessor's Database. At the end of the assessment, the Assessment Team combines their data into one database and passes the files back to the database administrator. The administrator then loads the data into the Manager's Database for printing and analysis.

X1.2.4 Part IV of Grossi and Kunreuther illustrates how catastrophe models can be utilized in developing risk management strategies for natural disasters and terrorism. It analyzes how insurers employ a specific risk management strategy—requiring homeowners to adopt specific mitigation measures—in determining the pricing of a policy and the amount of coverage to offer. Utilizing data from three modeling firms, three hypothetical insurance companies are formed to provide earthquake or hurricane coverage to homeowners in Oakland, CA, Long Beach, CA, and Miami/Dade County, FL. The analyses illustrate the impact of loss reduction measures and catastrophe modeling uncertainty on an insurer's profitability and likelihood of insolvency. Part IV concludes with an examination of the challenges of using catastrophe models for terrorism risk.

[8] Available from Federal Emergency Management Agency (FEMA), P.O. Box 10055, Hyattsville, MD 20782-8055, http://www.fema.gov/hazus.

X2. SOURCES OF HAZARD DATA

X2.1 Natural Hazards

X2.1.1 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, and coastal and river flooding are available through multiple U.S. government sources.

X2.1.2 The U.S. Geological Survey (USGS) is one source of such information. The USGS has produced background information covering the areas within the 48 contiguous states with "relatively high risk or relatively frequent actual occurrences" of seven natural hazards: floods, earthquakes, landslides, volcanic eruptions, costal storms and tsunamis, wildfires, and outbreaks of disease in wildlife populations.[9] A starting point for data gathering about these hazards is available at USGS.[10] 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.[11] Moreover, the USGS National Earthquake Information Center (NEIC),[12] National Seismic Hazard Mapping Project,[13] and Advanced National Seismic System (ANSS)[14] 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[15] 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,[16] 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.[17]

X2.1.3 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.[18] 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 in 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.[19]

X2.1.4 The National Weather Service collects state and national data about the consequences of severe weather in the United States.[20] Data for 1995 through 2004 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.

X2.1.5 Data about natural hazard risks are also provided through private industry sources. The insurance industry is a key source. The Insurance Information Institute (III)[21] and the Insurance Services Office (ISO)[22] 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.[23] 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.

X2.2 Man-Made Hazards

X2.2.1 Data about the frequency and geography of man-made hazards in the United States are also available through

[9] Available from U.S. Geological Survey (USGS), USGS National Center, 12201 Sunrise Valley Drive, Reston, VA 20192, http://www.usgs.gov/themes/hazard.html.

[10] Available from U.S. Geological Survey (USGS), USGS National Center, 12201 Sunrise Valley Drive, Reston, VA 20192, http://www.usgs.gov/themes/hazpics.html.

[11] Available from U.S. Geological Survey (USGS), USGS National Center, 12201 Sunrise Valley Drive, Reston, VA 20192, http://pubs.usgs.gov/fs/natural-disasters/index.html.

[12] Available from U.S. Geological Survey (USGS), USGS National Center, 12201 Sunrise Valley Drive, Reston, VA 20192, http://earthquake.usgs.gov.

[13] Available from U.S. Geological Survey (USGS), USGS National Center, 12201 Sunrise Valley Drive, Reston, VA 20192, http://earthquake.usgs.gov/hazmaps.

[14] Available from U.S. Geological Survey (USGS), USGS National Center, 12201 Sunrise Valley Drive, Reston, VA 20192, http://earthquakes.usgs.gov/anss.

[15] Available from U.S. Geological Survey (USGS), USGS National Center, 12201 Sunrise Valley Drive, Reston, VA 20192, http://coastal.er.usgs.gov/coastal-classification/index.html.

[16] Available from U.S. Geological Survey (USGS), USGS National Center, 12201 Sunrise Valley Drive, Reston, VA 20192, http://coastal.er.usgs.gov/hurricanes/index.html,

[17] Available from U.S. Geological Survey (USGS), USGS National Center, 12201 Sunrise Valley Drive, Reston, VA 20192, http://water.usgs.gov/osw/techniques/floodfreq.html.

[18] Available from Federal Emergency Management Agency (FEMA), P.O. Box 10055, Hyattsville, MD 20782-8055, http://www.fema.gov/business/nfip/mscjumppage.shtm.

[19] Available from ESRI, 8615 Westwood Center Drive, Vienna, VA 22182-2218, http://www.esri.com.

[20] Available from National Oceanic and Atmospheric Administration (NOAA), Office of Climate, Water, and Weather Services, 1325 East West Highway, Silver Spring, MD 20910, http://www.nws.noaa.gov/om/hazstats.shtml.

[21] Available from Insurance Information Institute (III), http://www.iii.org.

[22] Available from Insurance Services Office (ISO), http://www.iso.com.

[23] Available from Swiss Re, 175 King Street, Armonk, New York 10504, http://www.swissre.com.

public and private sources. The Federal Bureau of Investigation (FBI) collects statistics concerning the reported incidences of crime through the Bureau of Justice Statistics[24] and National Institute of Justice Data Resources[25] programs. Data from these programs are also available at the National Archive of Criminal Justice Data,[26] which is housed by the University of Michigan's Inter-University Consortium for Political and Social Research.

[24] Available from U.S. Department of Justice, Federal Bureau of Investigation (FBI), Uniform Crime Reports, Criminal Justice Information Services Division, Federal Bureau of Investigation, 1000 Custer Hollow Road, Clarksburg, West Virginia 26306, http://www.ucrdatatool.gov.

[25] Available from National Institute of Justice, 810 Seventh Street NW, Washington, DC, 20531, http://www.nij.gov/funding/data-resources-program/welcome.htm.

[26] Available from National Archive of Criminal Justice Data, http://www.icpsr.umich.edu/NACJD/index.html.

X2.2.2 For some man-made 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.[27] 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*[28] is available for 1995 through 2003. The FBI series, *Terrorism in the United States*,[29] is available for 1996 through 2001.

[27] Available from U.S. Chemical Safety and Hazard Investigation Board, 2175 K Street NW, Washington, DC 20037, http://www.csb.gov.

[28] Available from U.S. Department of State, 2201 C Street NW, Washington, DC 20520, http://www.state.gov/s/ct/rls/pgtrpt.

[29] Available from U.S. Department of Justice, Federal Bureau of Investigation (FBI), http://www.fbi.gov/stats-services/publications/reports_and_publications.

X3. COST-EFFECTIVENESS TOOL FOR CAPITAL ASSET PROTECTION

X3.1 The cost-effectiveness software tool, developed by the National Institute of Standards and Technology, helps users make straightforward and consistent comparisons of risk mitigation strategies based on standardized measures of economic performance. The cost-effectiveness software tool was designed to support the Perform Economic Evaluation step described in Section 9.

X3.2 The cost-effectiveness software tool is based on ASTM Standard Practice E917 life-cycle cost analysis. The software allows building owners and managers to define hazard scenarios, identify possible consequences of those scenarios, and compare combinations of strategies to mitigate those consequences.

X3.3 The flexibility of the life-cycle cost method facilitates the classification and analysis of costs in a variety of ways. The result is a more focused representation of costs, referred to as the cost-accounting framework. The objective of producing this framework and employing it in the software tool 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.

X3.4 The cost-accounting framework was designed so that additional measures of economic performance could be easily calculated. Specifically, the cost-accounting framework allows three additional measures to be computed in a manner consistent with ASTM Standard Practices. These measures are: the present value net savings (Practice E1074), the savings-to-investment ratio (Practice E964), and the adjusted internal rate of return (Practice E1057). Multiple measures of economic performance are desirable because many decision makers need measures of magnitude (life-cycle costs and present value net savings) and of return (savings-to-investment ratio and adjusted internal rate of return) to assess economic performance. Multiple measures, when used appropriately, ensure consistency in both setting priorities and selecting projects for funding.

X4. A CASE-STUDY ON USING THE THREE-STEP PROTOCOL TO DEVELOP A COST-EFFECTIVE RISK MITIGATION PLAN AGAINST INTENTIONALLY-SET FIRES

X4.1 *Background*—The purpose of this appendix is to illustrate the three step protocol—perform a risk assessment, specify combinations of risk mitigation strategies for evaluation, and conduct an economic evaluation—using a case-study example. The case-study example develops a cost-effective risk mitigation plan for at-risk Michigan communities seeking to protect themselves from intentionally-set fires. Previous research suggests that crime prevention and urban revitalization programs may be as valuable as fire suppression in reducing incidence and the damage from intentionally-set fires **(23)**. While the case-study is based on a real-world example and uses actual data, its description, assumptions, and findings are meant to highlight elements of the three-step protocol rather than to justify certain actions or policies in Michigan.

X4.2 *Data and Assumptions*—The state of Michigan is the study site for this case-study analysis. The number of intentionally-set fires that occurred over a five-year period (2001 to 2005) is modeled as a function of county-level crime, socioeconomic, weather, land classification, and law enforcement variables, as well as physical and social measures of neighborhood disorder (that is, the incidence of prostitution, vandalism, vagrancy, curfew violation, public drunkenness, drug possession and sale, and runaways). The primary dataset used for the intentionally-set fire portion of the analysis is the U.S. Fire Administration's (USFA) National Fire Incident Reporting System (NFIRS), version 5.0. Between 2001 to 2005, Michigan reported 21 277 intentionally-set fires. In this analysis, an intentionally-set fire is defined as a fire caused by the "deliberate misuse of a heat source or a fire of an incendiary nature" **(23)**. The design of the risk assessment model is to use econometric techniques to regress the count of reported intentionally-set fires against a set of explanatory variables, which include the crime, socioeconomic, weather, land classification, law enforcement, and disorder-based variables. These data were assembled from several sources, as documented in Table X4.1. Summary statistics are also provided in Table X4.1.

X4.3 *Perform Risk Assessment*—The steps of the risk assessment are to: (*1*) *establish risk mitigation objectives and constraints* and to (*2*) *conduct assessment and document findings*. The risk mitigation objective for this analysis is to limit intentionally-set fires in at-risk communities of Michigan. The risk of intentionally-set fire is assessed using (*a*) a statistical model to estimate the occurrence of neighborhood-based intentionally-set fire (intentionally-set structure and vehicle ignitions), and (*b*) loss estimates (life and property) derived from reported fire incident data.

X4.3.1 *Intentionally-Set Fire Occurrence*—In this analysis underreporting of intentionally-set fires is expected as this is consistent with other property crimes (for example, MacDonald **(34)**). Further, NFIRS is a voluntary system, also making underreporting a potential issue. Although Michigan state law requires reporting, some fire departments demonstrate inconsistency in their reporting. Most fire departments continuously reported fire incidents over the study period, although some did not. Gaps tended to include whole months, meaning it was rare to find a department reporting only a single incident or a few per month. Because it was not known whether these gaps were reporting gaps or accurately reflect periods of no fire activity, a metric to measure fire department reporting by county was developed. The metric was calculated as the annual proportion of months that a fire department reported fire incidents, averaged over each county (county/year is unit of observation in this analysis). The median proportion of reporting months, averaged over each county, was 0.77. This implies that a typical fire department reported to NFIRS about 9 to 10 months per year. Thus, a zero-inflated Poisson (ZIP) model is used to regress the counts of intentionally-set fire ignitions occurring in each county/year combination on a set of explanatory variables, while allowing for an abundance of reported zeros in the dataset (that is, more zeros than would be expected in a typical Poisson process). This reporting metric is used in the ZIP to correct for the underreporting. This will help ensure unbiased parameter estimates.

X4.3.1.1 *Statistical Model*—The zero-inflated Poisson occurrence (or count) model is specified as:

$$\Pr(A_{it} = 0) = \Pr(s_{it} = 0) = (1 - \Pr(s_{it} = 0))e^{-\lambda_{it}} \tag{X4.1}$$

$$\Pr(A_{it} = a_{it}) = \frac{(1 - \Pr(s_{it} = 0))e^{-\lambda_{it}}\lambda_{a_{it}}^{it}}{a_{it}!},\ a_{it} = 0, 1, 2, \ldots \tag{X4.2}$$

where A is the count of reported intentionally-set fires; i indexes the county; t indexes the year; s is an indicator variable identifying the reporting state (=0 if intentionally-set fires are never reported; =1 otherwise); it is assumed that the probability of 'intentionally-set fires are never reported' state can be estimated as a function of covariates $\mathbf{x}$ ('inflation factors') and parameters $\boldsymbol{\gamma}$, such that $\Pr(s_{it} = 0) = F(z_{it}, \gamma)$; the expected number of reported intentionally-set fires per period, given intentionally-set fires are reported, is: $\lambda_{it} = e^{\beta' x_{it}}$, where the number of reported intentionally-set fires are a function of covariates $\mathbf{x}$ ('count factors') and parameters $\boldsymbol{\beta}$.

Eq X4.1 estimates the probability that the number of intentionally-set fires is always zero. This probability equals the probability that intentionally-set fires are never reported (even when they occur) multiplied by the exponential of the count of intentionally-set fires when fires are not reported (that is, e^0 or 1) *plus* the probability that intentionally-set fires are reported multiplied by the exponential of the count of

TABLE X4.1 Summary Statistics of the Data

Variable Name	Definition	Source	Mean	Min	Max
INTENTIONALLY-SET	# Reported intentionally-set fires	**(24)**	46.45565	0	2564
ARSON_AR	(# Arson arrests)/(# Arson reported)	**(25)**	0.1733453	0	4
VAC	(# Vacant housing units)/(# Housing units)	**(26)**, **(27)**	0.0296018	0	0.1033487
DIS	# Petty crimes	**(25)**	515.1768	1	13719
DIS_POL	(# Petty crimes)/(# Police)	**(25)**, **(28)**	2.44972	0.1666667	10.83333
TMAX	Mean maximum temperature	**(29)**	57.00832	49.14641	63.26159
PRECIP	Mean annual precipitation	**(29)**	32.73005	18.09	46.32
POL_POP	(# Police)/Population	**(28)**, **(30)**	0.0017811	0.0007517	0.0105055
DU	Deviation in annual unemployment rate	**(31)**	0.4472155	-1.483333	2.416667
VAC_YPOP	(VAC)/(Youth population)	**(26)**, **(32)**	6.18e-06	0	0.0000567
VAC_POP	(VAC)/(Population)	**(31)**	7.86e-07	0	7.65e-06
TREND	Trend variable	**(26)**, **(30)**	3.002421	1	5
LAND_GH	Proportion of county in grassland	**(33)**	0.0513102	0.0052565	0.1600165
LAND_SL	Proportion of county in shrub-land	**(33)**	0.0176907	0.0004426	0.4300563
LAND_MF	Proportion of county in mixed forest	**(33)**	0.36214	0.0006783	0.1942517
LAND_DF	Proportion of county in deciduous forest	**(33)**	0.2374806	0.0543533	0.5131885
LAND_OT	Proportion of county in other land type	**(33)**	0.5972801	0	0.9296144
REPORT	FIRS fire department reporting metric	**(24)**	0.7343844	0.1833333	1
CRIME	# Index crimes	**(25)**	588.1186	0	18019
CRIME_POL	(# Index crimes)/(# Police)	**(25)**, **(28)**	2.296987	0	8.166667

intentionally-set fires when reported. In this latter situation, a count of zero reported intentionally-set fires can occur, but only because no fire actually occurred.

Eq X4.2 estimates the probability that the number of intentionally-set fires is zero or some positive number. This probability is similar to the standard Poisson structure except it is modified by (that is, multiplied by) the probability that the intentionally-set fires are actually reported. Note when zero-inflation due to underreporting does not occur, the probability that intentionally-set fires are not reported is zero (that is, $\Pr(s_{it} = 0) = 0$ and Eq X4.1 and Eq X4.2 reduce to the standard Poisson structure.

The expected number of intentionally-set fires per period is:

$$E[a_{it} \mid x_{it}] = (1 - F(z_{it}, \gamma))e^{\beta' x_{it}} \quad (X4.3)$$

where $F(z_{it}, \gamma) = \Pr(s_{it} = 0)$, with the reporting metric (described above) included as a zero-inflation factor. In this analysis the probability that intentionally-set fires are never reported ($\Pr(s_{it} = 0)$) is estimated using the logit specification, so that $F(z_{it}, \gamma) = (1 + e^{\gamma' z_{it}})^{-1}$. The following log-likelihood function is maximized to estimate the parameters, $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$:

$$\begin{aligned} \ln L = \sum_{i=1}^{N} \sum_{t=1}^{T} (1 - s_{it}) \\ [\ln\{(1 + e^{\gamma' z_{it}})^{-1}\} + \ln\{1 - (1 + e^{\gamma' z_{it}})^{-1}\} - e^{\beta' x_{it}}] \\ + s_{it}[\ln\{1 - (1 + e^{\gamma' z_{it}})^{-1}\} - e^{\beta' x_{it}} + a_{it}\beta' x_{it} - \ln(a_{it}!)] \end{aligned} \quad (X4.4)$$

All police, crime, vacancy rate, and population-based data are lagged one-year in the model to avoid simultaneity bias. The parameter estimates of the occurrence model are shown in Table X4.2. A Vuong statistic of 1.40 (p = 0.08) supports the ZIP model specification over the Poisson.

X4.3.2 *Consequences of Intentionally-Set Fires*—Table X4.3 provides several statistics related to losses associated with reported intentionally-set fires in Michigan. The total impact (economic loss from property damage plus the economic value of fatalities and injuries) per reported intentionally-set fire is shown. Reported intentionally-set residential fires are the most impactful, as they tend to involve loss of life. These fires average in cost $94 thousand per fire. Reported intentionally-set non-residential and vehicle fires average $27 thousand and $43 thousand in cost per fire, respectively.

X4.4 *Specify Combinations of Risk Mitigation Strategies for Evaluation*—The steps for specifying combinations of risk mitigation strategies includes: (*1*) *review alternative risk mitigation strategies*; (*2*) *select candidate combinations of risk mitigation strategies;* and (*3*) *develop cost estimates and sequence of cash flows for each candidate combinations*.

X4.4.1 *Review Alternative Risk Mitigation Strategies*—Several risk mitigation strategies have been identified in the literature. Three mitigation strategies, which are the focus of this analysis, are increasing policing, decreasing community social disorder, and decreasing the vacancy rate of buildings. Other risk mitigation strategies exist. For instance research has demonstrated the economic returns to fire prevention effectiveness can be quite significant (for example, see Prestemon et al.

TABLE X4.2 Results of Zero Inflated Poisson Regression

Variable	Parameter Estimates	Standard Error	Elasticities[A]
ARSON AR	-2.36E-01[B]	6.00E-02	-4.09E-02
VAC	3.27E+01[B]	4.59E-01	9.68E-01
PIS	9.57E-05[B]	3.51E-06	4.93E-02
DIS POL	-1.71E-01[B]	1.20E-02	-4.20E-01
TMAX	6.80E-02[B]	4.94E-03	3.87E+00
PRECIP	-3.85E-02[B]	2.59E-03	-1.26E+00
POL POP	-6.40E+01[B]	7.68E+00	-1.14E-01
DU	4.78E-02[C]	2.49E-02	2.14E-02
VAC YPOP	3.41E+05[B]	3.14E+04	2.11E+00
VAC POP	-5.55E+06[B]	2.57E+05	-4.36E+00
TREND	-2.67E-02[C]	1.32E-02	-8.02E-02
Y2002	-2.70E-01[B]	3.15E-02	-5.42E-02
Y2003	2.51E-02	3.36E-02	5.04E-03
Y2004	3.19E-01[B]	2.99E-02	6.34E-02
CONSTANT	1.09E+00[B]	2.91E-01	
Inflation Factors			
LAND GH	3.96E+00	1.27E+01	-3.75E-05
LAND SL	-8.16E+00	9.27E+00	2.66E-05
LAND MF	-2.10E+01	1.72E+01	1.40E-04
LAND DF	-4.18E+00	3.78E+00	1.83E-04
LAND OT	-6.28E+00	4.62E+00	6.92E-04
REPORT	-2.61E+00	1.66E+00	3.54E-04
CRIME	-1.14E-02[C]	5.50E-03	1.24E-03
CRIME POL	4.53E-01[D]	2.75E-01	-1.92E-04
CONSTANT	4.42E+00	4.59E+00	

[A] Elasticities are calculated at the mean value of all explanatory variables.
[B] Denotes significant at 10 % level.
[C] Denotes significant at 5 % level.
[D] Denotes significant at 1 % level.

TABLE X4.3 Statistics of Reported Intentionally-Set Fires in Michigan from 2001 to 2005 (in Thousands of Present-Value 2008 Dollars)

	Fires	Fatalities		Injuries		Property Damage	Total Impact[A]	Impact per Fire[A]
		Civilian	Fire Service	Civilian	Fire Service			
Residential	2290	15	0	87	103	$47 418	$214 616	$94
Non-Residential	1052	0	0	13	19	$22 379	$28 379	$27
Vehicle	1356	6	0	3	2	$4 736	$58 182	$43

[A] The value of a statistical life is estimated at $8.75 million; the value of a statistical injury is estimated at $189 198 **(35)**.

(36)). However, for this analysis, detailed information about other mitigation strategies was not available.

X4.4.1.1 Police have arrest and detention powers, as well as the ability (responsibility) to investigate crime and to provide surveillance. During the study period in Michigan, police made 2968 arrests on 26 886 reported cases of arson. This represents an 11 % clearance rate. In 2006, the national clearance rate for arson was 18 % **(37)**.

X4.4.1.2 Community vigilance and organized neighborhood watch activities have been identified by U.S. Fire Administration **(38)** as a means of reducing arson threats. Some of the activities identified include reporting suspicious activity to police, cleaning-up overgrown vegetation around vacant buildings, and watching out for juveniles (who comprise half of the suspects arrested for arson) **(38)**. More generally, community attitudes towards crime and reporting practices have been linked to the volume of crime in an area **(39)**. Urban decay and social disorder is often linked to higher crime rates **(40)**.

X4.4.1.3 Fires in vacant buildings have been identified as a fire concern due to the increasing numbers of vacant buildings **(41)**. Intentionally-set fires account for 43 % of all fires in vacant buildings, and comprise 25 % of all intentionally-set fires. Reducing the number of vacant buildings is one strategy discussed by National Vacant Properties Campaign **(42)** and Interfire **(43)**. While the city of Detroit has used such a strategy to combat Halloween arson in the 1980s and 1990s **(44)**, other cities, such as Little Rock and New York City, have demonstrated that arson threats can be reduced by dealing with vacant and abandoned buildings **(45)**.

X4.4.1.4 These mitigation strategies offer the potential to work both directly and indirectly at limiting the number of intentionally-set fires. For example, police directly limit intentionally-set fires by making arrests or by surveilling neighborhoods. Neighborhood watch groups can alert police to suspicious activity or notify fire departments when fires occur. The removal of vacant buildings eliminates a potential target. However, related to the research on community attitudes and urban decay, these strategies potentially provide indirect impacts by limiting the social conditions that promote crime, which includes arson.

X4.4.1.5 While the three strategies have been identified as means of reducing intentionally-set fires, this is an empirical question, which can be tested. The risk model, described above, used regression techniques to evaluate the amount of variation in the annual count of intentionally-set fires explained by the three selected mitigation strategies. The results demonstrated that police, social disorder, and vacancy rates are correlated with the total number of reported intentionally-set fires in ways expected by theory. Specifically, reducing vacancy rates (VAC) and instances of social and physical disorder (DIS), or increasing police levels (POL_POP), or both, are found to reduce the number of future reported intentionally-set fires. Further, the results of the occurrence model can be use to determine how changes to these factors affect the expected magnitude of change in reported intentionally-set firesetting. Specifically, the elasticities of the model (that is, how a 1 % change in a variable affects some percent change in the number of reported intentionally-set fires) can be estimated from the model as:

$$\frac{\partial\, E\,[a_{it} \mid x_{it}]}{\partial\, x_{it}} \frac{x_{it}}{a_{it}} = (1 - f(z_{it}, \gamma))\, e^{\beta' x_{it}}\, \beta' x_{it}\, a_{it}^{-1} \tag{X4.5}$$

X4.4.1.6 The elasticities are presented in Table X4.2. For example, the elasticity of reported intentionally-set fires with respect to the vacancy rate is 0.97, meaning a 1 % decrease in the ratio of vacant houses to all houses results in a 0.97 % decline in the following year's reported intentionally-set fires (holding the ratio of vacancy rate to youth population and ratio of vacancy rate to population constant; holding all other variables at their means).

X4.4.2 *Select Candidate Combinations of Risk Mitigation Strategies*—Three mitigation strategies are individually evaluated: (*1*) an increase in policing (that is, increase in police to population ratio [POL_POP]); (*2*) a decrease in the vacancy rate [VAC] (holding other interactions constant); and (*3*) an increase in community surveillance activity by local residents, labeled here as "neighborhood watch activity," which causes a decrease in physical and social measures of disorder (DIS).

X4.4.2.1 The strategies chosen focus on reducing the occurrence of fire rather than on limiting losses given a fire. Average losses could be reduced, however, if the mitigation techniques alter preferred fire targets. For instance, vacant houses may be preferred targets of intentionally-set firesetters, so the removal of such targets may cause firesetters to substitute to other, more available targets, such as vehicles. Thus, assuming the same amount of firesetting, the mitigation strategy would result in an average per fire loss of $43 thousand instead of $94 thousand. This represents a per fire savings of $51 thousand (on average).

X4.4.3 *Develop Cost Estimates and Sequence of Cash Flows for Each Candidate Combinations*—The costs and benefits of mitigation are estimated. To understand the potential impact that mitigation strategies have, a counterfactual analysis is used to measure the change in reported intentionally-set fires had mitigation occurred from 2001 to 2005. The three scenarios explored include: (*1*) had policing been increased 1 %; (*2*) had the vacancy rate been decreased 1 %; or (*3*) had enhanced neighborhood watch activity resulted in a 1 % decline in disorder (that is, the incidence of for prostitution, vandalism, vagrancy, curfew violation, public drunkenness, drug possession and sale, and runaways). This analysis uses a 7 % discount rate and all dollar estimates are reported in 2008 constant dollars.

X4.4.3.1 *Benefits*—The value of an intentionally-set fire avoided is estimated at $64 108 (result not shown). This was estimated as the weighted average of the cost per intentionally-set fire incident across residential, non-residential, and vehicle fires (see Table X4.3). Table X4.4 presents the estimated change in the value of intentionally-set fires due to a 1 % change in the individual mitigation strategies. The discounted benefits are calculated as the multiple of the number of intentionally-set fires avoided and the value of the avoided incident. For instance, reducing the vacancy rate 1 % is expected to have reduced the number of reported intentionally-set fires in the state of Michigan in 2001 by 29. This has a present value benefit of $2.9 million.

X4.4.3.2 *Benefit Comparison*—The three mitigation strategies affect the number of reported intentionally-set fires in different ways. Increasing police levels 1 % reduces the number of reported intentionally-set fires by 37 over the five-year study period; decreasing the number of vacant structures by 1 % reduces the number of reported intentionally-set fires by 501 over the study period; increasing neighborhood watch activity so to reduce the incidence of neighborhood disorder by 1 % reduces the number of reported intentionally-set fires by 133 over the study period. This produces present value benefits totaling $3.3 million for policing, $44.4 million for vacancy reduction, and $11.8 million for increased neighborhood watch activity.

X4.4.3.3 *Costs*—Table X4.4 presents the discounted costs of mitigation strategies.

(1) Policing Costs—The cost of increasing the police to population ratio (POL_POP) 1 % was estimated to require a 1 % increase in the total police budget. The average annual statewide cost of policing in Michigan was $1.99 billion (result not shown). A 1 % increase therefore requires an additional $19.9 million (result not shown). Because an increase in the number of police would produce a wealth of additional benefits, besides the reduction in intentionally-set fires, only a portion of the $19.9 million was attributed to intentionally-set fire mitigation effort. Based on data from the Uniform Crime Report **(25)**, the report of arson crime comprised only 0.97 % of all reported index crimes, on average for Michigan. Thus, $0.2 million (result not shown) was estimated as the annual cost of increased police for the reduction of reported intentionally-set fires. Over the five-year study period this amounts to a present value cost of $1.8 million.

(2) Building Demolition Costs—The cost of reducing the vacancy rate was estimated as the cost required to demolish a residential structure. Only demolition costs were considered. Legal and related-process costs were not considered. These are likely to vary across the United States. In this analysis, the cost of reducing the vacancy rate is calculated as the multiple between the number of vacant structures required to reduce the vacancy rate 1 % and the maximum value of demolishing a single-family, one-story wood-framed house ($6349). The demolition cost was obtained from RS Means CostWorks **(46)**. (The maximum single-family, one-story value was chosen because it falls in between the minimum and maximum value associated with a two-family, two-story house.) In Detroit, published estimates for the removal of vacant houses have ranged from an average of $2500 to $10 000 per house **(47, 48)**. Based on the structure of the risk occurrence model, the 1 % decrease in the vacancy rate requires all the demolition to have occurred in 2000 (that is, costs accrue in 2000 and the benefits occur in 2001 and beyond). Over the five-year study period this amounts to a present value cost of $22.6 million.

(3) Volunteering Costs—The cost of increasing neighborhood watch effort across Michigan is estimated as the social cost of increasing volunteer hours so as to produce a reduction in the incidence of physical and social disorder by 1 %. Because an explicit link between neighborhood watch participation and the incidence of disorder is not available, an assumption is made that 34 000 hours of additional participation is required each year to reduce disorder 1 %. The 34 000 hour requirement was chosen because during Detroit's response to Devil's Night, a maximum of 34 000 volunteers

TABLE X4.4 Economics of Intentionally-Set Fire Risk Mitigation Strategies in Michigan

	Expected Change in the Number of Intentionally-Set Fires					
	2001	2002	2003	2004	2005	Total
Police	-2	-10	-9	-8	-8	-37
Vacant Houses	-29	-131	-128	-110	-103	-501
Neighborhood Watch	-2	-43	-38	-26	-24	-133

	Benefits (in Thousands of Present-Value 2008 Dollars)					
	2001	2002	2003	2004	2005	Total
Police	$238	$929	$848	$671	591$	$3 276
Vacant Houses	$2 934	$12 644	$11 515	$9 223	$8 123	$44 440
Neighborhood Watch	$244	4 138$	$438	2 173$	$1 851	$11 843

	Cots (in Thousands of Present-Value 2008 Dollars)					
	2001	2002	2003	2004	2005	Total
Police	$312	$427	$399	$373	$348	$1 849
Vacant Houses	$22 564					$22 564
Neighborhood Watch	$1 195	$1 117	$1 044	$976	$912	$5 244

patrolled city streets in 1993 **(44)**. A 1 % reduction in disorder equates to 426 fewer incidents, on average per year. Thus the ratio of volunteer hours to incidents prevented is 80 hours to 1. The hourly value of volunteer time in Michigan is estimated to be $20.46 **(49)**. Over the five-year study period this amounts to a present value cost of $5.2 million.

X4.4.3.4 *Cost Comparison*—The three mitigation strategies identified require different funding amounts to achieve a 1 % change in their levels. Removing abandoned buildings requires the most capital at $22.6 million, followed by increased neighborhood watch activity at $5.2 million, and increased policing at $1.9 million.

X4.5 *Perform Economic Evaluation*—The steps for performing the economic evaluation includes: (*1*) *select appropriate economic methods for evaluating the candidate combinations of risk mitigation strategies*; (*2*) *compute measures of economic performance for each candidate combination*; and (*3*) *recompute measures of economic performance taking into consideration uncertainty and risk*.

X4.5.1 *Economic Methods for Evaluating the Candidate Combinations of Risk Mitigation Strategies*—Three economic measures are used: (*1*) present value net benefits (Practice E1074); (*2*) benefit-to-cost ratio (Practice E964); and (*3*) adjusted internal rate of return (Practice E1057).

X4.5.2 *Compute Measures of Economic Performance for Each Candidate Combination*—Table X4.5 presents the findings of the baseline economic evaluation. Removing vacant houses produces a present value net benefit (PVNB) of $21.9 million; increasing neighborhood watch participation yields a PVNB of $6.6 million; increasing police levels produces a PVNB of $1.4 million. Thus, all of the mitigation strategies are cost-effective. While removing vacant houses achieves the largest net benefit, increasing neighborhood watch participation actually yields a better per dollar return on investment, as it produces the largest benefit-to-cost ratio (BCR) (2.26) and adjusted internal rate of return (AIRR) (0.26). All strategies produce significant returns on investment dollars, as evident by each AIRR > 0.20 (that is, the minimum acceptable rate is 0.07, as dictated by the discount rate).

X4.5.3 *Recompute Measures of Economic Performance Taking into Consideration Uncertainty and Risk*—Monte Carlo simulation is used to analyze the sensitivity of the baseline results to changes in select inputs. A total of 10 000 trials was performed.

X4.5.3.1 *Sensitivity Analysis Inputs*—Table X4.6 presents the variables used in the uncertainty analysis, which include: the discount rate, the value of an avoided intentionally-set fire, the proportion of the police budget used to police intentionally-set firesetting, demolition costs, and the amount of volunteer hours needed to reduce the incidence of disorder by 1 %. The value of fire avoidance follows a custom distribution based on values found in Table X4.3. For instance, 49 % of the reported intentionally-set fires occurred in residential structures, with an average impact (property damage plus loss of life and injury incurred) of $93 719. The distribution of demolition costs correspond with RS Means reporting of the minimum demolition costs associated with a single-family, one-story house and the maximum demolition costs associated with a two-family, two-story house. All other factors were chosen based on expert judgment.

X4.5.3.2 *Sensitivity Analysis Results*—Table X4.7 presents the results of the Monte Carlo simulation. For each mitigation strategy, the mean and median PVNB, BCR, and AIRR indicate that each strategy is likely to be cost-effective. All economic performance measures suggest that there is some likelihood that a strategy will not achieve cost-effectiveness, as indicated by the negative PVNB in the minimum column. The likelihood is largest for increased policing. Expansion of the neighborhood watch program appears to offer the least risk, as it offers the largest return on the dollar, although the removal of abandoned buildings yields the largest expected payoff.

X4.6 *Final Decision*—The three mitigation strategies offer communities with very different mechanisms to affect the number of reported intentionally-set fires in structures and vehicles. Increased policing by law enforcement and neighborhood activists provides communities with increased detection of potential firesetters, as well as means to apprehend and punish setters of illegal fires. Law enforcement policing also provides a deterrent effect. The demolition of vacant structures limits the number of possible "good" targets for firesetters. (At a community-level these may affect intentionally-set fire rates only by displacing the fire in time or space, perhaps making it another community's issue [for instance, see Weisburg et al. **(50)**]). In addition, all three strategies work to minimize urban decay, which has been shown to affect crime rates. This could indirectly lead to fewer intentionally-set fires. The choice between the mitigation strategies may largely be determined by the available budget. With an infinite budget, all three would be economically worthwhile as suggested by their individual returns. A joint solution reflecting interdependence among the three strategies was not analyzed. If budget is a concern, increased policing offers the most inexpensive solution, followed by increased neighborhood watch participation, which does not require a budget, per se, but rather a significant commitment of residents' time. The removal of vacant structures offers the largest returns, but comes with the largest price. A more detailed analysis would jointly optimize changes to all three mitigation strategies, thereby indentifying the unique combination of effort resulting in the "least cost plus loss"

TABLE X4.5 Economic Evaluation of Intentionally-Set Fire Risk Mitigation Strategies

	Present Value Net Benefits (in Thousands of 2008 Dollars)	Benefit-to-Cost Ratio	Adjusted International Rate of Return
Police	$1 418	1.76	0.20
Vacant Houses	$21 876	1.97	0.23
Neighborhood Watch	$6 600	2.26	0.26

TABLE X4.6 Uncertainty Variables Used in Sensitivity Analysis

Input	Distribution	Most-Likely	Minimum	Maximum
Discount Rate	Uniform	0.07	0.04	0.10
Proportion of Budget Policing Arson	Triangular	0.010	0.005	0.015
Demolition Cost	Triangular	6 349	3 694	9 235
Volunteering Hours	Triangular	34 000	17 000	51 000

Input	Distribution	Most-Likely	Least-Likely	Intermediately Likely
Value of Fire Avoidance	Custom[A]	$93 719 (p = 0.49)	$26 976 (p = 0.22)	$42 907 (p = 0.29)

[A] The values of the custom distribution show the value followed by its probability in parenthesis.

TABLE X4.7 Results of the Monte Carlo Sensitivity Analysis

NOTE 1—All dollars are in thousands of present-value 2008 dollars.

	Trials	Mean	Minimum	25 %	Median (50 %)	75 %	Maximum
Police							
PVNB	10 000	$1 425	$(1 621)	$(20)	$1 048	$2 899	$4 297
BCR	10 000	1.85	0.49	0.99	1.79	2.55	5.07
AIRR	10 000	0.18	-0.08	0.07	0.20	0.29	0.50
Vacant Houses							
PVNB	10 000	$21 360	$(17 929)	$2 298	$13 924	$41 944	$57 059
BCR	10 000	2.02	0.54	1.10	1.91	2.86	5.16
AIRR	10 000	0.20	-0.05	0.09	0.22	0.32	0.48
Neighborhood Watch							
PVNB	10 000	$6 630	$(3 388)	$1 466	$4 656	$11 973	$16 355
BCR	10 000	2.37	0.62	1.27	2.31	3.29	6.56
AIRR	10 000	0.24	-0.03	0.12	0.26	0.36	0.58

associated with intentionally-set firesetting. The least-cost-plus-loss solution would ensure that no change in the mix of mitigation strategies, including any expansion of the programs, could produce a smaller combination of program costs plus the losses-associated with intentionally-set fires.

X4.7 *Limitations*—The purpose of this appendix is to illustrate the three step protocol using a case-study example. While the case-study is based on a real-world example and uses actual data, its description, assumptions, and findings are meant to highlight elements of the three-step protocol rather than to justify certain actions or policies in Michigan. The risk model was parameterized using data for Michigan over the period 2001 to 2005. Caution should be taken before extrapolating these findings to other areas of the United States or to other time periods. The conditions that existed in Michigan, and captured in the model, may not exist elsewhere.

X4.7.1 The mitigation strategies chosen for analysis were not meant to be exhaustive. They were chosen given the success of these types of programs in the 1980s and 1990s for Detroit in dealing with Halloween arson **(44)**, and because they have been identified more generally as potential solutions to limiting arson. More practically, they were evaluated because data existed to test these relationships.

X4.7.2 While the statistical model demonstrated that the mitigation strategies each were correlated with the total number of reported intentionally-set fires, it was not known how the strategies affected the individual incident types—residential, non-residential, and vehicle intentionally-set fires. Because of this, the economic benefits were based on a weighted average of the cost per intentionally-set fire across incident type. Had these mitigation strategies affected only residential incidents, then their economic performance would have increased. However, had these mitigation strategies affected only non-residential or vehicle incidents, then their economic performance would have decreased. They would not have been cost-effective if they only affected the number of non-residential incidents, but they would have been cost-effective if they affected only the number of vehicle incidents (holding all other assumptions constant).

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