NISTIR 5863

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Institute of Standards and Technology

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

Benefits and Costs of Research: A Case Study of the Fire Safety Evaluation System

Robert E. Chapman and Stephen F. Weber

July 1996
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899

U.S. DEPARTMENT OF COMMERCE
Michael Kantor, Secretary
Technology Administration
Mary L. Good, Under Secretary for Technology
National Institute of Standards and Technology
Arati Prabhakar, Director

Abstract

The National Institute of Standards and Technology (NIST) is improving its resource allocation process by doing "microstudies" of its research impacts on society. This report is one of a series of microstudies prepared by NIST's Building and Fire Research Laboratory (BFRL).

This report focuses on a critical analysis of the economic impacts from past BFRL research efforts leading to the development and introduction of the performance-based Fire Safety Evaluation System (FSES) for health care facilities. The FSES was developed as an alternative to prescriptive compliance to the Life Safety Code for hospitals and nursing homes participating in the Medicare and Medicaid programs.

This study of the FSES illustrates how to apply in practice a series of standardized methods to evaluate and compare the economic impacts of alternative research investments. The study is presented in sufficient detail to understand the basis for the economic impact analysis and to reproduce the results. It is an *ex post* study in that it is based on past research efforts.

The results of this study demonstrate that the FSES has generated substantial cost savings to hospitals and nursing homes across the nation. The present value of savings nationwide attributable to the FSES is nearly $1 billion ($987 million in 1995 dollars). Furthermore, because of BFRL's timely involvement and leadership, the FSES was adopted into the Life Safety Code in 1981. The first fully-documented use of the FSES was in 1983. If BFRL had not participated in the development of the FSES, adoption into the Life Safety Code would likely have taken place in 1988. Consequently, potential cost savings accruing to hospitals and nursing homes over the period 1983 through 1989 would have been foregone. These cost savings are $564 million in 1995 dollars. These cost savings measure the value of BFRL's contribution for its research investment of approximately $4.5 million.

Keywords

benefit-cost analysis; building economics; buildings; construction; economic analysis; fire safety; impact evaluation; life-cycle costing; performance standards; research impacts.

Preface

This study was conducted by the Office of Applied Economics in the Building and Fire Research Laboratory (BFRL) at the National Institute of Standards and Technology (NIST). This study is designed to help BFRL estimate the economic impacts resulting from its research and to estimate the return on BFRL's research investment dollars. The intended audience for this report is the National Institute of Standards and Technology as well as other government and private research groups that are concerned with determining efficient allocations of their research budgets.

The measurement of economic impacts of research is a major interest of BFRL and of NIST. Managers need to know the impact of their research programs in order to achieve the maximum social benefits from their limited budgets. The standardized methods for measuring economic impacts employed in this study are essential to support BFRL's effort to evaluate the cost effectiveness of completed research projects. As additional experience is gained with the application of these standardized methods, their use will enable BFRL to select the "best" among competing research programs, to evaluate how cost effective are existing research programs, and to defend or terminate programs on the basis of their economic impact. This need for measurement methods exists across programs in BFRL, in NIST, and in other research laboratories.

Acknowledgments

The authors wish to thank all those who contributed so many excellent ideas and suggestions which we have attempted to incorporate into this report. Special appreciation is extended to Dr. Harold E. Marshall and to Ms. Barbara C. Lippiatt of the Office of Applied Economics at NIST's Building and Fire Research Laboratory (BFRL) for the thoroughness of their reviews and for their many insights and to Ms. Laurene Linsenmayer for her assistance in preparing the manuscript for review and publication. Special appreciation is also extended to Mr. Harold E. "Bud" Nelson of Hughes Associates, Inc., formerly with BFRL, for his pioneering work on the Fire Safety Evaluation System (FSES). Thanks are due to Mr. Richard Laeng of the U.S. Public Health Service (PHS) for providing access to detailed information on more than 80 active service military hospitals which were surveyed by the PHS between 1985 and 1994. Thanks are also due to Mr. Mayer Zimmerman of the Health Care Finance Administration, to Mr. Douglas Erickson of the American Hospital Association, and to Mr. Thomas Jaeger of Gage-Babcock and Associates, for their assistance in estimating the rates of use of the FSES in hospitals and nursing homes. The report has also benefitted from the reviews and technical comments provided by Mr. Stephen R. Petersen and by Mr. Richard W. Bukowski of BFRL.

Contents

Contents (continued)

List of Exhibits

List of Tables

Contents (continued)

Page

Executive Summary

This report is the second of a series of studies on the economic impacts of research conducted by NIST's Building and Fire Research Laboratory (BFRL)[i]. It focuses on BFRL research that led to the development, adoption, and implementation of the performance-based Fire Safety Evaluation System (FSES) for health care facilities. The FSES was developed as an alternative to prescriptive compliance to the Life Safety Code for hospitals and nursing homes participating in Medicare and Medicaid. The study estimates the cost savings from using FSES-based modifications to promote fire safety in existing hospitals and nursing homes over the period from 1975 through 1995. That part of dollar savings attributable specifically to BFRL's research efforts is also estimated.

This study of the FSES illustrates how to apply in practice a series of standardized methods to evaluate and compare the economic impacts of alternative research investments. The study is presented in sufficient detail both to understand the basis for the economic impact analysis and to reproduce the results. It is an *ex post* study in that it estimates savings that have already been realized in the past (1975-1995).

There are six chapters and two appendices. Chapter 1 explains the purpose, scope, and general approach of the study. The methodology and standardized methods used to measure the FSES's economic impacts are described in chapter 2. Chapter 3 traces the development of the FSES as an alternative to prescriptive compliance to the Life Safety Code for hospitals and nursing homes participating in Medicare and Medicaid. Chapter 4 describes the assumptions and supporting data used to establish values for the key parameters of the study: the discount rate, the level of FSES adoption, numbers of health care facilities and beds, and the per unit cost savings. Chapter 5 reports estimates of the total nationwide cost savings from using FSES from 1975 through 1995, the portion of those savings attributable specifically to BFRL's research efforts, as well as a detailed sensitivity analysis. Chapter 6 concludes the report with a summary and suggestions for further research. How the FSES measures safety performance is the subject of appendix A. Appendix B provides the mathematical formulation for BFRL's optimization software. This software identifies lower cost equivalent solutions for Life Safety Code compliance and measures the cost savings compared with prescriptive compliance.

Chapter 2 presents the five economic evaluation methods that are most appropriate for measuring the cost savings impacts of research programs: (1) Present Value of Net Benefits (PVNB); (2) Present Value of Net Savings (PVNS); (3) Benefit-to-Cost Ratio (BCR); (4) Savings-to-Investment Ratio (SIR); and (5) Adjusted Internal Rate of Return (AIRR). The PVNB (PVNS) measures the overall magnitude of the benefits (cost savings) net of the costs of undertaking the research. The BCR (SIR) measures the benefits (cost savings) per unit cost of the research. The AIRR is the annual percentage yield from a project over the study period, taking into account the reinvestment of interim receipts. All five methods apply to Accept/Reject decisions. Both PVNB and PVNS are appropriate for Design/Size decisions (selecting one among mutually exclusive alternatives). BCR, SIR, and AIRR are appropriate for ranking alternatives under a budget constraint. A format for summarizing economic impacts of research investments is also presented in Exhibit 2.1.

---

[i]The first report in the series focused on two building technology applications—ASHRAE Standard 90-75 for residential energy conservation and 235 shingles, an improved asphalt shingle for sloped roofing. See Chapman, Robert E., and Sieglinde K. Fuller. 1996. *Benefits and Costs of Research: Two Case Studies in Building Technology*. NISTIR 5840. Gaithersburg, MD: National Institute of Standards and Technology.

Chapter 3 describes the problem addressed by the BFRL research effort as well as the accomplishments achieved by the research. Concern over fire safety in hospitals and nursing homes caused Congress to make certification for participation in the Medicare and Medicaid programs contingent upon complying with the Life Safety Code. Because the Life Safety Code is a prescriptive code (i.e., it prescribes fixed solutions to fire safety in designated occupancies), many health care facilities were faced with costly renovations. In 1975, the Department of Health and Human Services (then HEW) sought technical support from BFRL (then the Center for Fire Research). This support led to the development of the Fire Safety Evaluation System (FSES), a framework for determining how combinations of several widely-accepted fire safety systems can be used to provide a level of safety equivalent to that prescribed by the Life Safety Code.[ii] Optimization software developed by BFRL economists builds on the FSES equivalency approach to offer facility managers a menu of solutions, many of which result in significant cost savings.[iii] The optimization software has been extensively utilized by the U.S. Public Health Service (PHS) on 86 active service military hospitals. The PHS data set provides an excellent cross section of the overall hospital population, facilitating an evaluation of nationwide cost savings attributable to the FSES. BFRL's active role in the development of the FSES led to its acceptance into the Life Safety Code in 1981. Without BFRL's participation in the development of the FSES, it is likely that acceptance into the Life Safety Code would have been delayed at least seven years.

The key assumptions and supporting data are in Chapter 4. The study period over which costs and savings are measured consists of the 21 years from 1975 through 1995. The base year is 1995, and all amounts are calculated in present value 1995 dollars. The discount rate is 7 percent (real), which is the OMB discount rate in effect for government projects in 1995. The PHS data set is used to develop estimated cost savings for active service military hospitals. Cost savings on a per bed basis ($1290) are derived from the PHS data set and applied to VA hospitals, non-federal hospitals, and nursing homes. Rates of use of the FSES for VA hospitals, non-federal hospitals, and nursing homes are based on information from government and industry experts.

As reported in Chapter 5 and summarized there in Exhibit 5-1, the results of this study demonstrate that the FSES has generated substantial cost savings to hospitals and nursing homes across the nation. The present value of savings nationwide attributable to the FSES is nearly $1 billion ($987 million in 1995 dollars). Furthermore, because of BFRL's timely involvement and leadership, the FSES was adopted into the Life Safety Code in 1981. The first fully-documented use of the FSES was in 1983. If BFRL had not participated in the development of the FSES, adoption into the Life Safety Code would likely have taken place in 1988. Consequently, potential cost savings accruing to hospitals and nursing homes over the period 1983 through 1989 would have been foregone. These cost savings are $564 million in 1995 dollars. These cost savings measure the value of BFRL's contribution for its research investment of approximately $4.5 million. Stated in present value terms, every public dollar invested in BFRL's FSES-related research generated $126 in cost savings to the public (i.e., an SIR of 126). The annual percentage yield (AIRR) from the FSES project over the study period is 35 percent.

[ii] The current version of the FSES is National Fire Protection Association (NFPA). 1995. *Guide on Alternative Approaches to Life Safety*. NFPA 101A. Quincy, MA: National Fire Protection Association.

[iii] The first version of the software is Chapman, Robert E., and William G. Hall. 1983. *User's Manual for the Fire Safety Evaluation System Cost Minimizer Computer Program*. NBSIR 83-2797. Gaithersburg, MD: National Bureau of Standards. The current version of the software is Weber, Stephen F., and Barbara C. Lippiatt. 1994. *ALARM 1.0—Decision Support Software for Cost-Effective Compliance with Fire Safety Codes*. NISTIR 5554. Gaithersburg, MD: National Institute of Standards and Technology.

Because a number of factors are uncertain, Chapter 5 concludes with a comprehensive sensitivity analysis. The purpose of the sensitivity analysis was to evaluate the impact of changing the values of three key variables in combination. The three variables are: (1) the discount rate; (2) the per unit cost savings; and (3) the delay in adoption. All changes were selected so as to represent variations about the baseline values of each key variable. Each key variable was set at one of three different levels. In all, 27 different sets of results were obtained. For each of the 27 different sets of results, PVNS, SIR, and AIRR were calculated. The PVNS ranges from $119.4 to $1,335.3 million., the SIR from 30 to 318, and the AIRR from 24 % to 41%. These sensitivity results demonstrate the significant impact which BFRL's research on the FSES had on the health care community. The high values of these key economic measures over such a wide range of assumptions, show definitively that BFRL's research is having an impact on the sectors of the national economy which it serves. See Exhibit 5-1 for a two-page summary of the impact study and the resulting economic measures.

Chapter 6 discusses additional areas of research that might be of value to government agencies and other institutions that are concerned with an efficient allocation of their research budgets. These areas of research are concerned with: (1) the development of a standard classification of research benefits and costs; (2) factors affecting the diffusion of new technologies; (3) conducting *ex ante* evaluations with scheduled follow-ups; and (4) evaluations based on multiattribute decision analysis.

1. Introduction

1.1 Background

The pressures of competing in the global marketplace are affecting nearly every U.S. business. Now more than ever, U.S. businesses are finding that they must continuously improve their products and services if they are to survive and prosper. Research, with its potential for incremental and breakthrough improvement, is of central importance to most businesses' continuous improvement efforts. It is now widely recognized that a key component of the competitiveness problem lies in the "inability of American companies (or, more accurately, the U.S.-based portions of what are fast becoming global technology firms) to transform discoveries quickly into high-quality products and into processes for designing, manufacturing, marketing, and distributing such products."[1]

Increasingly, the winners in the competitiveness race are those businesses that most rapidly make use of the fruits of research (e.g., new data, insights, inventions, prototypes). Efforts underway at the National Institute of Standards and Technology (NIST) and elsewhere in the U.S. focus on speeding up the commercial application of basic and applied research results. *The purpose of this report and its companion*[2] *is to respond to the following question: "how do we measure the results of our investments in technology development and application?"*[3] A case study approach is used to illustrate how standardized evaluation methods may be used to measure the economic impacts of such investments.

NIST's research laboratories serve all sectors of U.S. industry through focused research programs. Each laboratory has cultivated strong working relationships with industrial, trade and professional organizations in its areas of technology concentration. The program of NIST's Building and Fire Research Laboratory (BFRL) is guided by a prioritized research agenda developed by experts from the building and fire communities. Its performance prediction and measurement technologies enhance the competitiveness of U.S. industry and public safety. Specifically, BFRL is dedicated to improving the life-cycle quality of constructed facilities. BFRL studies structural, mechanical, and environmental engineering, fire science and fire safety engineering, building materials, and computer integrated construction practices.

To further strengthen its ties to industry, BFRL is actively participating in the Subcommittee on Construction and Building of the National Science and Technology Council (NSTC). The NSTC, a cabinet-level group charged with setting federal technology policy, coordinates research strategies across a broad cross-section of public and private interests. The Subcommittee on Construction and Building

---

[1] Reich, Robert W. 1989. "The Quiet Path to Technological Preeminence." *Scientific American* (October): pp. 41-7.

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

[3] Good, Mary, and Arati Prabhakar. 1994. "Foreword." In Mark Bello and Michael Baum, *Setting Priorities and Measuring Results at the National Institute of Standards and Technology.* Gaithersburg, MD: National Institute of Standards and Technology.

coordinates and defines priorities for federal research, development, and deployment related to the industries that produce, operate, and maintain constructed facilities, including, buildings and infrastructure.[4]

BFRL has long recognized the value of measuring the impacts of its research program. Previous studies have shown that even modest research efforts within BFRL are capable of producing significant impacts.[5] One reason for such outcomes is the unique mix of research facilities and skills possessed by BFRL and its staff. Through many years of active collaboration with its various user communities, BFRL's research findings are highly regarded when new construction, building, and disaster mitigation technologies are considered for introduction into the U.S. market.

1.2 Purpose

This report is the second in a series of impact studies prepared by BFRL. It focuses on a fire technology application—the Fire Safety Evaluation System (FSES) for health care facilities. An earlier companion document[6] focuses on two building technology applications—ASHRAE Standard 90-75 for residential energy conservation and 235 shingles, an improved asphalt shingle for sloped roofing.

This report employs standardized methods to evaluate the economic impacts of the FSES. This "case study" approach illustrates the main purpose of this report, namely how to apply in practice standardized methods to evaluate and compare the economic impacts of research investments. The standardized methods for measuring economic impacts employed in this study are essential to support BFRL's effort to evaluate the cost effectiveness of completed research projects. This need for measurement methods exists across programs in BFRL, in NIST, and in other research laboratories.

1.3 Scope and Approach

This report takes a long-run view of research planning and evaluation. The focus is on specific benefits and costs of research investments, with little attention being given to institutional considerations and other constraining factors. Examples of such constraining factors which research managers are likely to find important are the compatibility of research projects with the organization's mission and the ability to perform those projects within budget constraints.

Little attention is given in this report to the step-by-step process by which research in BFRL (or other laboratories) makes its way (i.e., diffuses) as a new technology through codes, standards, or other processes to the ultimate user. Modeling the diffusion process for a new technology is a major research task in itself.

---

[4] Seven goals to enhance the competitiveness of the U.S. construction industry are explicit in the mission of the Subcommittee. For a detailed description of these goals and how the Subcommittee on Construction and Building will approach them, see Wright, Richard N., Arthur H. Rosenfeld, and Andrew J. Fowell. 1995. *Construction and Building: Federal Research and Development in Support of the U.S. Construction Industry.* Washington, DC: National Science and Technology Council.

[5] Marshall, Harold E., and Rosalie T. Ruegg. 1979. *Efficient Allocation of Research Funds: Economic Evaluation Methods with Case Studies in Building Technology.* NBS Special Publication 558. Gaithersburg, MD: National Bureau of Standards.

[6] Chapman and Fuller, *Two Case Studies in Building Technology.*

This report has five chapters and two appendices in addition to the Introduction. The body of this report, chapters 2 through 5, consists of a case study of the Fire Safety Evaluation System (FSES) for health care facilities. The approach taken in this report is to present all FSES-related information in sufficient detail *both to understand* the basis for the economic impact analysis *and to reproduce* the results of the economic impact analysis. The case study of the FSES is *ex post* in that it is based on past research efforts. For a two-page summary of the case study, see section 5.1.

The case study of the FSES provides estimates of the economic impacts from past BFRL research efforts leading to the development and introduction of the performance-based FSES for health care facilities. The methodology and the standardized methods employed in the study to measure the FSES's economic impacts are described in chapter 2. Chapter 3 traces the development of the FSES as an alternative to prescriptive compliance to the Life Safety Code for hospitals and nursing homes participating in the Medicare and Medicaid programs. Assumptions about those years over which costs and savings are tabulated, the appropriate discount rate, and the level of adoption of the FSES by existing hospitals and nursing homes are necessary to measure the FSES's economic impacts. These assumptions are described in chapter 4. Estimates of the cost savings from using FSES-based modifications to promote fire safety in existing hospitals and nursing homes over the period from 1975 through 1995 are the focus of chapter 5. In addition, that part of dollar savings that appears attributable specifically to BFRL's research efforts is estimated. Chapter 5 also includes a sensitivity analysis to provide the reader with additional background and perspective on the economic impacts of BFRL's FSES-related research efforts.

Chapter 6 concludes the report with a summary and suggestions for further research.

How the FSES measures safety performance is the subject of appendix A. Appendix B provides the mathematical formulation for BFRL's optimization software. This software identifies lower cost equivalent solutions for Life Safety Code compliance and measures the cost savings compared with prescriptive compliance.

2. Analyzing Economic Impacts: Approach

This chapter focuses on laying out an approach for conducting an economic impact study. First, however, it is useful to introduce two types of analysis which are essential if the results of the economic impact study are to have meaning. These two types of analysis are: (1) baseline analysis; and (2) sensitivity analysis.

The starting point for conducting an economic impact study is referred to as the baseline analysis. In the baseline analysis, all data (i.e., all input variables and any functional relationships among these variables) entering into the benefit, cost, and savings calculations are fixed at their likely values. These likely values reflect the fact that some information going into the analysis is uncertain. Consequently, the values of these data which are subject to uncertainty are set based on some measure of central tendency. Two common measures of central tendency are the mean (e.g., the sum of the individual values of the items divided by the number of items in the sample) and the median (e.g., the middle value in a rank ordering of the individual values of the items in the sample). Throughout this report, likely value and baseline value are used interchangeably. Baseline data represent a fixed state of analysis based on likely values. For this reason, the results and the analysis of these results are referred to as the baseline analysis. Throughout this report, the term baseline analysis is used to denote a complete analysis in all respects but one; it does not address the effects of uncertainty.

Sensitivity analysis measures the impact on project outcomes of changing the values of one or more key input variables about which there is uncertainty. Sensitivity analysis can be performed for any measure of economic performance (e.g., present value of net benefits, present value of net savings, benefit-to-cost ratio, savings-to-investment ratio, adjusted internal rate of return). Since sensitivity analysis is easy to use and understand, it is widely used in the economic evaluation of government and private-sector applications. Therefore, a sensitivity analysis complements the baseline analysis by evaluating the changes in output measures when selected key sets of data vary about their likely (i.e., baseline) values. Readers interested in a comprehensive survey on methods for dealing with uncertainty for use in government and private-sector applications are referred to the study by Marshall[7] and the subsequent video[8] and workbook.[9]

2.1 Description of Evaluation Methods

Several methods of economic evaluation are available to measure the economic performance of a research program, a new technology, a building, a building system, or like investment, over a specified time period. These methods include, but are not limited to, present value of net benefits, present value of net savings, benefit-to-cost ratio, savings-to-investment ratio, and the adjusted internal rate of return. These methods differ in the way in which they are calculated and, to some extent, in their applicability to particular types of investment decisions. The methods described in this section are based on ASTM standard practices.[10]

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

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

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

[10]American Society for Testing and Materials (ASTM). Third Edition, 1994. *ASTM Standards on Building Economics*. Philadelphia, PA: American Society for Testing and Materials.

Detailed descriptions of each of the standardized methods are given in the companion report.[11] Readers interested in an excellent, in-depth survey covering these as well as other methods are referred to Ruegg and Marshall.[12]

In order to describe each of the standardized methods, it is necessary to first introduce and define a series of terms. These terms are used to define each of the standardized methods. Throughout this section the following terms are used as the basis for defining the standardized methods:

$a*$	=	the alternative under analysis;
t	=	a unit of time, where $-t^{\alpha}$ is the earliest point (i.e., beginning of the study period) before the base year (i.e., t=0) and T is the last point after the base year (i.e., end of the study period);
L	=	the length of the study period (e.g., $t^{\alpha} + T$);
B_t^{a*}	=	the benefits for alternative $a*$ in year t;
I_t^{a*}	=	the investment costs for alternative $a*$ in year t;
C_t^{a*}	=	the non-investment costs for alternative $a*$ in year t;
$\overline{C_t^{a*}}$	=	the combined cost for alternative $a*$ in year t (i.e., $\overline{C_t^{a*}} = I_t^{a*} + C_t^{a*}$);
S_t^{a*}	=	the savings for alternative $a*$ in year t;
d	=	the discount rate.

Throughout this section the prefix, *PV*, is used to designate dollar denominated quantities in present value terms. The present value is derived by discounting (i.e., using the discount rate) to adjust all benefits, costs, and savings—past, present, and future—to the base year (i.e., t=0). The dollar denominated quantities defined above and their associated present value terms are: the present value of benefits (*PVB*), the present value of investment costs (*PVI*), the present value of non-investment costs (*PVC*), the present value of combined costs ($PV\overline{C}$), and the present value of savings (*PVS*).

[11]Chapman and Fuller, *Two* Case *Studies in Building Technology.*

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

2.1.1 Present Value of Net Benefits and Present Value of Net Savings

The present value of net benefits (PVNB) method is reliable, straightforward, and widely applicable for finding the economically efficient choice among alternatives (e.g., building systems). It measures the amount of net benefits from investing in a given alternative instead of investing in the foregone opportunity (e.g., some other alternative or maintenance of the *status quo*).

PVNB is computed by subtracting the time-adjusted costs of an investment from its time-adjusted benefits. If PVNB is positive, the investment is economic; if it is zero, the investment is as good as the next best investment opportunity; if it is negative, the investment is uneconomical. Emphasis is on economic efficiency because the method is appropriate for evaluating alternatives which compete on benefits, such as revenue or other advantages which are measured in dollars, in addition to costs.

The present value of net savings (PVNS) method is the PVNB method recast to fit the situation where there are no important benefits in terms of revenue or the like, but there are reductions in future costs (e.g., reductions in the cost of ownership to consumers).[13] By treating savings like revenue benefits, the PVNB method may be reformulated as the PVNS method.

The PVNB for a given alternative, $a*$, may be expressed as:

$$\begin{aligned} PVNB^{a^*} &= PVB^{a^*} - \overline{PVC^{a^*}} \\ &= \sum_{t=-t^{\alpha}}^{T} \left(B_t^{a^*} - \overline{C_t^{a^*}} \right) / (1+d)^t \end{aligned} \qquad 2.1$$

If there are no important benefits in terms of revenue or the like, but there are reductions in future costs, then, the PVNS for a given alternative, $a*$, may be expressed as:

$$\begin{aligned} PVNS^{a^*} &= \sum_{t=-t^{\alpha}}^{T} \left(S_t^{a^*} - I_t^{a^*} \right) / (1+d)^t \\ &= \left(PVS^{a^*} \right) - PVI^{a^*} \end{aligned} \qquad 2.2$$

If the decision maker anticipates revenues from the investment, then use the PVNB measure. If the decision maker expects costs to be reduced, then use the PVNS measure. The PVNS measure is used in the case study of the Fire Safety Evaluation System (FSES) for health care facilities.

[13] If there are any benefits, say in the form of revenues or other positive cash flows, add them to the cost savings associated with the alternative under analysis.

2.1.2 Benefit-to-Cost Ratio and Savings-to-Investment Ratio

The benefit-to-cost ratio (BCR) and the savings-to-investment ratio (SIR) are numerical ratios whose size indicates the economic performance of an investment. The BCR is computed as benefits, net of future non-investment costs, divided by investment costs. The SIR is savings divided by investment costs. The SIR is the BCR method recast to fit the situation where the investment's primary advantage is lower costs. SIR is to BCR as PVNS is to PVNB.

A ratio less than 1.0 indicates an uneconomic investment; a ratio of 1.0 indicates an investment whose benefits or savings just equal its costs; and a ratio greater than 1.0 indicates an economic project. A ratio of, say, 4.75 means that the investor (e.g., the general public for a public-sector research program) can expect to receive $4.75 for every $1.00 invested (e.g., public funds expended), over and above the required rate of return imposed by the discount rate.

The BCR for a given alternative, a^*, may be expressed as:

$$BCR^{a^*} = \left(PVB^{a^*} - PVC^{a^*} \right) / \ PVI^{a^*} = \frac{\sum_{t=-t^\alpha}^{T} \left(B_t^{a^*} - C_t^{a^*} \right) / \ (1+d)^t}{\sum_{t=-t^\alpha}^{T} I_t^{a^*} / \ (1+d)^t} \qquad 2.3$$

The SIR for alternative a^* may be expressed as:

$$SIR^{a^*} = PVS^{a^*} / \ PVI^{a^*} = \frac{\sum_{t=-t^\alpha}^{T} S_t^{a^*} / \ (1+d)^t}{\sum_{t=-t^\alpha}^{T} I_t^{a^*} / \ (1+d)^t} \qquad 2.4$$

As was the case for the PVNB and PVNS measures, use the BCR if the decision maker anticipates revenues from the investment, and use the SIR if the decision maker anticipates costs to be reduced. The SIR measure is used in the case study of the FSES.

2.1.3 Adjusted Internal Rate of Return

The adjusted internal rate of return (AIRR) is the annual yield from a project over the study period, taking into account reinvestment of interim receipts. Because the AIRR calculation explicitly includes the reinvestment of all net cash flows, it is instructive to introduce a new term, terminal value (TV). The terminal value of an investment, a^*, is the future value (i.e., the value at the end of the study period) of reinvested net cash flows excluding all investment costs. The terminal value for an investment a^*, is denoted as TV^{a^*}.

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

The AIRR is defined as the interest rate, r^*, applied to the terminal value, TV^{a^*}, which equates (i.e., discounts) it to the time equivalent value of the initial outlay of investment costs. It is important to note that all investment costs are discounted to a time equivalent initial outlay (i.e., to the beginning of the study period) using the discount rate, *d*.

Several procedures exist for calculating the AIRR. These procedures are derived and described in detail in the companion report.[14] The most convenient procedure for calculating the AIRR is based on its relationship to the BCR (SIR). This procedure results in a closed-form solution for r^*. The AIRR—expressed as a decimal—is that value of r^* for which:

$$
\begin{aligned}
r^* &= (1+d)\,(BCR^{a^*})^{\frac{1}{L}} - 1 \\
&= (1+d)\,(SIR^{a^*})^{\frac{1}{L}} - 1
\end{aligned}
\qquad 2.5
$$

where r^* = AIRR expressed as a decimal; and

L = the length of the study period.

2.1.4 Summary of Methods[15]

The methods presented in the previous sections provide the basis for evaluating the economic performance of research investments. The equations underlying the methods presented earlier were all based on ASTM standardized methods. Although all of these methods can be used to evaluate accept or reject type decisions, there are several distinctions between the methods which are worth noting. These distinctions are important because they relate to the decision maker's objective function.

[14]Chapman and Fuller, *Two Case Studies in Building Technology.*

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

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

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

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

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

(4) how to prioritize or rank independent projects when the allowable budget can not fund them all.

Each type of investment decision is important in a research environment. First, and foremost, decision makers need to know whether or not a particular project or program should be undertaken in the first place. Second, how should a particular research project/program be configured? The third type of decision builds on the second and introduces an important concept, interdependence. Many research projects/programs are multidisciplinary and are analogous to a portfolio. In addition, there may be both economies of scale (e.g., spreading out the use of specialized equipment) and of scope (e.g., packaging of staff talents). Consequently, for a given set of skills, laboratory facilities, candidate projects, and implied interdependencies, the problem becomes how to choose that combination of projects which maximizes PVNB (PVNS). The fourth type of decision introduces a budget constraint. The key here is how to get the most impact for the given budget amount.

Table 2-1 provides a summary of when it is appropriate to use each of the evaluation methods described earlier. Note that the PVNB (PVNS) method is appropriate in three of the four cases. Only in the presence of a budget constraint is the use of PVNB (PVNS) inappropriate and even in that case it plays an important role in computing the aggregate measure of performance.

Table 2-1. Summary of Appropriateness of Each Standardized Evaluation Method for Each Decision Type

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

In summary, there are several reasons why multiple measures are necessary. First and foremost, managers want to know if a particular research project is economic. Reference to table 3-1 shows that all of the evaluation methods address this type of decision. Furthermore, these evaluation methods may be used *ex ante* for emerging technologies as well as *ex post* for past research projects. Second, as issues of design, sizing, and packaging combinations of projects become the focus of attention—as often occurs in conjunction with budget reviews—the PVNB (PVNS) method emerges as the principle means for evaluating a project's or program's merits.[16] Finally, the tightening budget picture involves setting priorities. Multiple measures, when used appropriately, ensure consistency in both setting priorities and selecting projects for funding. The results from the case study of the FSES presented in chapter 5 illustrate the importance of multiple evaluation methods.

2.2 Methodology

The presentation and analysis of the results of an economic impact study are central to understanding and accepting its findings. If the presentation is clear and concise and if the analysis strategy is logical, complete, and carefully spelled out, then the results should stand up under close scrutiny. This section outlines a generic format to employ for economic impact studies in general and which meets the two previously-cited conditions. The generic format is built upon the following three factors: (1) the significance of the research effort; (2) the analysis strategy; and (3) the calculation of key benefit and cost measures. A specific format, tailored to BFRL, is given in exhibit 2-1; it is used as the basis for summarizing the case study of the FSES.

The three factors for the generic format referenced above are now related to the specific format given in exhibit 2-1. Exhibit 2-1 is divided into two columns. The first column contains three entries 1.a, 2, and 3.a. These entries correspond to the three factors referenced in the previous paragraph. Their purpose is to provide sufficient information to understand the basics of the research effort under analysis. The second column contains two entries 1.b and 3.b. These entries highlight the **key** observations from entries 1.a and 3.a, respectively. These key observations may be thought of as talking points for summarizing the research effort under analysis. Exposition of the generic format serves two purposes. First, it provides a means for organizing an in-depth economic impact study for presentation. Second, it provides a vehicle for clearly and concisely presenting the salient results of an economic impact study to senior research managers (e.g., laboratory directors). A summary for the case study of the FSES is provided at the beginning of chapter 5.

[16]If incremental values of the BCR (SIR) or AIRR are computed, they can be used to make design/size and packaging decisions, see Ruegg and Marshall, *Building Economics*.

Exhibit 2-1. Format for Summarizing the Economic Impacts of BFRL Research Efforts

.a Significance of Research Effort:	1.b Key Points:
'escribe why the research is important and how BFRL became ɩvolved. *'escribe the changes brought about by the BFRL research effort.*	*Highlight two or three key points which convey why this research effort is important.*

. Analysis Strategy:

'escribe how the present value of total benefits (savings) to the nation stemming from all contributions to ɩe research effort was determined.

'escribe how the present value of ***total costs*** *to the nation stemming from all contributors to the research ffort was determined.*

'escribe how the present value ***net benefits (savings)*** *to the nation was determined.*

'escribe how the present value of ***total benefits (savings)*** *attributable to BFRL's research effort was etermined.*

'escribe how the present value of ***total costs*** *attributable to BFRL's research effort was determined.*

'escribe how the present value of ***net benefits (savings)*** *attributable to BFRL's research effort was etermined.*

'escribe how any ***additional measures*** *were calculated and how BFRL's contribution was determined.*

ummarize key data and assumptions: (a) Base year; (b) Length of study period; (c) Discount rate or minimum cceptable rate of return; (d) Data; and (e) Other.

.a Calculation of Benefits, Costs, and Additional leasures:	3.b Key Measures:
'otal Benefits (Savings): *'eport the present value of the total benefits (savings) attributable ɔ BFRL's research effort.* **'otal Costs:** *'eport the present value of the total costs attributable to BFRL's esearch effort.* **let Benefits (Savings):** *'eport the present value of net benefits (savings) attributable to 'FRL's research effort.* **ɩdditional Measures:** *'eport the values of any additional measures calculated.*	Report the calculated value of the Present Value of Net Benefits (PVNB) ***or*** *the Present Value of Net Savings (PVNS)* attributable to BFRL **and** at least one of the following: * Benefit-to-Cost Ratio (BCR) *or Savings-to-Investment Ratio (SIR)* * Adjusted Internal Rate of Return (AIRR)

2.2.1 Significance of Research Effort

This section of an economic impact study sets the stage for the results which follow. The goal at this point is to clearly describe:

(1) why the research is important and how the organization conducting the research became involved; and

(2) why some or all of the changes brought about were due to the research organization's contribution.

Emphasis is placed on providing dollar estimates to define the magnitude of the problem. If any non-financial characteristics are of key importance to senior management, they should be listed and described briefly. A clear tie into the research organization's mission or vision is included to demonstrate why the organization conducting the research is well qualified and well positioned to participate in the research effort. The section concludes with a statement of the research organization's contribution.

2.2.2 Analysis Strategy

This section of an economic impact study focuses on documenting the steps taken to ensure that the analysis strategy was logical and complete. Particular emphasis is placed on summarizing the key data and assumptions, including any constraints which limited the scope of the study. Responses are provided for key data and assumptions concerning: (a) the base year for the study; (b) the length of the study period; and (c) the discount rate or minimum acceptable rate of return used.

Special emphasis is placed on documenting the *sources and validity* of any data used to make estimates or projections of key benefit and cost measures. This section establishes an audit trail from the raw data, through data manipulations (e.g., represented by equations and formulae), to the results, which describe:

(1) the present value of **total benefits (savings)** to the nation stemming from all contributors to the research effort under study;

(2) the present value of **total costs** for all contributors to the research effort under study, any users of the new technology under study, and any third parties affected by either the research effort or the use of the new technology;

(3) the present value of **net benefits (savings)** to the nation stemming from all contributors to the research effort under study, any users of the new technology under study, and any third parties affected by either the research effort or the use of the new technology;

(4) the present value of **total benefits (savings)** attributable to the research organization's contribution;

(5) the present value of **total costs** attributable to the research organization's contribution;

(6) the present value of **net benefits (savings)** attributable to the research organization's contribution; and

(7) any **additional measures** that were calculated.

2.2.3 Calculation of Benefits, Costs, and Additional Measures

This section of an economic impact study focuses on reporting the calculated values of the key benefit and cost measures, as well as any additional measures which are deemed appropriate. As was noted in section 2.1.4, it is essential to report the calculated value of the present value of net benefits *or the present value of net savings* attributable to the research organization's contribution and at least one of the following:

(a) the benefit-to-cost ratio *or the savings-to-investment ratio*; or

(b) the adjusted internal rate of return.

Summaries of the following information are also reported:

(1) the present value of the total benefits (savings) attributable to the research organization's contribution;

(2) the present value of the total costs attributable to the research organization's contribution;

(3) the present value of net benefits (savings) attributable to the research organization's contribution; and

(4) the values of any additional measures calculated.

3. The Problem of Fire Safety in Hospitals and Nursing Homes

Although multiple death fires in hospitals and nursing homes are rare occurrences, the potential for major loss of life and property does exist and is recognized in the selection of fire safety measures. This potential and its implied need for a national commitment to fire safety in hospitals and nursing homes has been emphasized in congressional hearings. Public Law 92-603, the 1972 Amendments to the Social Security Act, made certification for participation in the Medicare and Medicaid programs contingent upon passing the Life Safety Code. This new requirement ensured that a national commitment to fire safety in hospitals and nursing homes would be made.

3.1 The Life Safety Code

The Life Safety Code[17] published by the National Fire Protection Association (NFPA) is currently the most widely used guide for identifying the minimum level of fire safety in buildings. When Public Law 92-603 was enacted, the Life Safety Code was a prescriptive code; it provided fixed solutions to fire safety in designated occupancies (e.g., hospitals and nursing homes). Since its origin in 1913, the Life Safety Code has been constantly revised as more reliable technical and empirical evidence has become available.

Prior to the passage of Public Law 92-603, the Joint Commission on Accreditation of Hospitals (JCAH) applied a *de facto* standard encouraging the installation of safety devices such as sprinklers. The goal of JCAH's approach was to increase safety while avoiding the necessity of major reconstruction. After the passage of Public Law 92-603, JCAH conducted a national survey of 105 hospitals in 33 states and the District of Columbia.[18] A validation survey was then carried out by the Department of Health Education and Welfare (HEW). When HEW inspected the same facilities previously surveyed by JCAH, they uncovered 3,854 deficiencies where JCAH had found only 2,745. Most of the disagreement was in the interpretation of the Life Safety Code. HEW inspectors uncovered 1,633 Life Safety Code violations where JCAH had uncovered 256.[19]

Information on the impacts to the health-care sector of requiring prescriptive compliance to the Life Safety Code became available shortly after the passage of Public Law 92-603. In the event that a facility is inspected and found to be in non-compliance, it is required to file a "plan of correction." This plan details the way in which repairs are to be effected so as to bring the facility into compliance with the prescriptive provisions of the Life Safety Code. Under certain circumstances, where the costs of prescriptive compliance are deemed to be "unnecessarily burdensome," the facility may request a waiver. The waiver permits the facility to operate and to be deemed in compliance. However, the regulatory authority periodically reviews the facility's waivers to determine whether or not they constitute a significant safety hazard.

[17]National Fire Protection Association (NFPA). 1994. *Life Safety Code*. NFPA 101, 1994 edition. Quincy, MA: National Fire Protection Association.

[18]Lewis, H.L. 1975. "The Uncertain Future of JCAH." *Modern Healthcare*: pp. 20-4.

[19]*Ibid.*

The initial reaction of the hospital community to Public Law 92-603 was therefore to request waivers where deviations from the prescriptive provisions of the Life Safety Code resulted. Whereas large hospitals, by virtue of their more experienced administrative staff and their construction characteristics, tended to be able to prepare plans of correction with waivers included, smaller hospitals (i.e., less than 100 beds) were faced with major renovation. The situation in nursing homes was even more serious and many facilities were faced with the possibility of closing.

By 1975, the situation had become acute. Analyses based on the original surveys by JCAH and HEW found that 62 percent of the hospitals inspected did not comply with the prescriptive provisions of the Life Safety Code.[20] Based on a review of plans of correction, Feeley, *et al*, concluded that between 10 and 50 percent of the beds in non-complying hospitals could be forced out of service by strict enforcement of the Life Safety Code.[21]

3.2 The Fire Safety Evaluation System for Health Care Facilities

The magnitude of the problem and the potential for adverse effects on the health-care industry prompted HEW (now the Department of Health and Human Services (HHS)) to seek technical support from NIST's BFRL (then the National Bureau of Standards (NBS) Center for Fire Research). This support was justified based on a provision in the Life Safety Code which allows for alternative solutions.

In 1975, researchers at BFRL began work on what was to become the Fire Safety Evaluation System (FSES) for health care facilities. The goal of the FSES is to provide a framework for determining how combinations of several widely-accepted fire safety systems can be used to provide a level of safety equivalent to that required by the Life Safety Code. The FSES would therefore qualify as an alternative to prescriptive compliance to the Life Safety Code.

The developers of the FSES based their system on three major concepts.[22] They are:

(1) *Occupancy Risk:* the number of people affected by a given fire, the level of fire they are likely to encounter, and their ability to protect themselves.

(2) *Building Safety Parameters:* the ability of the building and its fire protection system to provide measures of safety commensurate with the risk.

(3) *Safety Redundancy:* in-depth protection, through the simultaneous use of alternative safety methodologies, such as, Containment, Extinguishment, and People Movement. The design of the FSES is intended to ensure that the failure of a single protection device or method will not result in a major failure of the entire system.

---

[20] *Ibid.*

[21] Feeley, R., D.C. Walsh, and J.E. Fielding. 1978. "Structural Codes and Patient Safety: Does Strict Compliance Make Sense?" *American Journal of Law and Medicine* : pp. 447-454.

[22] Nelson, H.E., and A.J. Shibe. 1978. *A System for Fire Safety Evaluation of Health-Care Facilities.* NBSIR 78-1555. Gaithersburg, MD: National Bureau of Standards.

The development of the FSES and its incorporation into the Life Safety Code spanned a period of several years. Initial work was begun on the FSES in 1975. The early work on the system focused on a review of the Life Safety Code and the establishment of several panels of experts. These experts were used to develop values for all of the entries on the FSES worksheets (see appendix A, exhibits A-1 through A-4). A series of typical health care facilities were then evaluated using both the FSES and the Life Safety Code to ensure that the system satisfied the intent of the code. Once consensus among the experts was achieved, the FSES was released for comment.

Between 1979 and 1980, representatives of BFRL and the Health Care Finance Administration (HCFA) met with members of several NFPA committees responsible for developing the 1981 edition of the Life Safety Code. The basic FSES was revised to incorporate the recommendations of the various NFPA committees and reissued. The reissued version of the FSES, published in a report by Nelson and Shibe,[23] and a study by Chapman, Chen, and Hall[24] were instrumental in the HCFA's adoption of the FSES as a means of evaluating alternative arrangements to achieve compliance with the Life Safety Code for health care facilities participating in the Medicare and Medicaid programs.[25] However, state fire inspectors could still require prescriptive compliance to the Life Safety Code. It was therefore necessary to incorporate the FSES into the Life Safety Code as a technical appendix.

The FSES first appeared as Appendix C in the 1981 edition of the Life Safety Code. Subsequent revisions to the Life Safety Code in 1985, 1988, 1991, and 1994 continued to recognize the FSES as an alternative to prescriptive compliance. Furthermore, the last two editions, 1991 and 1994, of the Life Safety Code have issued special documents which include the FSES. These editions, NFPA 101M[26] and NFPA 101A,[27] include detailed descriptions of the FSES and instructions for using it to evaluate safety equivalence in hospitals and nursing homes.

3.3 Certification Process for Hospitals and Nursing Homes

The Social Security Act mandates providers whose services are reimbursed by the Medicare and Medicaid programs to meet minimum federal participation requirements. To participate in the Medicare and Medicaid programs, hospitals and nursing homes must be "certified," meaning they meet these federal participation requirements. An important part of these participation requirements is meeting the levels of fire safety specified in the Life Safety Code (e.g., compliance with either NFPA 101 or NFPA 101A).

Hospitals participating in the Medicare and Medicaid programs may seek certification in two different ways: accreditation or direct certification from HCFA. Approximately 5,000 of the nation's hospitals participating in the two programs are "accredited" by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO), formerly the JCAH. JCAHO conducts a building survey to evaluate and

[23]Nelson, H.E., and A.J. Shibe. 1980. *A System for Fire Safety Evaluation of Health-Care Facilities*. NBSIR 78-1555-1. Gaithersburg, MD: National Bureau of Standards.

[24]Chapman, Robert E., Phillip T. Chen, and William G. Hall. 1979. *Economic Aspects of Fire Safety in Health-Care Facilities: Guidelines for Cost-Effective Retrofits*. NBSIR 79-1902. Gaithersburg, MD: National Bureau of Standards.

[25]*Federal Register* 45, No. 146, July 28, 1980: 50264-5.

[26]National Fire Protection Association (NFPA). 1992. *Alternative Approaches to Life Safety*. NFPA 101M. Quincy, MA: National Fire Protection Association.

[27]National Fire Protection Association (NFPA). 1995. *Guide on Alternative Approaches to Life Safety*. NFPA 101A. Quincy, MA: National Fire Protection Association.

document the fire safety measures which are in place and the severity of any deficiencies. JCAHO notifies HCFA once a hospital has been accredited, or becomes non-accredited, and provides information on the results of the building survey. Because HCFA recognizes JCAHO as having "deemed status," hospitals accredited by JCAHO are certified for participation in the two programs. Alternatively, non-accredited hospitals wishing to participate in the Medicare or Medicaid programs may seek certification directly from HCFA. This group is composed primarily of small community hospitals.[28] In such cases, a building survey is conducted by the state fire marshal's office. The results of the building survey are reported to HCFA and, if satisfactory, the hospital is certified for participation in the two programs.

All nursing homes which wish to participate in the two programs are certified by HCFA. HCFA classifies Medicare-certified facilities as "skilled nursing facilities" and Medicaid-certified facilities as "nursing facilities." The Social Security Act authorizes HHS to contract with state survey agencies to determine, by inspection (i.e., building surveys) at intervals designated by law, whether or not skilled nursing facilities meet the Medicare participation requirements. The Social Security Act also sanctions state survey agencies to perform the same survey tasks for Medicaid-participating facilities. HCFA and the state agencies use the results of these building surveys as the basis to approve, deny, or terminate a facility's participation in either the Medicare or Medicaid programs.

In addition to federal certification, all health care facilities—whether they are Medicare, Medicaid, or private pay—must be licensed by the state. Licensure requirements are state-specific and in some cases are more stringent than those imposed by the Medicare and Medicaid programs.

3.4 Cost Estimating Software

A computerized version of the FSES was developed to estimate the costs of retrofitting existing hospitals and nursing homes to comply with the Life Safety Code. The software was developed originally to be used with the 1981 edition of the Life Safety Code.[29] The current version, ALARM, is based on the 1994 edition of the Life Safety Code.[30] The objective of the software is to balance score improvements against the costs of retrofitting so that the least-cost means of achieving compliance to the Life Safety Code can be identified. A menu of solutions, referred to as compliance strategies, is also generated to facilitate choices based on factors other than construction costs.

The software uses as its primary input information collected as an integral part of the building survey (i.e., a building fire safety evaluation). This information permits the current condition, also referred to as the current state, of each building safety parameter in each fire zone in the building to be unambiguously identified. Information is also collected on potential retrofits. Potential retrofits for each building safety parameter in a given fire zone correspond to those entries in FSES table 4 (see exhibit A-2) which result in score improvements. During the course of the building survey, a series of worksheets are used to record information on key components which map into the entries in FSES table 4. Information on key components is used to generate cost estimates for each potential retrofit. It is not necessary to generate a

[28]Community hospitals include all non-federal, short-term general and other special hospitals.

[29]Chapman, Robert E., and William G. Hall. 1983. *User's Manual for the Fire Safety Evaluation System Cost Minimizer Computer Program*. NBSIR 83-2797. Gaithersburg, MD: National Bureau of Standards.

[30]Weber, Stephen F., and Barbara C. Lippiatt. 1994. *ALARM 1.0--Decision Support Software for Cost-Effective Compliance with Fire Safety Codes*. NISTIR 5554. Gaithersburg, MD: National Institute of Standards and Technology.

cost estimate for the current state of a building safety parameter in a fire zone because it is always possible to stay in the current state at zero cost. Entries in FSES table 4 which result in lower scores are referred to as precluded retrofits. The software assigns an extremely high cost to precluded retrofits to guarantee that they will not be included in any compliance strategy.

The software identifies the least-cost solution (i.e., optimal combination of retrofits) by using the following information:

(1) the current "state" of each building safety parameter in each fire zone in the building;

(2) the minimum "scores" needed for each fire zone to achieve compliance; and

(3) the anticipated cost of each potential retrofit measure.

In addition to the least-cost solution, the software contains a procedure for systematically generating alternative solutions, many of which are close in cost to the optimum. Two groups of solutions are generated to facilitate the design selection process. The first group is based on the input condition of each building safety feature in each fire zone. The objective here is to provide an opportunity for each "current state" to be in a solution ***and*** for each "potential retrofit" to be in a solution. The second group of alternative solutions is based on a pre-specified set of design variable qualifiers. The objective here is to ensure design compatibility across fire zones. The second group of solutions is used to produce a set of compliance strategies, usually between 5 and 15, for the entire building within which the key design variable qualifiers are held constant. To facilitate comparisons, these compliance strategies are printed out in ascending order of cost.

By using this software-based approach, decision makers have greater flexibility in choosing from a menu of compliance strategies. Specifically, the added information provided by the alternative solutions enables health care facility administrators and construction specialists to assess better the cost impacts of complying with the Life Safety Code. In addition, the information conveyed by the alternative solutions provides an opportunity to consider non-construction costs in the selection of the "best" compliance strategy.

4. Analyzing Economic Impacts: Data and Assumptions

This chapter focuses on describing the data and assumptions needed to evaluate the economic impacts of the Fire Safety Evaluation System (FSES) for health care facilities. A clear statement of the assumed values of key parameters underlying the analysis is vital to understanding how the analysis was conducted. The assumptions covered in this chapter focus on the setting of the assumed values of the three following key parameters: (1) the starting and ending points in the study period; (2) the base year; and (3) the discount rate. The assumed values of these three key parameters figure prominently in evaluating the economic impacts of the FSES. Documenting the assumptions and the rationale behind the setting of the assumed values of these three key parameters is necessary to ensure that: (1) all costs and savings are discounted to an equivalent time basis for purpose of comparison; and (2) readers can follow the flow of the analysis, gain insights useful for their own applications, and reproduce our results.

The starting and ending points in the study period define both the scope of the study period—those years over which costs and savings are tabulated—and the length of the study period—a key parameter in the AIRR calculation. The base year establishes the anchor point for all cost and savings calculations. Because cash flows, both costs and savings, are distributed throughout the study period, the choice of the discount rate is of central importance to the analysis.

Facts and data are essential components in any rigorous analysis. Factual information on the number of hospital and nursing home beds were tabulated from published sources. These data provide the basis for estimating the savings associated with the use of the FSES in health care facilities. However, to develop realistic estimates of cost savings, it is necessary to generate estimated values for the following four factors: (1) the likely per unit savings (e.g., cost savings per bed); (2) the overall rate of adoption of the FSES for each type of health care facility (i.e., active service military hospitals, Veterans Administration hospitals, non-federal hospitals, and nursing homes); (3) the years during the study period for which each type of health care facility used the FSES; and (4) the annual number of beds covered by the FSES for each type of health care facility. Much of the discussion in sections 4.4 through 4.6 is aimed at establishing an audit trail for how the values of these four factors were estimated. The goal of sections 4.4 through 4.6 is two fold. First, it establishes the sources and validity of the data used in this case study. Second, it provides readers with valuable insights on an essential component of an economic impact analysis for them to use in their own applications.

4.1 Length of Study Period

The study period begins in 1975 and ends in 1995. Any costs and/or savings which occur after 1995 are not included. Two factors were instrumental in determining the beginning and end of the study period.

(1) The study period begins in 1975, which is when BFRL began developing the FSES. Most of the costs for the research and development work that NIST and other groups performed were incurred between 1975 and 1981. The effort to develop the cost estimating software began in 1978. The software was first disseminated broadly in 1983. Subsequent revisions were made to the software to keep pace with changes in the Life Safety Code and the FSES. The most recent changes were completed in 1994.

(2) The end of the study period is 1995. By 1995, the FSES was well established as an alternative to prescriptive compliance to the Life Safety Code. Although the use of the FSES is expected to become more widespread as more decision makers become aware of its potential, no costs or savings are projected beyond 1995. While few additional costs are anticipated after 1995, savings will continue to accrue to hospitals and nursing homes using the FSES well into the future. This approach of ignoring net savings accruing beyond 1995 was taken to ensure that the estimates of costs and savings related to the development and use of the FSES were conservative.

4.2 Base Year for Computing Costs and Savings

The base year for computing all costs and savings related to the development and use of the FSES is 1995. There are two reasons, one primary and one secondary, why 1995 was selected as the base year.

(1) Although the economic impact study is *ex post* (i.e., it is based on completed research), the use of the FSES is expected to become more widespread in the future. By using 1995 as the base year, this economic impact study is able to maintain a forward looking perspective without projecting adoption rates for the FSES into the future. Therefore, having 1995 as the base year, helps to support a conservative approach to estimating FSES-related costs and savings.

(2) A preliminary economic impact study was conducted in 1995. The 1995 study focused on the cost-saving potential of the FSES; it made use of an extensive data set provided to NIST by the U.S. Public Health Service (PHS). The PHS data set is described in section 4.4. The PHS data set, as compiled by NIST, was structured in a way which facilitated converting all FSES-related construction costs and savings to constant 1995 dollars. The conversion was accomplished by using the Construction Cost Index for the year in which PHS surveyed the hospital.

4.3 Discount Rate

The baseline analysis for this economic impact study of the FSES uses a real discount rate of 7 percent to convert dollar amounts to present values. This rate is specified in Section 8.b of *OMB Circular A-94*[31] as the rate for all benefit-cost analyses of public investments and regulatory programs that provide benefits or incur costs to the general public. For purposes of this analysis, all FSES-related research costs are classified as a public investment. The benefits which accrue to the public are in the form of cost savings.

OMB recommends that separate analyses be used to evaluate the sensitivity of key economic measures to variations in the discount rate. The sensitivity analysis presented in section 5.3.2 evaluates the implications of raising or lowering the discount rate.

4.4 U.S. Public Health Service Data Set

Since 1985, the U.S. Public Health Service (PHS) has conducted on-site surveys of 89 hospitals (53 Air Force, 33 Army, 1 Indian Health Service, and 2 non-federal community hospitals). All hospitals surveyed by the PHS used the FSES as the basis for achieving safety equivalent to the Life Safety Code. In addition,

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

all hospitals surveyed used the cost estimating software developed by BFRL to generate a list of compliance strategies for each hospital. The PHS provided information to NIST on each of the 89 hospitals surveyed. This information included:

(1) the name and location of the hospital;

(2) the year in which the hospital was surveyed;

(3) the size of the hospital (e.g., the number of beds and the floor area);

(4) the cost of prescriptive compliance to the Life Safety Code; and

(5) the least-cost, FSES-based compliance strategy.

Additional information was collected on a subset of the hospitals surveyed by PHS. This information was used to develop estimates of the likely savings, on a per bed basis, attributable to the use of the FSES. This information and the approach used to develop estimates of savings is described in section 4.6.

In reviewing the information on the 89 hospitals surveyed by the PHS, it was noted that the hospitals ranged in size from a low of 10 beds to a high of 1408 beds. Reference to the American Hospital Association document *Hospital Statistics*[32] suggested a means for classifying the 89 hospitals by size (i.e., number of beds) into three categories. The resulting distribution of hospitals is summarized in table 4-1. Reference to table 4-1 reveals that almost half of the hospitals surveyed by PHS have less than 100 beds; they accounted for only 13 percent of the 17,898 beds covered by the PHS surveys. The average number of

Table 4-1. Distribution of Hospitals Surveyed by the U.S. Public Health Service: 1985-1995

Facility Size (Number of Beds)	Facility-Based Statistics		Bed-Based Statistics		Average Number of Beds by Facility Size
	Number	Percent	Number	Percent	
<100	43	42.32	2,316	12.94	54
100-300	28	31.46	4,584	25.61	164
>300	18	20.22	10,998	61.45	611
TOTAL	89	100.00	17,898	100.00	201

[32] American Hospital Association. 1994. *Hospital Statistics*. 1994-1995 Edition. Chicago, IL: American Hospital Association.

beds in hospitals having less than 100 beds which were surveyed by PHS was 54. The average number of beds across all 89 hospitals surveyed was 201.

It is useful to compare the information on the hospitals surveyed by the PHS to information on the overall population of hospitals. Based on information published by the American Hospital Association in its 1994-1995 Edition of *Hospital Statistics*, there were 6,467 hospitals in the United States. The distribution of the overall population of hospitals is summarized in table 4-2.

Table 4-2. Distribution of U.S. Hospitals: 1993[A]

Facility Size (Number of Beds)	Facility-Based Statistics		Bed-Based Statistics		Average Number of Beds by Facility Size
	Number	Percent	Number	Percent	
<100	2,909	44.98	157,461	13.53	54
100-300	2,416	37.36	427,081	36.71	177
>300	1,142	17.66	578,918	49.76	507
TOTAL	6,467	100.00	1,163,460	100.00	180

[A]American Hospital Association, *Hospital Statistics*, Table 3, p. 12.

Comparison of table 4-2 to table 4-1 reveals a number of strong similarities. First, the two sets of percentage numbers under the column heading "Facility-Based Statistics" show close agreement between the distribution of hospitals surveyed by the PHS and the overall population. Second, the two sets of percentage numbers under the column heading "Bed-Based Statistics" show remarkable agreement for the hospitals with less than 100 beds and general agreement for the two categories of larger hospitals. Finally, the two sets of figures under the heading "Average Number of Beds by Facility Size" show good overall agreement.

In addition to the information in table 4-1 and table 4-2, information on the average floor area per patient bed was reviewed. For the 89 hospitals surveyed by PHS, a figure of 127.5 square meters (1372 square feet) per bed resulted. The corresponding figure for the overall population of hospitals was 134.7 square meters (1450 square feet) per bed. The similarities between the two tables and the information on floor area per bed indicate that the costs and savings experienced in the hospitals surveyed by the PHS are likely to be indicative of the overall population of hospitals. Developing estimates of cost savings for the overall population and the applicability of the PHS data set to nursing home occupancies is the subject of section 4.6.

4.5 Use of the Fire Safety Evaluation System in Health Care Facilities

Information on the use of the FSES in health care facilities comes from a number of sources. These sources include HCFA, PHS, the Veterans Administration (VA), the American Hospital Association, the American Health Care Association, and experts on the FSES.

In developing estimated FSES adoption rates for hospitals, it is useful to first classify hospitals into two broad categories: (1) federal hospitals; and (2) non-federal hospitals. Table 4-3 shows the distribution of hospitals according to this classification. Information on the number of beds in each classification is also included in the table. Reference to table 4-3 reveals that the 316 federal hospitals contain 87,847 beds. Non-federal hospitals are further subdivided into five subgroups. Community hospitals are by far the largest subgroup of non-federal hospitals (i.e., 5,261 out of 6,151). Of the 6,151 non-federal hospitals, 5,879 are certified for participation in the Medicare program.[33] The rate is even higher for community hospitals; 5,154 out of 5,261 are certified for participation in the Medicare program. It is important to note that the 272 non-federal hospitals which are not certified for participation in the Medicare program still have to be licensed by the state. Consequently, estimates on the number of non-federal hospitals and the number of beds covered by the FSES are based on the 6,151 figure recorded in table 4-3.

Detailed information is available on two important classes of federal hospitals: (1) active service military hospitals; and (2) Veterans Administration (VA) hospitals. The PHS data set includes 86 active service military hospitals. According to PHS, virtually all of the active service military hospitals which have used the FSES are included in their data set. Because information is available both on the year in which the survey was conducted and the number of beds in each hospital surveyed, it is possible to derive actual figures—both overall and annually—on the number of beds covered by the FSES. The actual number of beds covered by the FSES in active service military hospitals is known to be 17,260. Information provided by the VA indicates that 110 VA hospitals have used the FSES since 1983.

Based on additional information provided by the VA, the total number of beds in VA hospitals covered by the FSES is estimated to be 42,260. Information on federal hospitals covered by the FSES is summarized in table 4-4.

The basis for estimating FSES adoption rates for non-federal hospitals was provided by the American Hospital Association (AHA). Actual rates were not available from AHA. However, Douglas Erickson, Director of Design and Construction of the AHA, estimates that approximately 20 percent of the nation's community hospitals have used the FSES since 1985.[34] Discussions with experts on the FSES and with HCFA supported Erickson's estimate of 20 percent. The same 20 percent adoption rate is used for the four other subgroups of non-federal hospitals. These four subgroups total 890 hospitals, 725 of which are certified for participation in the Medicare program. Information on non-federal hospitals covered by the FSES is summarized in table 4-4.

---

[33] American Hospital Association, *Hospital Statistics*, Table 10A, p. 204.
[34] Telephone interview with Douglas Erickson of AHA (9/20/95).

Table 4-3. Distribution of Hospitals by Classification: 1993[A]

Classification	Facilities	Beds
Federal	316	87,847
Non-federal	6,151	1,075,613
Community	5,261	918,786
Psychiatric	741	133,892
Long-term general And other special	117	20,794
Hospital units of Institutions	28	1,721
TB and other Respiratory diseases	4	420
TOTAL	6,467	1,163,460

[A]American Hospital Association, *Hospital Statistics*, Table 3, p. 12.

Table 4-4. Estimated Number of Hospital Beds Covered by the Fire Safety Evaluation System: 1983-1995[A]

Classification	Facilities	Beds
Federal	196	57,520
Veterans Administration	110	40,260
Active Service Military	86	17,260
Non-federal	1,230	215,120
TOTAL	1,426	272,640

[A]Information on the number of Veterans Administration hospitals covered by the FSES are actual rather than estimated values. Information on the number of active service hospitals and on the number of beds in active service military hospitals covered by the FSES are also actual rather than estimated values.

In developing estimated FSES adoption rates for nursing homes, it is useful to first classify nursing homes into three categories. These categories correspond to the type of certification which the nursing home holds. These types of certification are: (1) Medicare only; (2) Medicaid only; and (3) dual (i.e., both Medicare and Medicaid). Table 4-5 shows the distribution of nursing homes according to this classification. Information on the number of beds in each classification is also included in the table.

Table 4-5. Distribution of Nursing Homes by Type of Certification: 1994[A]

Type of Certification	Facilities	Beds
Medicare Only	1,061	45,682
Medicaid Only	4,357	1,030,587
Dual	11,190	597,774
TOTAL	16,608	1,674,043

[A]American Health Care Association, *Facts and Trends*, pp. 31-2.

Reference to table 4-5 reveals that the nation's 16,608 nursing homes certified for participation in the Medicare and Medicaid programs contain 1,674,043 beds.[35]

The basis for estimating FSES adoption rates for nursing homes was provided by the American Health Care Association (AHCA). Actual rates were not available from AHCA. However, Thomas Jaeger of Gage, Babcock and Associates, who is the primary consultant to the AHCA on fire-safety issues, estimates that approximately 15 percent of the nation's nursing homes participating in the Medicare and Medicaid programs have used the FSES since 1985.[36] Discussions with experts on the FSES and with HCFA supported Jaeger's estimate of 15 percent. Jaeger also stated that larger chains of nursing homes have used the FSES extensively, whereas the smaller groups and independent homes do so rarely. Information on nursing homes covered by the FSES is summarized in table 4-6.

Table 4-6. Estimated Number of Nursing Home Beds Covered by the Fire Safety Evaluation System: 1985-1995

Type of Certification	Facilities	Beds
Medicare Only	159	6,850
Medicaid Only	654	154,590
Dual	1,678	89,670
TOTAL	2,491	251,110

4.6 Estimation of Per Unit Cost Savings

The information from the PHS data set allowed estimates of the difference between the cost of prescriptive compliance to the Life Safety Code and the least-cost, FSES-based compliance strategy to be calculated for each of the 89 hospitals in the data set. These savings averaged 30 percent across all hospitals analyzed.

[35]American Health Care Association. 1995. *Facts and Trends: The Nursing Facility Sourcebook.* Washington, DC: American Health Care Association.

[36]Telephone interview with Thomas Jaeger of Gage, Babcock and Associates (9/26/95).

In reviewing these savings, it was decided that using the 30 percent across-the-board savings might overstate the expected savings attributable to the FSES. For example, the cost estimating software does not use any information on non-construction costs in developing FSES-based solutions. Non-construction costs might include a shorter period of renovation, the use of in-house personnel to perform certain renovation tasks, or less disruption during the renovation process. Non-construction costs are important to decision makers. Consequently, decision makers often wish to see more than the least-cost, FSES-based compliance strategy. This important issue was recognized by the developers of the cost estimating software. By generating a family of compliance strategies, the software helps decision makers evaluate the tradeoffs between construction and non-construction costs. Past experience has shown that the cost of the solution actually implemented often exceeds slightly the least-cost, FSES-based compliance strategy.

In order to develop a better estimate of the likely value of the cost savings attributable to the FSES, detailed information was collected on six of the 89 hospitals surveyed by PHS. Two hospitals from each of the three size categories (i.e., less than 100 beds, 100 to 299 beds, 300 or more beds) were selected for detailed review. This review focused on an analysis of all solutions and not just the least-cost, FSES-based compliance strategy and the cost of prescriptive compliance. The goal was to determine a likely value for savings (i.e., one which does not overstate savings) which is based on the results of the PHS surveys (i.e., which is fact based). The detailed analysis consisted of five steps.

First, for each of the six hospitals selected, all distinct solutions whose costs were more than the least-cost, FSES-based compliance strategy but were less than the cost of prescriptive compliance were recorded. This step produced 32 distinct solutions across the six hospitals selected (i.e., the average number of distinct solutions for each hospital was 5.33). The cost of each distinct solution is designated as the reference cost.

Second, a range for each distinct solution was calculated. This range is equal to the difference between the cost of prescriptive compliance and the least-cost, FSES-based compliance strategy for the specific hospital being analyzed. Although there were 32 distinct solutions, there were only six distinct ranges, one for each of the six specific hospitals being analyzed. Therefore, each distinct solution for the same hospital had the same range. The range represents the maximum potential savings for the specific hospital being analyzed.

Third, a delta cost was calculated for each distinct solution. The delta cost is equal to the difference between the reference cost and the least-cost, FSES-based compliance strategy. The delta cost represents the potential savings foregone by not selecting the least-cost, FSES-based compliance solution.

Fourth, a ratio equal to the delta cost divided by the range was computed for each distinct solution. This ratio provides a measure of how close each distinct solution is to the least-cost, FSES-based compliance strategy. The ratio is bounded below by zero (i.e., equal in cost to the least-cost, FSES-based compliance strategy) and above by one (i.e., equal in cost to the cost of prescriptive compliance).

Finally, the ratios were rank ordered to produce a cumulative distribution function. Three points in the cumulative distribution function were selected. These points were: (1) the minimum (i.e., the least-cost, FSES-based compliance strategy); (2) the 25^{th} percentile (i.e., the 25^{th} percentile FSES-based cost); and (3) the median (i.e., the 50^{th} percentile FSES-based cost). Based on the sample data, the percent of maximum savings associated with each point is:

- 100 percent for the minimum;
- 72.3 percent for the 25^{th} percentile; and
- 46.5 percent for the median.

For purposes of the baseline analysis, the figure upon which all savings calculations are based is the 25^{th} percentile. The minimum and the median values are used in the sensitivity analysis. The 25th percentile was selected in order to yield a conservative estimate of actual savings resulting from the use of the FSES once decision makers had factored non-construction costs into their analysis of the alternative compliance strategies.

In order to derive the expected cost savings per bed attributable to the FSES based on the 25^{th} percentile, it is first necessary to obtain an estimate for the maximum savings per bed (i.e., the savings associated with the least-cost, FSES-based compliance strategy). The PHS data set provides such an estimate. Because the data set contained many small hospitals (i.e., those with less than 100 beds) which produced values of cost savings well in excess of $10,000 per bed, the median value of savings was selected as a better measure of central tendency than the mean. The median value of savings per bed for the 89 hospitals in the PHS data set was $1785 (in 1995 dollars). The mean value of savings per bed was $2115 (in 1995 dollars).

Using the median value from the PHS data set translates into an expected baseline cost savings of $1290 per hospital bed. This value of savings per hospital bed is used in all calculations except those for the 86 active service military hospitals in the PHS data set. Because the PHS data set includes actual values for the range (i.e., the difference between the cost of prescriptive compliance and the least-cost, FSES-based compliance strategy) for each hospital, it is sufficient to multiply the range by 0.723 (i.e., the proportion of maximum savings for the 25^{th} percentile) to estimate the savings due to the FSES for each active service military hospital in the PHS data set.

Estimating the expected savings per bed for nursing homes requires an additional calculation. First, referring to table 4-5, reveals that the average number of beds per nursing home is approximately 100. Furthermore, the average number of beds per nursing home has averaged close to 100 since the late 1980s. Second, the PHS data set contains 23 hospitals with between 70 and 130 beds. Savings per bed in these smaller hospitals are thought to be typical of those expected in nursing homes.

An analysis of the 23 hospitals subset from the PHS data set produced a median value of the savings per bed of $1970 (in 1995 dollars). The mean value of savings was considerably higher. The $1970 savings per bed figure is based on the difference between the cost of prescriptive compliance and the least-cost, FSES-based compliance strategy. Applying the proportion of maximum savings for the 25th percentile, 0.723, results in an expected savings per bed of $1425 (in 1995 dollars). This figure for expected savings exceeds that of the typical hospital by more than $100 per bed. Consequently, in order to produce a conservative estimate of savings for nursing homes, we shall use the median value across all 89 hospitals in the PHS data set of $1785, which translates into an expected savings due to the FSES of $1290 per nursing home bed.

5. Measurement of Economic Impacts

The results of the economic impact study of the Fire Safety Evaluation System (FSES) for health care facilities are presented in this chapter. Results are presented for two basic cases. First, the cost savings nationwide achievable through the use of the FSES are derived. These cost savings demonstrate the importance of the FSES as a cost containment mechanism and provide a basis for estimating the value of BFRL's contribution. Second, the cost savings attributable to BFRL are estimated and compared to its investment in FSES-related research.

Key economic measures are calculated to show the present value of savings (PVS), the present value of net savings (PVNS), the savings-to-investment ratio (SIR), and the adjusted internal rate of return (AIRR) which are attributable to BFRL's research on the FSES. These values are derived by measuring how cost savings nationwide would have been reduced if BFRL had not been involved in the development of the FSES. Information from fire safety experts was used to develop an estimate of how the use of the FSES would have been delayed, were it not for BFRL's role as the developer of the FSES. This delay is tied to the adoption of the FSES into the Life Safety Code. Without BFRL's involvement, the likely delay for the adoption of the FSES into the Life Safety Code is estimated to be seven years.

Because a number of factors, including the delay for the adoption of the FSES into the Life Safety Code, are uncertain, a sensitivity analysis is performed. The sensitivity analysis shows the impact of changing the values of three key variables in combination. The three variables are: (1) the discount rate; (2) the per unit cost savings (i.e., per active service military hospital or per bed for VA hospitals, non-federal hospitals, and nursing homes); and (3) the delay in adoption.

The results of this study demonstrate that the FSES has generated substantial cost savings to hospitals and nursing homes across the nation. The present value of savings nationwide attributable to the FSES is nearly \$1 billion (\$987 million in 1995 dollars). Furthermore, because of BFRL's timely involvement and effective leadership, the FSES was adopted into the Life Safety Code in 1981. The first fully-documented use of the FSES was in 1983—a two-year lag from when the FSES was first adopted into the Life Safety Code. If BFRL had not participated in the development of the FSES, adoption into the Life Safety Code would likely have taken place in 1988. Consequently, potential cost savings accruing to hospitals and nursing homes over the period 1983 through 1989 would have been foregone. These cost savings are in excess of \$0.5 billion (\$564 million in 1995 dollars). These cost savings measure the value of BFRL's contribution for its research investment of approximately \$4.5 million. Stated in present value terms, every public dollar invested in BFRL's FSES-related research generated \$126 in cost savings to the public (i.e., an SIR of 126). The annual percentage yield (AIRR) from the FSES project over the study period is 35 percent.

5.1 BFRL Summary Impact Statement

Exhibit 5-1 is a summary impact statement, covering the background, approach, and results of the study. Exhibit 5-1 utilizes the framework introduced in chapter 2 (see exhibit 2-1).

Exhibit 5-1. Summary of Economic Impacts of BFRL Research on the Fire Safety Evaluation System for Health Care Facilities

1.a Significance of Research Effort:

Concern over fire safety in hospitals and nursing homes caused Congress to make certification for participation in the Medicare and Medicaid programs contingent upon complying with the Life Safety Code. Because the Life Safety Code is a prescriptive code (i.e., it prescribes fixed solutions to fire safety in designated occupancies), many health care facilities were faced with costly renovations.

In 1975, the Department of Health and Human Services (then HEW) sought technical support from BFRL (then the Center for Fire Research). This support led to the development of the Fire Safety Evaluation System (FSES), a framework for determining how combinations of several widely-accepted fire safety systems can be used to provide a level of safety equivalent to that prescribed by the Life Safety Code. Optimization software developed by BFRL economists builds on the FSES equivalency approach to offer facility managers a menu of solutions, many of which result in significant cost savings. The software has been extensively utilized by the U.S. Public Health Service (PHS) on more than 80 active service military hospitals. The PHS data set provides a good cross section of the overall hospital population, facilitating an evaluation of cost savings attributable to the FSES. BFRL's active role in the development of the FSES led to its acceptance into the Life Safety Code in 1981. Without BFRL's participation in the development of the FSES, it is likely that acceptance into the Life Safety Code would have been delayed at least seven years.

1.b Key Points:

- Concern over fire safety in hospitals and nursing homes caused Congress to make certification for participation in the Medicare and Medicaid programs contingent upon complying with the Life Safety Code.
- BFRL's participation led to the adoption of the FSES into the Life Safety Code in 1981. Without BFRL's participation, adoption of the FSES into the Life Safety Code would likely have been postponed until 1988.
- BFRL's optimization software identifies lower cost equivalent solutions for Life Safety Code compliance and measures the cost savings compared with prescriptive compliance.

2. Analysis Strategy:

The objective of the study is to (1) evaluate *ex post*, for the period 1975 through 1995, the cost savings of the FSES as a means of achieving compliance to the Life Safety Code in hospitals and nursing homes, and (2) estimate BFRL's contribution to these cost savings. The approach is to estimate in 1995 present value (PV) dollars:

(1) **Present Value Cost Savings Nationwide** in hospitals and nursing homes which employed the FSES as a means of upgrading their facilities to comply with the Life Safety Code. Cost savings nationwide are estimated for each year from 1975 to 1995 and summed.

(2) **Present Value Savings (PVS) attributable to BFRL** by including the savings only for those years which accrued due to BFRL's participation (i.e., 1975 to 1989).

(3) **Present Value Net Savings (PVNS) attributable to BFRL** by subtracting from BFRL PVS the present value investment costs to BFRL (PV Costs).

(4) **Savings-to-Investment Ratio (SIR) attributable to BFRL** by taking the ratio of BFRL PVS to BFRL PV Costs. A ratio > 1 indicates an economically worthwhile project.

(5) **Adjusted Internal Rate of Return (AIRR)**, the annual rate of return over the study period on BFRL's investment. An AIRR > the discount rate indicates that the project is economically worthwhile.

Data and Assumptions:

- The period over which costs and savings are measured begins in 1975 and ends in 1995. Hence the length of the study period is 21 years.
- The base year is 1995 and all amounts are calculated in PV 1995 dollars.
- The discount rate is 7 percent (real), which is the OMB discount rate in effect for government projects in 1995.
- The PHS data set is used to develop estimated cost savings for active service military hospitals. Cost savings on a per bed basis ($1290) are derived from the PHS data set and applied to VA hospitals, non-federal hospitals and nursing homes.
- Rates of use of the FSES for VA hospitals, non-federal hospitals, and nursing homes are based on information from government and industry experts.

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

- Savings and Costs:

Present Value Cost Savings Nationwide:
Sum from 1975 to 1995 of present value of cost savings nationwide by year
=$987.3 million

Present Value Savings (PVS) Attributable to BFRL:
Sum from 1975 to 1989 of present value of cost savings nationwide by year
=$564.1 million

Present Value Investment Costs (PV Costs) to BFRL:
Sum from 1975 to 1995 of present value of investment cost to BFRL by year
=$4.466 million

Present Value Net Savings (PVNS) Attributable to BFRL:
Difference between present value savings (PVS) attributable to BFRL and present value investment costs (PV Costs) to BFRL
=$564.1 - $4.466 =$559.6 million

- Additional Measures:

SIR of BFRL Contribution:
Savings-to-Investment Ratio on BFRL investment
=$564.1/$4.466 =126

AIRR of BFRL Contribution:
Adjusted Internal Rate of Return on BFRL investment
$=(1 + 0.07) * 126^{1/21} - 1$ =0.35

3.b Key Results:

Savings Attributable to BFRL:

	1995 Dollars ($ amounts in millions)
PVS	$564.1
PV Costs	$4.466
PVNS	$559.6
SIR	126
AIRR	35%

5.2 Cost Savings Nationwide

The PHS data set provided the basis for estimating the cost savings nationwide associated with the adoption and use of the FSES. Generating estimates of cost savings nationwide was a multi-step process, drawing upon information on active service military hospitals, VA hospitals, non-federal hospitals, nursing homes, as well as projections of per unit cost savings (i.e., per active service military hospital or per bed for other types of facilities) and time lines over which renovation takes place for each type of facility.

Estimating savings for active service military hospitals was a two-step process. First, for the 86 active service military hospitals contained in the PHS data set, information on the year of the survey, the number of beds in the hospital, and the estimated maximum cost savings per unit (i.e., per hospital) from the least-cost, FSES-based compliance strategy, was available for each hospital. Second, it was necessary to adjust the estimated maximum cost savings per unit downward to the level associated with the 25^{th} percentile (i.e., per unit cost savings were multiplied by 0.723). These two steps result in estimates of the annual baseline cost savings for the 86 active service military hospitals in the PHS data set. These estimates along with supporting information are summarized in table 5-1. Column (1) of the table records the year in which the survey, and hence the cost savings, takes place. Note that the first surveys took place in 1985. Column (2) provides information on the number of active service military hospital beds covered by the FSES. Annual baseline cost savings (in thousands of 1995 dollars) for active service military hospitals are shown in column (3). Baseline cost savings are computed using the estimated maximum cost savings for each active service military hospital adjusted downward to the 25^{th} percentile (i.e., multiplied by 0.723).

Estimating savings for VA hospitals, non-federal hospitals, and nursing homes was also a two-stage process. First, it was necessary to develop a time line over which renovation took place. This was accomplished by taking the information on beds covered by the FSES, recorded in table 4-4 for VA hospitals and non-federal hospitals and in table 4-6 for nursing homes, and dividing each bed count by the number of years over which each type of facility had employed the FSES. Note that the bed counts from tables 4-4 and 4-6 already reflect that proportion of the overall population for each type of facility which employed the FSES. Because detailed information was not available on the timing of renovations for each type of facility which employed the FSES, a time line which is uniformly distributed seemed appropriate. Figures for each type of facility are summarized in table 5-2. Column (1) of the table records the year in which the renovation takes place. Note that the FSES was first employed in VA hospitals in 1983—a two-year lag from when the FSES was first adopted into the Life Safety Code. Estimates on the number of beds covered by the FSES for VA hospitals for each year from 1983 to 1995 are shown in column (2) of table 5-2. Based on information provided by experts associated with the American Hospital Association and the American Health Care Association, both non-federal hospitals and nursing homes began to employ the FSES in 1985. Annual estimates on the number of beds covered by the FSES for non-federal hospitals and for nursing homes are shown in columns (3) and (4) of table 5-2. The total number of beds covered by the FSES for VA hospitals, non-federal hospitals, and nursing homes are shown in column (5) of table 5-2. Second, the baseline cost savings per bed, derived in section 4.6, was applied to the total number of beds covered in each year. Column (6) records the baseline cost savings per bed. The level of savings (in thousands of 1995 dollars) is the product of each year's entry in column (5) and in column (6); it is recorded in column (7) of table 5-2.

Table 5-1. Baseline Cost Savings for Active Service Military Hospitals: 1975-1995

Year	Number of Beds Covered by FSES	Level of Savings (In Thousands of 1995 Dollars)
Col. (1)	Col. (2)	Col. (3)
1975	0	0
1976	0	0
1977	0	0
1978	0	0
1979	0	0
1980	0	0
1981	0	0
1982	0	0
1983	0	0
1984	0	0
1985	339	358
1986	1,159	4,518
1987	5,778	7,953
1988	5,348	9,086
1989	2,286	2,032
1990	150	45
1991	340	1,361
1992	1,311	868
1993	390	515
1994	159	51
1995	0	0

Table 5-2. Baseline Cost Savings for VA Hospitals, Non-Federal Hospitals, and Nursing Homes: 1975-1995[A]

Year	Number of Beds Covered by the FSES					
	Type of Facility			Total	Baseline Savings Per Bed	Level of Savings (In Thousands of 1995 Dollars)
	VA Hospitals	Non-Federal Hospitals	Nursing Homes			
Col. (1)	Col. (2)	Col. (3)	Col. (4)	Col. (5)	Col. (6)	Col. (7)
1975	0	0	0	0	1,290	0
1976	0	0	0	0	1,290	0
1977	0	0	0	0	1,290	0
1978	0	0	0	0	1,290	0
1979	0	0	0	0	1,290	0
1980	0	0	0	0	1,290	0
1981	0	0	0	0	1,290	0
1982	0	0	0	0	1,290	0
1983	3,096	0	0	3,096	1,290	3,994
1984	3,097	0	0	3,097	1,290	3,995
1985	3,097	19,556	22,828	45,481	1,290	58,670
1986	3,097	19,556	22,828	45,481	1,290	58,670
1987	3,097	19,556	22,828	45,481	1,290	58,670
1988	3,097	19,556	22,828	45,481	1,290	58,670
1989	3,097	19,556	22,828	45,481	1,290	58,670
1990	3,097	19,556	22,828	45,481	1,290	58,670
1991	3,097	19,556	22,828	45,481	1,290	58,670
1992	3,097	19,556	22,828	45,481	1,290	58,670
1993	3,097	19,556	22,828	45,481	1,290	58,670
1994	3,097	19,556	22,828	45,481	1,290	58,670
1995	3,097	19,560	22,830	45,487	1,290	58,678

[A] Excludes active service military hospitals.

The present value of baseline cost savings to the nation is summarized in table 5-3. Column (1) of the table records the year in which renovation takes place. Column (2) records, for each year, the cost savings (in thousands of 1995 dollars) for active service military hospitals. Column (3) records, for each year, the combined cost savings (in thousands of 1995 dollars) for VA hospitals, non-federal hospitals, and nursing homes. Column (4) records a year-by-year total (in thousands of 1995 dollars) across all four types of facilities (i.e., active service military hospitals, VA hospitals, non-federal hospitals, and nursing homes). Although each year's cost savings are recorded in thousands of 1995 dollars, savings which occur in different years must be brought forward to 1995 to be expressed in present value terms. Column (5) records the single compound amount factor—based on a real discount rate of 7%—used to bring forward (i.e., compound) to 1995 any cost savings which occur before 1995. The present value of each year's cost savings—the product of column (4) and column (5) for that year—is recorded in column (6) of table 5-3. The total, which equals present value cost savings nationwide, is recorded at the bottom of table 5-3. Reference to table 5-3 demonstrates the magnitude of the savings to the nation from using the FSES. Baseline cost savings to the nation are nearly $1.0 billion ($987.3 million in present value 1995 dollars).

5.3 BFRL Contribution

The measurement of the economic impacts of BFRL's contribution is divided into two parts. The first part builds on the baseline analysis of the previous section. Information on the costs of BFRL's FSES-related research efforts are introduced followed by an assessment of how cost savings to the nation would have been reduced had BFRL not participated in the development of the FSES. This approach allows a full array of economic measures—PVS, PV Costs, PVNS, SIR, AIRR—to be computed, thus giving a better measure of BFRL's impact on society. This analysis is presented in section 5.3.1. The second part is a sensitivity analysis aimed at evaluating how the values of the five economic measures change as the values of three key variables—the discount rate, the per unit cost savings, and the delay in adoption—are changed in combination. The sensitivity analysis is designed in a way to facilitate replication by others. This results in a series of interlinking tables, which constitute the bulk of section 5.3.2. Consequently, readers interested primarily in the results of the sensitivity analysis rather than the methodology, are encouraged to skip section 5.3.2 and go directly to section 5.4.

5.3.1 Baseline Analysis

Measuring the economic impacts of BFRL's contribution to the development of the FSES is the focus of this section. Information on BFRL's research efforts—in terms of its dollar investments—over the 21-year period from 1975 to 1995 are first presented. These figures demonstrate not only a significant, up-front research commitment by BFRL, but a continued effort as the FSES has evolved. Next, the likely delay in the adoption of the FSES into the Life Safety Code is addressed. Fire safety experts have suggested a range of values for the likely delay, including the strong possibility that the FSES would not have resulted in the time frame of this analysis. Consensus among experts implies a delay of 7 to 10 years. Because the Life Safety Code undergoes revisions approximately every three to four years, the likely first edition in which the FSES could have been incorporated without BFRL's input is the 1988 edition of the Life Safety Code. This translates into a seven-year delay. Finally, a full array of economic measures are presented to summarize the importance of BFRL's contribution to FSES-related research.

Table 5-3. Computation of Present Value Baseline Cost Savings: 1975-1995

Year	Cost Savings by Type of Facility (In Thousands of 1995 Dollars)		Total Cost Savings by Year (In Thousands of 1995 Dollars)	Single Compound Amount Factor	Present Value of Cost Savings Nationwide by Year (In Thousands of 1995 Dollars)
	Active Service Military Hospitals	All Other Facilities			
Col. (1)	Col. (2)	Col. (3)	Col. (4)	Col. (5)	Col. (6)
1975	0	0	0	3.870	0
1976	0	0	0	3.617	0
1977	0	0	0	3.380	0
1978	0	0	0	3.159	0
1979	0	0	0	2.952	0
1980	0	0	0	2.759	0
1981	0	0	0	2.579	0
1982	0	0	0	2.410	0
1983	0	3,994	3,994	2.252	8,995
1984	0	3,995	3,995	2.105	8,409
1985	358	58,670	59,028	1.967	116,119
1986	4,518	58,670	63,188	1.838	116,170
1987	7,953	58,670	66,623	1.718	114,472
1988	9,086	58,670	67,756	1.606	108,802
1989	2,032	58,670	60,702	1.501	91,098
1990	45	58,670	58,715	1.403	82,351
1991	1,361	58,670	60,031	1.311	78,688
1992	868	58,670	59,538	1.225	72,938
1993	515	58,670	59,185	1.145	67,761
1994	51	58,670	58,721	1.070	62,832
1995	0	58,678	58,678	1.000	58,678
				TOTAL	987,313

Information on BFRL's investments in FSES-related research is summarized in table 5-4. Column (1) of the table records the year in which FSES-related research investments were made. Column (2) records the value (in thousands of current dollars by year) of investment for each year. For example, in 1975 the investment was $75,000 (in 1975 dollars), in 1980 the investment was $100,000 (in 1980 dollars), and in 1985 the investment was $10,000 (in 1985 dollars). Investments over the 1975 to 1985 time period cover the initial research on the FSES, the formation of focus groups, generating consensus on the relative importance of the building safety parameters, performing analyses of actual health care facilities, conducting discussions with the National Fire Protection Association—including adoption of the FSES into the Life Safety Code, training staff at HHS and elsewhere on how to employ the FSES, and developing, testing, and issuing the first software package for identifying cost-effective, FSES-based compliance strategies. Investments in 1992, 1993, and 1994 cover the development of the second generation of the software package.[37]

Because the values in column (2) are in current dollars by year, where year ranges from 1975 to 1995, it is necessary to convert them to constant 1995 dollars and then to convert them to time equivalent dollars. This involves a two-step process. First, each year's current dollar investment is converted to a "real" investment in 1995 constant dollars through application of the Consumer Price Index (CPI). The conversion factors, for each year, are shown in column (3). The constant 1995 dollar values (in $1,000) are the year-by-year products of the entries in columns (2) and (3); they are shown in column (4). The values in column (4) are converted into present value terms through use of a single compound amount factor, based on a real discount rate of 7%. The values of each year's single compound amount factor is given in column (5). The present values in thousands of 1995 dollars are recorded in column (6); they are the year-by-year product of the entries in columns (4) and (5), respectively. The present value of BFRL's research investments, PV Costs, totals $4.466 million; this value is recorded at the bottom of column (6).

The estimated cost savings attributable to BFRL are shown in table 5-5. Column (1) of the table records each year in which savings are possible. Column (2) carries forward the information from column (6) of table 5-3; it records the present value of cost savings nationwide (in thousands of 1995 dollars) on a year-by-year basis.

Because BFRL's research effort resulted in a faster adoption of the FSES into the Life Safety Code, those savings which would have been forgone in the event of a delay are attributable to BFRL. Therefore, any savings prior to the "delayed" adoption of the FSES into the Life Safety Code in 1988 would have been foregone. It is important to note that adoption into the Life Safety Code as an alternative to prescriptive compliance did not lead to immediate use of the FSES. Reference to column (2) of table 5-2 shows that the first use of the FSES was in 1983—two years after adoption into the Life Safety Code. Upon further examination of table 5-2, it is revealed that widespread use of the FSES did not begin until 1985—four years after adoption into the Life Safety Code. Consequently, in order to maintain a conservative estimate of the savings attributable to BFRL, we shall assume that the shorter two-year lag in usage of the FSES prevails across all facility types. Furthermore, we assume that no savings which accrue after the two-year lag (i.e., in 1990 through 1995) are attributable to BFRL. Such an accounting framework may be handled through use of a 0-1 weighting factor. For those years in which savings are attributable to BFRL, the

[37]This research was funded directly by the Public Health Service and conducted by economists in the Office of Applied Economics (OAE). The research was initiated while the OAE was in the Computing and Applied Mathematics Laboratory and completed after their transfer to BFRL.

Table 5-4. Summary of BFRL Research Investments: 1975-1995

Year	Annual Dollar Amount (In Thousands of Current Dollars by Year)	Conversion Factor by Year (Current Dollars to Constant 1995 Dollars)	Investment Cost by Year (In Thousands of 1995 Dollars)	Single Compound Amount Factor by Year	Present Value of Investment Cost by Year (In Thousands of 1995 Dollars)
Col. (1)	Col. (2)	Col. (3)	Col. (4)	Col. (5)	Col. (6)
1975	75	2.571	193	3.870	746
1976	75	2.425	182	3.617	658
1977	75	2.281	171	3.380	578
1978	75	2.119	159	3.159	502
1979	100	1.956	196	2.952	578
1980	100	1.799	180	2.759	496
1981	100	1.639	164	2.579	423
1982	20	1.536	31	2.410	74
1983	20	1.473	29	2.252	66
1984	10	1.416	14	2.105	30
1985	10	1.371	14	1.967	27
1986	0	1.337	0	1.838	0
1987	0	1.296	0	1.718	0
1988	0	1.252	0	1.606	0
1989	0	1.198	0	1.501	0
1990	0	1.150	0	1.403	0
1991	0	1.105	0	1.311	0
1992	80	1.074	86	1.225	105
1993	80	1.047	84	1.145	96
1994	80	1.025	82	1.070	88
1995	0	1.000	0	1.000	0
				TOTAL	4,466

Table 5-5. Estimated Cost Savings Attributable to BFRL

Year	Present Value of Costs Savings Nationwide by Year (In Thousands of 1995 Dollars)	BFRL Baseline Weighting Factor (7-Year Delay)	Present Value of Cost Savings by Year Attributable to BFRL (In Thousands of 1995 Dollars)
Col. (1)	**Col. (2)**	**Col. (3)**	**Col. (4)**
1975	0	1	0
1976	0	1	0
1977	0	1	0
1978	0	1	0
1979	0	1	0
1980	0	1	0
1981	0	1	0
1982	0	1	0
1983	8,995	1	8,995
1984	8,409	1	8,409
1985	116,119	1	116,119
1986	116,170	1	116,170
1987	114,472	1	114,472
1988	108,802	1	108,802
1989	91,098	1	91,098
1990	82,351	0	0
1991	78,688	0	0
1992	72,938	0	0
1993	67,761	0	0
1994	62,832	0	0
1995	58,678	0	0
		TOTAL	564,065

weighting factor takes on a value of 1. The year-by-year values of the BFRL "baseline" weighting factor are given in column (3) of table 5-5. The present value of savings attributable to BFRL is the product of each year's present value of cost savings nationwide in column (2) and the value of the BFRL baseline weighting factor in column (3). The present value of savings attributable to BFRL on a year-by-year basis is given in column (4) of table 5-5. The total, which equals present value savings (PVS), is recorded at the bottom of table 5-5. Baseline PVS is in excess of \$0.5 billion (\$564.1 million in present value 1995 dollars).

Given the values of PV Costs and PVS attributable to BFRL, it is now possible to derive three other economic impact measures. These measures are: (1) present value net savings (PVNS) attributable to BFRL; (2) the savings-to-investment ratio (SIR) on BFRL's research investment; and (3) the adjusted internal rate of return (AIRR) on BFRL's research investment.

The PVNS attributable to BFRL, expressed in millions of present value 1995 dollars and based on the approach outlined in section 2.1.1, is equal to:

$$\begin{aligned} \text{PVNS} &= \text{PVS} - \text{PV Costs} \\ &= \$564.1 - \$4.466 \\ &= \$559.6 \text{ million} \end{aligned}$$

Utilizing the approach outlined in section 2.1.2, the SIR on BFRL's research investment is equal to:

$$\begin{aligned} \text{SIR} &= \text{PVS} / (\text{PV Costs}) \\ &= \$564.1 / \$4.466 \\ &= 126 \end{aligned}$$

Utilizing the approach outlined in section 2.1.3, the AIRR on BFRL's research investment is equal to:

$$\begin{aligned} \text{AIRR} &= (1 + 0.07) * 126^{1/21} - 1 \\ &= 0.35 \\ &= 35\% \end{aligned}$$

The values of the five economic impact measures just derived are the "baseline" values which appear in section 3.b of exhibit 5-1. These values also figure in the sensitivity analysis, which is the subject of the next section.

5.3.2 Sensitivity Analysis

Because a number of factors are uncertain, a sensitivity analysis was performed. The purpose of the sensitivity analysis was to evaluate the impact of changing the values of three key variables in combination.

The three variables are: (1) the discount rate; (2) the per unit cost savings; and (3) the delay in adoption. All changes were selected so as to represent perturbations about the baseline values of each key variable. Each key variable was set at one of three different levels. In all, 27 different sets of results were obtained. For each of the 27 different sets of results, the values of the five economic impact measures—PVS, PV Costs, PVNS, SIR, and AIRR—were calculated.

The key variables and the three levels for each, along with a descriptor of that level, are shown in table 5-6. Notice that each of the three variables has a level which corresponds to the baseline setting. In each case, the baseline value is recorded first. For example the baseline value for the discount rate is 7% (real). Two other values for the discount rate, 10% and 4%, are selected to bracket the baseline value. In each of the other cases, the values employed in the sensitivity analysis bracket the value of the baseline value for the variable of interest. Consequently, only one of the 27 different sets of results corresponds to the "baseline" analysis.

The discount rate affects calculations in a number of ways. The investment costs, PV Costs, for BFRL's research efforts are affected by the choice of the discount rate as well as the present value of savings, PVS, attributable to BFRL. Because the base year is 1995, all costs and savings are brought forward (i.e., compounded). The single compound amount factor is used to bring all relevant costs and savings forward. Reference to table 5-7 shows that for each year over the study period, the single compound amount factor is lowest for a discount rate of 4% and highest for a rate of 10%. For example, the values for 1985 are 1.967 for 7%, 1.480 for 4%, and 2.594 for 10%. Therefore, applying these factors to either costs or savings will result in intermediate (i.e., baseline) values for 7%, lower values for 4%, and higher values for 10%. The resulting values of the five economic impact measures will vary accordingly.

The present value of BFRL's investment costs, as a function of the discount rate, is summarized in table 5-8. Column (1) of the table records the year in which FSES-related research investments were made. Column (2), (3), and (4) record the value (in thousands of present value 1995 dollars) of the investments for each year. Column (2) records the present value for each year based on the baseline value of the discount rate (i.e., 7%). The values in column (2) are the product of the year-by-year values in column (4) of table 5-4 and column (2) of table 5-7.[38] The present value of BFRL's investment costs, PV costs, based on the baseline discount rate of 7%, totals $4.466 million; this value is recorded at the bottom of column (2) of table 5-8. Column (3) records the present value for each year based on the high value of the discount rate (i.e., 10%). The values in column (3) are the product of the year-by-year values in column (4) of table 5-4 and column (3) of table 5-7. The present value of BFRL's investment costs, PV costs, based on the high discount rate of 10%, totals $7.017 million; this value is recorded at the bottom of column (3) of table 5-8. Column (4) records the present value for each year based on the low value of the discount rate (i.e., 4%). The values in column (4) are the product of the year-by-year values in column (4) of table 5-4 and column (4) of table 5-7. The present value of BFRL's investment costs, PV costs, based on the low discount rate of 4%, totals $2.849 million; this value is recorded at the bottom of column (4) of table 5-8.

The per unit cost savings have a major impact on the values of the economic impact measures. Table 5-9 records the resulting level of savings (in thousands of 1995 dollars) for active service military hospitals.

[38]For 1975, the investment cost (in thousands of 1995 dollars) recorded in column (4) of table 5-4 is 193, the single compound amount factor recorded in column (2) of table 5-7 is 3.870, and their product (in thousands of present value 1995 dollars) recorded in column (2) of table 5-8 is 746.

The three values—baseline, high, and low—correspond to the levels associated with the 25^{th} percentile (i.e., 72.3% of maximum savings), minimum FSES (i.e., 100% of maximum savings), and median (i.e., 48.5% of maximum savings). The resulting values for each year are shown in table 5-9; column (2) for the baseline, column (3) for the high, and column (4) for the low.

Table 5-10 and 5-11 provide the basis for estimating cost savings for VA hospitals, non-federal hospitals, and nursing homes. The three levels of per unit cost savings, in this case cost savings per bed, are given in table 5-10. The three levels are: (1) baseline $1290; (2) high $1785; and (3) low $830. The level of savings (in thousands of 1995 dollars) for each year and for each level of per unit cost savings are shown in table 5-11. To compute the level of savings for each year, we make use of information on the year-by-year combined number of beds covered by the FSES for VA hospitals, non-federal hospitals, and nursing homes; this information is summarized in column (5) of table 5-2. The entries in column (2) of table 5-11 are the year-by-year products of column (2) of table 5-10 and column (5) of table 5-2; they reflect the baseline value of $1290 for per unit cost savings. The entries in column (3) of table 5-11 are the year-by-year products of column (3) of table 5-10 and column (5) of table 5-2; they reflect the high value of $1785 for per unit cost savings. The entries in column (4) of table 5-11 are the year-by-year products of column (4) of table 5-10 and column (5) of table 5-2; they reflect the low value of $830 for per unit cost savings.

The combined cost savings for active service military hospitals, VA hospitals, non-federal hospitals, and nursing homes are given in table 5-12. Column (2) of the table is equal to the year-by-year sum of column (2) of table 5-9 and column (2) of table 5-11. The entries in column (2) correspond to the baseline value of per unit savings. Column (3) of the table is equal to the year-by-year sum of column (3) of table 5-9 and column (3) of table 5-11. The entries in column (3) correspond to the high value of per unit savings. Column (4) of the table is equal to the year-by-year sum of column (4) of table 5-9 and column (4) of table 5-11. The entries in column (4) correspond to the low value of per unit savings.

The present value of cost savings as a function of the discount rate is summarized in table 5-13. Column (1) of the table records each year in which cost savings are possible. Columns (2), (3), and (4) record for the baseline discount rate of 7%, the estimated savings (in thousands of 1995 dollars) for baseline per unit savings, high per unit savings, and low per unit savings, respectively. Columns (5), (6), and (7) record for the high discount rate of 10%, the estimated savings (in thousands of 1995 dollars) for baseline per unit savings, high per unit savings, and low per unit savings, respectively. Columns (8), (9), and (10) record for the low discount rate of 4%, the estimated savings (in thousands of 1995 dollars) for baseline per unit savings, high per unit savings, and low per unit savings, respectively.

The weighting factors as a function of the length of delay without BFRL's participation are summarized in table 5-14. Column (1) of the table records each year in which cost savings are possible. Column (2) reproduces column (3) of table 5-5, the seven-year baseline delay. Column (3) records the weights associated with the possible delay of 10 years. Notice that the same two-year lag in use of the FSES is incorporated into the entries in column (3). Column (4) records the weight associated with the "least likely" delay of four years. Notice that the same two-year lag in use of the FSES is incorporated into the entries in column (4).

Table 5-6. Key Variables Analyzed in the Sensitivity Analysis

Variable Name	Levels	Description
Adoption Delay	Baseline	7 years: Length of delay without BFRL's involvement
	Possible	10 years: Length of delay without BFRL's involvement
	Least Likely	4 years: Length of delay without BFRL's involvement
Per unit Cost Savings	Baseline	25th percentile: (a) 72.3% of maximum savings for active service military hospitals or (b) $1,290 per bed for VA hospitals, non-federal hospitals, and nursing homes
	High	Minimum FSES: (a) 100% of maximum savings for active service military hospitals or (b) $1,785 per bed for VA hospitals, non-federal hospitals, and nursing homes
	Low	Median (50th percentile): (a) 46.6% of maximum savings for active service military hospitals or (b) $830 per bed for VA hospitals, non-federal hospitals, and nursing homes
Discount Rate	Baseline	7% (real): As stipulated in OMB *Circular A-94*, revised 1992
	High	10% (real)
	Low	4% (real)

Table 5-7. Single Compound Amount Factors Used in the Sensitivity Analysis

Year	Single Compound Amount Factor by Year		
	Baseline	High	Low
	7 Pct.	10 Pct.	4 Pct.
Col. (1)	Col. (2)	Col. (3)	Col. (4)
1975	3.870	6.727	2.191
1976	3.617	6.116	2.107
1977	3.380	5.560	2.026
1978	3.159	5.054	1.948
1979	2.952	4.595	1.873
1980	2.759	4.177	1.801
1981	2.579	3.797	1.732
1982	2.410	3.452	1.665
1983	2.252	3.138	1.601
1984	2.105	2.853	1.539
1985	1.967	2.594	1.480
1986	1.838	2.358	1.423
1987	1.718	2.144	1.369
1988	1.606	1.949	1.316
1989	1.501	1.772	1.265
1990	1.403	1.611	1.217
1991	1.311	1.464	1.170
1992	1.225	1.331	1.125
1993	1.145	1.210	1.082
1994	1.070	1.100	1.040
1995	1.000	1.000	1.000

Table 5-8. Present Value of BFRL Research Investments as a Function of the Discount Rate: 1975-1995

Year	Present Value of Investment Cost by Year (In Thousands of 1995 Dollars)		
	Discount Rate		
	Baseline (7 Pct.)	High (10 Pct.)	Low (4 Pct.)
Col. (1)	Col. (2)	Col. (30	Col. (4)
1975	746	1,297	422
1976	658	1,112	383
1977	578	951	347
1078	502	803	310
1979	578	899	366
1980	496	751	324
1981	423	622	284
1982	74	106	51
1983	66	92	47
1984	30	40	22
1985	27	36	20
1986	0	0	0
1987	0	0	0
1988	0	0	0
1989	0	0	0
1990	0	0	0
1991	0	0	0
1992	105	114	97
1993	96	101	91
1994	88	90	85
1995	0	0	0
TOTAL	4,466	7,017	2,849

Table 5-9. Estimated Cost Savings for Active Service Military Hospitals: 1975-1995

	Level of Savings by Year (In Thousands of 1995 Dollars)		
Year	Baseline (25th Percentile)	High (Minimum FSES)	Low (Median)
Col. (1)	Col. (2)	Col. (3)	Col. (4)
1975	0	0	0
1976	0	0	0
1977	0	0	0
1978	0	0	0
1979	0	0	0
1980	0	0	0
1981	0	0	0
1982	0	0	0
1983	0	0	0
1984	0	0	0
1985	358	496	231
1986	4,518	6,249	2,912
1987	7,953	11,000	5,126
1988	9,086	12,567	5,856
1989	2,032	2,811	1,310
1990	45	62	29
1991	1,361	1,882	877
1992	868	1,201	560
1993	515	712	332
1994	51	71	33
1995	0	0	0

Table 5-10. Estimated Cost Savings Per Bed for VA Hospitals, Non-Federal Hospitals, and Nursing Homes[A]

Year	Level of Savings Per Bed by Year		
	Baseline (25th Percentile)	High (Minimum FSES)	Low (Median)
Col. (1)	Col. (2)	Col. (3)	Col. (4)
1975-1995	$1,290	$1,785	$830

[A]Excludes active service military hospitals.

Table 5-11. Estimated Cost Savings for VA Hospitals, Non-Federal Hospitals, and Nursing Homes[A]

Year	Level of Savings by Year (In Thousands of 1995 Dollars)		
	Baseline (25th Percentile) $1,290	High (Minimum FSES) $1,785	Low (Median) $830
Col. (1)	Col. (2)	Col. (3)	Col. (4)
1975	0	0	0
1976	0	0	0
1977	0	0	0
1978	0	0	0
1979	0	0	0
1980	0	0	0
1981	0	0	0
1982	0	0	0
1983	3,994	5,526	2,570
1984	3,995	5,528	2,571
1985	58,670	81,184	37,749
1986	58,670	81,184	37,749
1987	58,670	81,184	37,749
1988	58,670	81,184	37,749
1989	58,670	81,184	37,749
1990	58,670	81,184	37,749
1991	58,670	81,184	37,749
1992	58,670	81,184	37,749
1993	58,670	81,184	37,749
1994	58,670	81,184	37,749
1995	58,678	81,194	37,754

[A]Excludes active service military hospitals.

Table 5-12. Estimated Cost Savings for all Health Care Facilities: 1975-1995

Year	Level of Savings by Year (In Thousands of 1995 Dollars)		
	Baseline (25th Percentile)	High (Minimum FSES)	Low (Median)
Col. (1)	Col. (2)	Col. (3)	Col. (4)
1975	0	0	0
1976	0	0	0
1977	0	0	0
1978	0	0	0
1979	0	0	0
1980	0	0	0
1981	0	0	0
1982	0	0	0
1983	3,994	5,526	2,570
1984	3,995	5,528	2,571
1985	59,029	81,679	37,980
1986	63,189	87,433	40,661
1987	66,623	92,184	42,875
1988	67,756	93,750	43,605
1989	60,703	83,994	39,059
1990	58,715	81,245	37,778
1991	60,031	83,065	38,626
1992	59,539	82,385	38,309
1993	59,185	81,895	38,081
1994	58,722	81,255	37,782
1995	58,678	81,194	37,754

Year	Discount Rate								
	Baseline (7 Percent)			High (10 Percent)			Low (4 Percent)		
	Level of Savings (In Thousands of 1995 Dollars)			Level of Savings (In Thousands of 1995 Dollars)			Level of Savings (In Thousands of 1995 Dollars)		
	Baseline (25th Percentile)	High (Minimum FSES)	Low (Median)	Baseline (25th Percentile)	High (Minimum FSES)	Low (Median)	Baseline (25th Percentile)	High (Minimum FSES)	Low (Median)
Col. (1)	Col. (2)	Col. (3)	Col. (4)	Col. (5)	Col. (6)	Col. (7)	Col. (8)	Col. (9)	Col. (10)
1975	0	0	0	0	0	0	0	0	0
1976	0	0	0	0	0	0	0	0	0
1977	0	0	0	0	0	0	0	0	0
1978	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0	0
1983	8,995	12,446	5,787	12,534	17,344	8,065	6,394	8,848	4,114
1984	8,409	11,636	5,411	11,399	15,772	7,334	6,150	8,510	3,957
1985	116,119	160,676	74,713	153,106	211,855	98,511	87,377	120,905	56,220
1986	116,170	160,742	74,754	148,996	206,162	95,878	89,937	124,444	57,874
1987	114,472	158,389	73,668	142,813	197,604	91,907	91,179	126,160	58,678
1988	108,802	150,543	70,021	132,038	182,693	84,974	89,163	123,369	57,382
1989	91,098	126,053	58,617	107,539	148,801	69,196	76,808	106,280	49,422
1990	82,351	113,951	52,986	94,561	130,846	60,842	71,436	98,847	45,963
1991	78,688	108,882	50,631	87,891	121,616	56,553	70,228	97,175	45,187
1992	72,938	100,925	46,930	79,246	109,654	50,989	66,973	92,671	43,092
1993	67,761	93,762	43,599	71,614	99,093	46,078	64,015	88,578	41,188
1994	62,832	86,942	40,427	64,595	89,380	41,561	61,071	84,505	39,294
1995	58,678	81,194	37,754	58,678	81,194	37,754	58,678	81,194	37,754
TOTAL	987,313	1,366,140	635,297	1,165,010	1,612,016	749,640	839,409	1,161,487	540,125

Table 5-14. Weighting Factors for Computing Cost Savings Attributable to BFRL

Year	Length of Delay Without BFRL's Involvement		
	7-Years (Baseline)	10-Years (Possible)	4-Years (Least Likely)
Col. (1)	Col. (2)	Col. (3)	Col. (4)
1975	1	1	1
1976	1	1	1
1977	1	1	1
1978	1	1	1
1979	1	1	1
1980	1	1	1
1981	1	1	1
1982	1	1	1
1983	1	1	1
1984	1	1	1
1985	1	1	1
1986	1	1	1
1987	1	1	0
1988	1	1	0
1989	1	1	0
1990	0	1	0
1991	0	1	0
1992	0	1	0
1993	0	0	0
1994	0	0	0
1995	0	0	0

5.4 Findings and Conclusions

The results of the sensitivity analysis are summarized in tables 5-15, 5-16, and 5-17. Each table summarizes the values of the five economic impact measures—PVS, PV Costs, PVNS, SIR, and AIRR—for 9 of the 27 different sets of results. Recall that the purpose of the sensitivity analysis was to evaluate the impact of changing the values of three key variables—the discount rate, the per unit cost savings, and the delay in adoption—in combination. All changes were selected so as to represent perturbations about the baseline values of each key variable.

Each table summarizes the results for a different adoption delay. Table 5-15 summarizes results for an adoption delay of 7 years (i.e., the baseline value). Table 5-16 summarizes results for an adoption delay of 10 years (i.e., a possible value). Table 5-17 summarizes results for an adoption delay of 4 years (i.e., the least likely value).

Each table is organized in the same way. The three columns, each of which contains three sets of values of the five economic impact measures, are a function of the per unit cost savings—baseline, high, low. The three rows, each of which contains three sets of values of the five economic impact measures, are a function of the discount rate—baseline, high, and low. The 9 "cells" in each table represent a unique combination of the per unit cost savings and the discount rate for the adoption delay of interest.

Table 5-15 summarizes the baseline estimates and the results of the sensitivity analysis for an adoption delay of 7 years. The shaded area shows the baseline estimates, which used the most likely values for the discount rate, the per unit cost savings, and the adoption delay. The remainder of the table summarizes the results of that portion of the sensitivity analysis where the adoption delay was held constant at 7 years. Turning to the results, we see that PVNS ranges from a low of $284.8 million for a discount rate of 4% and a low value of per unit cost savings to a high of $973.2 million for a discount rate of 10% and a high value of per unit cost savings. The SIR ranges from a low of 65 for a discount rate of 10% and a low value of per unit cost savings to a high of 217 for a discount rate of 4% and a high value of cost savings. The AIRR ranges from 30% to 39%.

Table 5-16 summarizes the results for an adoption delay of 10 years. The results in this table are higher than those in table 5-15. For example, comparing the baseline values for the discount rate and the per unit cost savings between table 5-15 and table 5-16 reveals that the PVNS in table 5-16 is $230 million higher and the SIR has increased by 40%, from 126 to 179. The values for PVNS in table 5-16 range from a low of $419.1 million for a discount rate of 4% and a low value of per unit cost savings to a high of $1,335.3 million for a discount rate of 10% and a high value of per unit cost savings. The SIR ranges from a low of 89 for a discount rate of 10% and a low value of per unit cost savings to a high of 318 for a discount rate of 4% and a high value of cost savings. The AIRR ranges from 32% to 41%.

Table 5-17 summarizes the results for an adoption delay of 4 years. The results in this table are lower than those in table 5-15. For example, comparing the baseline values for the discount rate and the per unit cost savings between table 5-15 and table 5-17 reveals that the PVNS in table 5-17 is $310 million lower and the SIR has decreased by more than 50%, from 126 to 56. The values for PVNS in table 5-17 range from a low of $119.4 million for a discount rate of 4% and a low value of per unit cost savings to a high of $444.1 million for a discount rate of 10% and a high value of per unit cost savings. The SIR ranges from

Table 5-15. Results of Sensitivity Analysis for an Adoption Delay of 7 Years[AB]

Discount Rate	Per Unit Cost Savings		
	Baseline (25th Percentile)	High (Minimum FSES)	Low (Median)
Baseline (7%)	PVS = $564.1 PVC = $4.466 PVNS = $559.6 SIR = 126 AIRR = 35%	PVS = $780.5 PVC = $4.466 PVNS = $776.0 SIR = 175 AIRR = 37%	PVS = $363.0 PVC = $4.466 PVNS = $358.5 SIR = 81 AIRR = 32%
High (10%)	PVS = $708.4 PVC = $7.017 PVNS = $701.4 SIR = 101 AIRR =37%	PVS = $980.2 PVC = $7.017 PVNS = $973.2 SIR = 140 AIRR = 39%	PVS = $455.9 PVC = $7.017 PVNS = $448.9 SIR = 65 AIRR = 34%
Low (4%)	PVS = $447.0 PVC = $2.849 PVNS = $444.2 SIR = 157 AIRR = 32%	PVS = $618.5 PVC = $2.849 PVNS = $615.7 SIR = 217 AIRR = 34%	PVS = $287.6 PVC = $2.849 PVNS = $284.8 SIR = 101 AIRR = 30%

[A]The values resulting from the baseline analysis are shown in the shaded portion of the table.
[B]All dollar figures are in thousands of 1995 dollars and are expressed in present value terms. All AIRR figures are expressed as a percent per annum over the entire length of the study period (i.e., the 21 years between 1975 and 1995 inclusive).

Table 5-16. Results of Sensitivity Analysis for an Adoption Delay of 10 Years [A]

Discount Rate	Per Unit Cost Savings		
	Baseline (25th Percentile)	High (Minimum FSES)	Low (Median)
Baseline (7%)	PVS = $798.0 PVC = $4.466 PVNS = $793.5 SIR = 179 AIRR = 37%	PVS = $1,104.2 PVC = $4.466 PVNS = $1,099.7 SIR = 247 AIRR = 39%	PVS = $513.5 PVC = $4.466 PVNS = $509.0 SIR = 115 AIRR = 34%
High (10%)	PVS = $970.1 PVC = $7.017 PVNS = $963.1 SIR = 138 AIRR = 39%	PVS = $1,342.3 PVC = $7.017 PVNS = $1,335.3 SIR = 191 AIRR = 41%	PVS = $624.2 PVC = $7.017 PVNS = $617.2 SIR = 89 AIRR = 36%
Low (4%)	PVS = $655.6 PVC = $2.849 PVNS = $652.8 SIR = 230 AIRR = 35%	PVS = $907.2 PVC = $2.849 PVNS = $904.4 SIR = 318 AIRR = 37%	PVS = $421.9 PVC = $2.849 PVNS = $419.1 SIR = 148 AIRR = 32%

[A] All dollar figures are in thousands of 1995 dollars and are expressed in present value terms. All AIRR figures are expressed as a percent per annum over the entire length of the study period (i.e., the 21 years between 1975 and 1995 inclusive).

Table 5-17. Results of Sensitivity Analysis for an Adoption Delay of 4 Years[A]

Discount Rate	Per Unit Cost Savings		
	Baseline (25th Percentile)	**High (Minimum FSES)**	**Low (Median)**
Baseline (7%)	PVS = $249.7 PVC = $4.466 PVNS = $245.2 SIR = 56 AIRR = 30%	PVS = $345.5 PVC = $4.466 PVNS = $341.0 SIR = 77 AIRR = 32%	PVS = $160.7 PVC = $4.466 PVNS = $156.2 SIR = 36 AIRR = 27%
High (10%)	PVS = $326.0 PVC = $7.017 PVNS = $319.0 SIR = 46 AIRR = 32%	PVS = $451.1 PVC = $7.017 PVNS = $444.1 SIR = 64 AIRR = 34%	PVS = $209.8 PVC = $7.017 PVNS = $202.8 SIR = 30 AIRR = 29%
Low (4%)	PVS = $189.9 PVC = $2.849 PVNS = $187.1 SIR = 67 AIRR = 27%	PVS = $262.7 PVC = $2.849 PVNS = $259.9 SIR = 92 AIRR = 29%	PVS = $122.2 PVC = $2.849 PVNS = $119.4 SIR = 43 AIRR = 24%

[A]All dollar figures are in thousands of 1995 dollars and are expressed in present value terms. All AIRR figures are expressed as a percent per annum over the entire length of the study period (i.e., the 21 years between 1975 and 1995 inclusive).

a low of 30 for a discount rate of 10% and a low value of per unit cost savings to a high of 92 for a discount rate of 4% and a high value of cost savings. The AIRR ranges from 24% to 34%.

The results of the sensitivity analysis demonstrate the significant impact which BFRL's research on the FSES had on the health care community. The high values of such key economic measures as PVNS, SIR, and AIRR, show clearly that BFRL's research is having an impact on the sectors of the national economy which it serves. Furthermore, these observations are maintained even under the most conservative assumptions.

6. Summary and Suggestions for Further Research

6.1 Summary

A formal resource allocation process for research is needed in both the public and private sectors. Research managers need guidelines for research planning so that they can maximize the payoffs from their limited resources. Furthermore, quantitative descriptions of research impacts have become a basic requirement in many organizations for evaluating budget requests. In addition, there are several reasons for measuring the economic impacts of a federal laboratory's research program. First, economic impact studies are a management tool; they help set priorities and point to new research opportunities. Second, as federal laboratories become more customer oriented, by revealing the "voice of the customer," such studies will strengthen the ties to industry and identify opportunities for leveraging federal research investments. Finally, changing requirements, such as the Government Performance and Results Act, will affect how federal research funds are allocated. Increasingly, federal agencies and laboratories which can not demonstrate that their research efforts complement those of industry and that they are having a positive impact on society will be at a disadvantage when competing for federal research funds.

The National Institute of Standards and Technology (NIST), a scientific research agency of the U.S. Department of Commerce's Technology Administration, is improving its resource allocation process by doing "microstudies" of its research impacts on society. This report is the outgrowth of a series of three microstudies prepared by NIST's Building and Fire Research Laboratory (BFRL). One of the microstudies was focused on a fire technology application—the Fire Safety Evaluation System (FSES) for health care facilities—and two were focused on building technology applications—ASHRAE Standard 90-75 for residential energy conservation and 235 shingles, an improved asphalt shingle for sloped roofing. This report incorporates the fire technology application. The two building technology applications are presented in a companion document.[39] This report is presented in a general framework so that it can be adopted for application by any government agency allocating research funds, and in some cases, by universities and private research firms as well.

This report employs standardized methods to evaluate the economic impacts of the FSES. This "case study" approach illustrates the main purpose of this report, namely how to apply in practice standardized methods to evaluate and compare the economic impacts of research investments. The case study is presented in sufficient detail to understand the basis for the economic impact analysis and to reproduce the results. The case study of the FSES provides estimates of the economic impacts from past BFRL research efforts leading to the development and introduction of the performance-based FSES for health care facilities. The FSES was developed as an alternative to prescriptive compliance to the Life Safety Code for health care facilities in the Medicare and Medicaid programs. The case study estimates the cost savings from using FSES-based modifications to promote fire safety in existing hospitals and nursing homes over the period from 1975 through 1995. Furthermore, that part of dollar savings that appears attributable specifically to BFRL's research efforts is estimated.

---

[39] Chapman and Fuller, *Two Case Studies in Building Technology.*

The results of this study demonstrate that the FSES has generated substantial cost savings to hospitals and nursing homes across the nation. The present value of savings nationwide attributable to the FSES is nearly $1 billion ($987 million in 1995 dollars). Furthermore, because of BFRL's timely involvement and effective leadership, the FSES was adopted into the Life Safety Code in 1981. The first fully-documented use of the FSES was in 1983. If BFRL had not participated in the development of the FSES, adoption into the Life Safety Code would likely have taken place in 1988. Consequently, potential cost savings accruing to hospitals and nursing homes over the period 1983 through 1989 would have been foregone. These cost savings are in excess of $0.5 billion ($564 million in 1995 dollars). These cost savings measure the value of BFRL's contribution for its research investment of approximately $4.5 million. Stated in present value terms, every public dollar invested in BFRL's FSES-related research generated $126 in cost savings to the public (i.e., an SIR of 126).

6.2 Suggestions for Further Research

The background work for this report uncovered additional areas of research that might be of value to government agencies and other institutions that are concerned with an efficient allocation of their research budgets. These areas of research are concerned with: (1) the development of a standard classification of research benefits and costs; (2) factors affecting the diffusion of new technologies; (3) conducting *ex ante* evaluations with scheduled follow-ups; and (4) evaluations based on multiattribute decision analysis.

6.2.1 The Development of a Standard Classification of Research Benefits and Costs

A recently published survey by the Civil Engineering Research Foundation shows that expenditures for research and development efforts in the areas of construction, building, and disaster mitigation technologies were over $2.1 billion in 1992.[40] Private industry, trade association, university, and government research bodies would like to know what are the economic impacts of these investments. The standardized evaluation methods employed in this report are appropriate for measuring these economic impacts. However, there is no systematic and comprehensive classification of research benefits and costs to guide analysts who must identify the benefits and costs associated with new construction, building, and disaster mitigation technologies that are used in these standardized evaluation methods. Such a classification, if developed, refined, and adopted as a standardized classification, could be used in several ways.[41] First, the classification will help researchers and research managers identify potential benefits and costs associated with candidate research projects and thereby help them choose those with maximum net benefits (maximum net savings). Second, the classification will provide a standardized basis for identifying benefits and costs in research proposals. Finally, the classification will make possible a consistent treatment of benefits and costs in *ex ante* evaluations of new technologies and in *ex post* evaluations of completed building- and fire-related research projects.

---

[40] Civil Engineering Research Foundation. 1993. *A Nationwide Survey of Civil Engineering-Related R&D*. Report no. 93-5006. Washington, DC: Civil Engineering Research Foundation.

[41] Although the standardized classification would be focused on identifying benefits and costs associated with building- and fire-related research projects, it would be generic to the extent that scientific research in general produces types of benefits and costs that are similar across technology areas. Thus the standardized classification will be applicable to many non-building- and non-fire-related technologies as well.

6.2.2 Factors Affecting the Diffusion of New Technologies

Reliable estimates of the data input values for the standardized evaluation methods cannot be made without some relatively sound basis for predicting the rate of diffusion and the ultimate level of adoption of a new technology. The rate of diffusion and the ultimate level of adoption of a new technology depend on many factors. Uncertainty about how a new technology will perform affects both its rate of diffusion and its ultimate level of adoption.

Two factors over which a research laboratory exerts some control and which have the potential to reduce uncertainty about new technologies are: (1) the research laboratory's information dissemination efforts; and (2) the research laboratory's participation in standards-making organizations. Additional research on these two factors is warranted for a number of reasons. First, the characteristics of information are changing dramatically. With the advent of the World Wide Web and the increased acceptance of electronic media, the fruits of research may be quickly and widely disseminated. The reliance on printed reports sent to a targeted audience as the sole vehicle for communication is being eclipsed by other means of information dissemination. This transition needs to be studied to ensure that the information dissemination strategy which emerges is tailored to the needs of the research laboratory's customer base. Second, research results in the form of technical reports often provide the basis for standards. Consequently, information dissemination efforts may be used to leverage private-sector activities aimed at standardization. Finally, standards are an important means for disseminating information on expected levels of performance and for measuring key performance characteristics (e.g., through the use of standard practices, specifications, and test methods). For new technologies, acceptance by a standards-making organization should lead both to higher rates of diffusion and to higher levels of adoption. Consequently, research on how a research laboratory's participation in standards-making organizations (e.g., those concerned with building codes and standards) affects the rates of diffusion and levels of adoption of new technologies will enable it to improve the efficiency with which it allocates staff and other resources to these activities.

6.2.3 Conducting *Ex Ante* Evaluations with Scheduled Follow-ups

The case study of the FSES presented in this report and the two case studies on building technology presented in the companion document are *ex post* evaluations of completed fire- and building-related research projects. From an analysis perspective, an *ex ante* evaluation of a new technology poses several challenges which are absent in an *ex post* evaluation of a completed research project. The biggest challenge involves the diffusion of a new technology (i.e., predicting the rate of diffusion and the ultimate level of adoption). Although two of the factors affecting the diffusion of a new technology were discussed in the previous suggestion for further research, much can be learned about the diffusion process by performing *ex ante* evaluations with the understanding that scheduled follow-up evaluations will be conducted.

The follow-up evaluation focuses on answering several key questions. These questions are aimed at learning more about the research laboratory's role and ability to move research results towards the market place *and* about the way in which firms and households (i.e., the intended users of the new technology) adopt and make use of the new technology. First, did the new technology become available to the intended users when anticipated in the *ex ante* evaluation? Second, is the new technology being adopted at the rate anticipated? Third, are the users which adopt the new technology experiencing the types of changes anticipated (e.g., cost savings, increased durability, increased reliability)? Finally, are the types of users which adopt the new technology the same as anticipated? If these questions are asked and the answers are reviewed, critiqued, and fed back to research managers, *ex ante* evaluations will become a key link in the research laboratory's continuous improvement efforts.

6.2.4 Evaluations Based on Multiattribute Decision Analysis

Many research investment alternatives differ in characteristics that decision makers consider important but that are not readily expressed in monetary terms. Because the five standardized evaluation methods consider only monetary benefits and monetary costs associated with alternative research investments, their application does not reflect the importance of these non-financial characteristics to the decision maker. When non-financial characteristics are important, decision makers need a method that accounts for these characteristics (also called attributes) when choosing among alternative research investments. A class of methods that can accommodate non-monetary benefits and costs is multiattribute decision analysis.[42]

The analytical hierarchy process (AHP) is one of a set of multiattribute decision analysis methods that considers non-financial characteristics in addition to common economic evaluation measures (e.g., the five standardized evaluation methods) when evaluating project alternatives. The AHP has several important strengths: (1) it is well-known and well-reviewed in the literature; (2) it includes an efficient attribute weighting process; (3) it incorporates hierarchical descriptions of attributes; (4) its use is facilitated by available software; and (5) it has been accepted by ASTM as a standard practice for investments related to buildings and building systems.[43]

The AHP and its associated software represent a powerful and versatile management tool. How to apply this management tool most productively in a research environment suggests additional research in two areas. First, what will be the relationship between the AHP software and the standard classification proposed earlier? Second, how will the AHP be used to assess fit to mission, to set priorities, or to evaluate performance against some other management goal? If research is conducted on the two topics just outlined, the AHP-based tool which emerges will provide a format for: (1) efficiently and reliably screening and selecting among alternative research investments (e.g., by embedding information from the standard classification of research benefits and costs, information on fit to mission, and on research priorities); (2) selecting research projects for in-depth analyses, either of the *ex ante* or *ex post* type of evaluation; and (3) selecting and scheduling follow-up evaluations.

---

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

[43]American Society for Testing and Materials. 1995. *Standard Practice for Applying Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems.* E 1765. Philadelphia, PA: American Society for Testing and Materials.

Appendix A. How the Fire Safety Evaluation System Measures Safety Performance

The FSES, as it is embodied in Chapter 3 of NFPA 101A, consists of four pages of worksheets containing seven tables (see exhibits A through A-4). FSES tables 1 through 3 on the first worksheet (see exhibit A-1) and FSES table 6 on the fourth worksheet (see exhibit A-4) use existing service activities to determine the level of safety performance required to be equivalent to the 1994 edition of the Life Safety Code.

The second worksheet, FSES table 4 (see exhibit A-2), provides the foundation for the cost estimating software described in section 3.4 and appeneix B. It gives the scores associated with all possible states within each of the 13 building safety parameters.[44] To evaluate each fire zone,[45] it is first necessary to identify the appropriate value associated with each of the 13 building safety parameters. The existing condition of the fire zone is then determined by recording each of these values on FSES table 4; the level of each building safety parameter is determined by the worst-case condition within the fire zone. Referring once again to exhibit A-2, it can be seen that those states which have a higher score represent potential retrofits. For example, if in the current state the flame spread rating on interior finishes in the corridor and exits is Class C, then both Class B and Class A flame spread ratings are potential retrofits.

The third worksheet, FSES table 5 (see exhibit A-3), provides a means for calculating the score associated with the four safety redundancy requirements. The four safety redundancy requirements are: (1) Containment Safety; (2) Extinguishment Safety; (3) People Movement Safety; and (4) General Safety. In order to calculate the score for each of the safety redundancy requirements, it is necessary to enter the state value identified in FSES table 4 as corresponding to the existing state of the building safety parameter into the appropriate spaces in the coded rows of exhibit A-3. No values are entered in the shaded spaces in exhibit A-3. Each of the four columns is then summed to get an overall score. These scores are labeled S_1, S_2, S_3, and S_4 in exhibit A-3.

The last tables (see exhibit A-4) provide the means for determining whether or not the fire zone generates a level of fire safety equivalent to that of the Life Safety Code. Basically, this is done by recording the four scores calculated in FSES table 5. The evaluation then selects the values from FSES table 6 for Containment Safety, Extinguishment Safety, and People Movement Safety for the appropriate building type and fire zone location.[46] The occupancy risk factor calculated through reference to FSES table 1 through 3 is then recorded. Based on these two sets of numbers, it is possible to test if the fire zone provided a level of safety equivalent to the Life Safety Code. This test is performed by determining if the difference between the first set of numbers, safety provided, and the second set of numbers, safety required, is greater than or equal to zero. In the event that the fire zone fails to pass the equivalency test, it will be necessary to select a retrofit strategy (i.e., a plan of correction) that will ensure the building safety parameters produce scores which match or exceed each of the four safety redundancy requirements.

---

[44] Each of the 13 building safety parameters are subdivided into a set of states. Each state has associated with it a score which best reflects either the relative risk posed by the state or its net contribution to life safety. More specifically, negative values reflect greater risks whereas positive values contribute toward a higher level of safety within the fire zone. The FSES treats a value of zero as "safety neutral."

[45] A fire zone is defined as a space separated from all other spaces by floors, horizontal exits, or smoke barriers.

[46] Since each of the 13 building safety parameters has a unique state which corresponds to prescriptive compliance, it is therefore possible to compute the score, or level of safety, provided by the Life Safety Code for Extinguishment, Containment, and People Movement Safety. These scores provide the basis for FSES table 6.

Exhibit A-1. Occupancy Risk Factor Calculation Worksheets

Table 1. Occupancy Risk Parameter Factors

Risk Parameters — **Risk Factor Values**

1. Patient Mobility (M)

Mobility Status	Mobile	Limited Mobility	Not Mobile	Not Movable
Risk Factor	1.0	1.6	3.2	4.5

2. Patient Density (D)

No. of Patients	1-5	6-10	11-30	>30
Risk Factor	1.0	1.2	1.5	2.0

3. Zone Location (L)

Floor	lst	2nd or 3rd	4th to 6th	7th and Above	Basements
Risk Factor	1.1	1.2	1.4	1.6	1.6

4. Ratio of Patients to Attendants (T)

Patients / Attendant	1-2 / 1	3-5 / 1	6-10 / 1	≥10 / 1	One or † More / None
Risk Factor	1.0	1.1	1.2	1.5	4.0

5. Patient Average Age (A)

Age	Under 65 Years and Over 1 Year	65 Years and Over 1 Year and Younger
Risk Factor	1.0	1.2

†A risk factor of 4.0 is charged to any zone that houses patients without any staff in immediate attendance.

Table 2. Occupancy Risk Factor Calculation

	M		D		L		T		A		F
Occupancy Risk	☐	x	☐	x	☐	x	☐	x	☐	=	☐

Table 3A. (New Buildings)

	F		R
1.0 x	☐	=	☐

Table 3B. (Existing Buildings)

	F		R
0.6 x	☐	=	☐

Exhibit A-2. Worksheet for Determining the Values of the Safety Parameters

Table 4. Safety Parameter Values

Safety Parameters	Parameter Values						
1. Construction	Combustible Types III, IV, and V				Noncombustible Types I and II		
Floor or Zone	000	111	200	211+2HH	000	111	222, 322, 433
First	-2	0	-2	0	0	2	2
Second	-7	-2	-4	-2	-2	2	4
Third	-9	-7	-9	-7	-7	2	4
4th and Above	-13	-7	-13	-7	-9	-7	4

Safety Parameters					
2. Interior Finish (Corridors and Exits)	Class C	Class B	Class A		
	-5(0)[f]	0(3)[f]	3		
3. Interior Finish (Rooms)	Class C	Class B	Class A		
	-3(1)[f]	1(3)[f]	3		
4. Corridor Partitions/Walls	None or Incomplete	<1/3 hr	≥ 1/3 <1 hr	≥ 1 hr	
	-10(0)[a]	0	1(0)[a]	2(0)[a]	
5. Doors to Corridor	No Door	<20 min FPR	≥ 20 min FPR	≥ 20 min FPR and Auto Clos.	
	-10	0	1(0)[d]	2(0)[d]	

Safety Parameters						
6. Zone Dimensions	Dead End			No Dead Ends > 30' and Zone Length is:		
	>100'	>50' to 100'	30' to 50'	>150'	100' to 150'	<100'
	-6(0)[b]	-4(0)[b]	-2(0)[b]	-2	0	1

Safety Parameters					
7. Vertical Openings	Open 4 or More Floors	Open 2 or 3 Floors	Enclosed with Indicated Fire Resist:		
			<1 hr	≥ 1 hr < 2 hr	≥ 2 hr
	-14	-10	0	2(0)[e]	3(0)[e]

Safety Parameters					
8. Hazardous Areas	Double Deficiency		Single Deficiency		No Deficiencies
	In Zone	Outside Zone	In Zone	In Adjacent Zone	
	-11	-5	-6	-2	0

Safety Parameters				
9. Smoke Control	No Control	Smoke Barrier Serves Zone	Mech. Assisted Systems by Zone	
	-5(0)[c]	0	3	

(Continued on next page)

Exhibit A-2. Worksheet for Determining the Values of the Safety Parameters (continued)

Table 4. Safety Parameter Values (continued)

Safety Parameters	Parameter Values				
10. Emergency Movement Routes	<2 Routes	Multiple Routes			
		Deficient	W/O Horizontal Exit(s)	Horizontal Exit(s)	Direct Exit(s)
	-8	-2	0	1	5
11. Manual Fire Alarm	No Manual Fire Alarm		Manual Fire Alarm		
			W/O F.D. Conn.	W/F.D. Conn.	
	-4		1	2	
12. Smoke Detection and Alarm	None	Corridor Only	Rooms Only	Corridor and Habit. Spaces	Total Spaces In Zone
	0(3)[g]	2(3)[g]	3(3)[g]	4	5
13. Automatic Sprinklers	None	Corridor and Habit. Space	Entire Building		
	0	8	10		

NOTES: [a]Use (0) where Parameter 5 is -10.
[b]Use (0) where Parameter 10 is -8.
[c]Use (0) on floor with less than 31 patients (existing buildings only).
[d]Use (0) where Parameter 4 is -10.
[e]Use (0) where Parameter 1 is based on first floor zone or on an unprotected type of construction (columns marked "U").
[f]Use ( ) if the area of Class B or C interior finish in the corridor and exit or room is protected by automatic sprinklers and Parameter 13 is 0.
[g]Use this value in addition to Parameter 13 if the entire zone is protected with quick-response automatic sprinklers.

For SI units: 1 ft x 3.048 = 1 m.

Exhibit A-3. Worksheet for Calculating Containment Safety, Extinguishment Safety, People Movement Safety, and General Safety

Table 5. Individual Safety Evaluations				
Safety Parameters	**Containment Safety (S_1)**	**Extinguishment Safety (S_2)**	**People Movement Safety (S_3)**	**General Safety (S_4)**
1. Construction				
2. Interior Finish (Corr. and Exit)				
3. Interior Finish (Rooms)				
4. Corridor Partitions/Walls				
5. Doors to Corridor				
6. Zone Dimensions				
7. Vertical Openings				
8. Hazardous Areas				
9. Smoke Control				
10. Emergency Movement Routes				
11. Manual Fire Alarm				
12. Smoke Detection and Alarm				
13. Automatic Sprinklers			÷2=	
Total Value	S_1 =	S_2 =	S_3 =	S_4 =

Exhibit A-4. Worksheets for Evaluating Fire Zone Safety Equivalency

Table 6. Mandatory Safety Requirements (For Use in Hospitals or Nursing Homes)

Zone Location	Containment (S_a)		Extinguishment (S_b)		People Movement (S_c)	
	New	Exist.	New	Exist.	New	Exist.
1st story	11	5	15(12)[A]	4	8(5)[A]	1
2nd or 3rd story[B]	15	9	17(14)[A]	6	10(7)[A]	3
4th story or higher	18	9	19(16)[A]	6	11(8)[A]	3

[A]Use ( ) in zones that do not contain patient sleeping rooms.
[B]For a 2nd story zone location in a *sprinklered* EXISTING facility, as an alternative to the mandoratory safety requirements values set specified in this table, the following mandatory values *set* shall be permitted to be used:
$S_a = 7$ and $S_b = 10$ and $S_c = 7$.

Table 7. Zone Fire Safety Equivalency Evaluation

						Yes	No
Containment Safety (S_1)	minus	Mandatory Containment (S_a)	≥	0	S_1 ☐ - S_a ☐ = C ☐		
Extinguishment Safety (S_2)	minus	Mandatory Extinguishment (S_b)	≥	0	S_2 ☐ - S_b ☐ = E ☐		
People Movement Safety (S_3)	minus	Mandatory People Movement (S_c)	≥	0	S_3 ☐ - S_c ☐ = P ☐		
General Safety (S_4)	minus	Occupancy Risk (R)	≥	0	S_4 ☐ - R ☐ = G ☐		

Appendix B. Cost Estimating Software: Mathematical Formulation

The core concept behind the software is a mathematical technique known as linear programming. In its usual context, linear programming deals with the problem of allocating limited resources among competing activities in an optimal way. The foundation of any linear programming problem is a mathematical model which describes the problem of concern. In this case, the mathematical model is the FSES, as specified by exhibits A-1 through A-4. The term "linear" refers to the requirement that all mathematical functions in the model are linear. The reason why all mathematical functions involved in the model are linear may be explained through reference to the FSES. In FSES table 4 (see exhibit A-2), there is a unique level for each building safety parameter possible at any given time in any given fire zone. This is due to the requirement that the most hazardous level associated with each building safety parameter within the fire zone under analysis determines its score. The score of each of the four safety redundancy requirements (Containment Safety, Extinguishment Safety, People Movement Safety, and General Safety) is achieved by inserting the appropriate values (e.g., the current state or a potential retrofit) from FSES table 4 into FSES table 5 and summing them (see exhibit A-3).

To capture the full range of entries in FSES table 4, one may think of each entry as a transition. Transitions from the current state to entries in FSES table 4 which result in higher scores represent potential retrofits. Transitions from the current state to entries in FSES table 4 which result in lower scores represent precluded retrofits. A transition from the current state to the current state reflects maintenance of the *status quo*. Each transition has a cost associated with it; these "transition costs" are constructed to encompass all possibilities.

The notation for exposition of the model is based on the FSES worksheets (see exhibits A-1 through A-4). Consider the numbered building safety parameters of FSES table 4 as rows, and denote them as i.[47] Consider the columns of FSES table 4 as states, and denote them by j.[48] The problem thus becomes one of minimizing the cost of compliance, where the objective function is a linear combination of the state variables, X_{ij}, and the transition costs, C_{ij}. In particular, the state variable, X_{ij}, takes on a value of 1 if the j^{th} state is in the solution and is 0 otherwise.

The problem may now be expressed algebraically as:

$$\textit{minimize} \sum_{i=1}^{13} \sum_{j=j_{\min}^{i}}^{j=j_{\max}^{i}} X_{ij}\, C_{ij} \qquad \text{B.1}$$

subject to:

[47] Although the first building safety parameter, construction, contains four rows, only one row is appropriate for a given fire zone.

[48] State variables are numbered consecutively from 1 to 56 (e.g., construction consists of state variables 1 through 7, and automatic sprinklers consists of state variables 54 through 56).

(a) a multiple-choice constraint for each of the 13 building safety parameters (i.e., one and only one state for each parameter may be included in the solution)

$$\sum_{j=j_{\min}^{i}}^{j=j_{\max}^{i}} X_{ij} = 1 \quad for \quad i = 1, \ldots, 13 \qquad \text{B.2a}$$

and

(b) a performance constraint for each of the 4 safety requirements

$$\sum_{i=1}^{13} \sum_{j=j_{\min}^{i}}^{j=j_{\max}^{i}} X_{ij} V_{ij} W_{ik} - Y_k = R_k \quad for \ k = 1, \ldots, 4 \qquad \text{B.2b}$$

where

i	=	1, ..., 13
j^{i}_{min}	=	the minimum state variable number associated with building safety parameter i;
j^{i}_{max}	=	the maximum state variable number associated with building safety parameter i;
k	=	the column of FSES table 5, whose value is 1 for Containment Safety, 2 for Extinguishment Safety, 3 for People Movement Safety, and 4 for General Safety;
X_{ij}	=	the state variable, whose value is specified by $X_{ij} \in \{0,1\}$;
C_{ij}	=	the transition cost of moving from the current state (i.e., pre-retrofit condition) of the i^{th} building safety parameter to the j^{th} state;
V_{ij}	=	the state variable's value as stipulated in FSES table 4;
W_{ik}	=	a weighting factor for the state variable's value (0, ½, or 1) as stipulated in FSES table 5;
Y_k	=	a non-negative surplus value; and
R_k	=	the safety requirement as stipulated in FSES tables 3 and 6.

The mathematical formulation specified by eqns B.1, B.2a, and B.2b, indicates that the problem is a binary (0-1) integer program. However, due to the structure imposed on the problem by the 13 multiple-choice constraints, the integrality requirements may be relaxed to non-negativity constraints. The associated linear programming relaxation is easily solved through application of the revised simplex method.

It should be noted that the linear programming relaxation may not produce an all integer solution. The software thus contains a post processor to impose integrality and to ensure that any of the interdependencies in FSES table 4 (see exhibit A-2) do not render the problem infeasible.

References

American Health Care Association. 1995. *Facts and Trends: The Nursing Facility Sourcebook.* Washington, DC: American Health Care Association.

American Hospital Association. 1994. *Hospital Statistics.* 1994-1995 Edition. Chicago, IL: American Hospital Association.

American Society for Testing and Materials. 1995. *Standard Practice for Applying Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems.* E 1765. Philadelphia, PA: American Society for Testing and Materials.

American Society for Testing and Materials (ASTM). Third Edition, 1994. *ASTM Standards on Building Economics.* Philadelphia, PA: American Society for Testing and Materials.

Chapman, Robert E., Phillip T. Chen, and William G. Hall. 1979. *Economic Aspects of Fire Safety in Health-Care Facilities: Guidelines for Cost-Effective Retrofits.* NBSIR 79-1902. Gaithersburg, MD: National Bureau of Standards.

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

Chapman, Robert E., and William G. Hall. 1983. *User's Manual for the Fire Safety Evaluation System Cost Minimizer Computer Program.* NBSIR 83-2797. Gaithersburg, MD: National Bureau of Standards.

Civil Engineering Research Foundation. 1993. *A Nationwide Survey of Civil Engineering-Related R&D.* Report No. 93-5006. Washington, DC: Civil Engineering Research Foundation.

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

Federal Register 45, No. 146, July 28, 1980: 50264-5.

Feeley, R., D.C. Walsh, and J.E. Fielding. 1978. "Structural Codes and Patient Safety: Does Strict Compliance Make Sense?" *American Journal of Law and Medicine*, pp. 447-454.

Good, Mary, and Arati Prabhakar. 1994. "Foreword." In Mark Bello and Michael Baum, *Setting Priorities and Measuring Results at the National Institute of Standards and Technology.* Gaithersburg, MD: National Institute of Standards and Technology.

Lewis, H.L. 1975. "The Uncertain Future of JCAH." *Modern Healthcare*, pp. 20-4.

Marshall, Harold E. 1995. *Least-Cost Energy Decisions for Buildings—Part III: Choosing Economic Evaluation Methods Video Training Workbook.* NISTIR 5604. Gaithersburg, MD: National Institute of Standards and Technology.

References (continued)

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

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

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

Marshall, Harold E., and Rosalie T. Ruegg. 1979. *Efficient Allocation of Research Funds: Economic Evaluation Methods with Case Studies in Building Technology.* NBS Special Publication 558. Gaithersburg, MD: National Bureau of Standards.

National Fire Protection Association (NFPA). 1995. *Guide on Alterative Approaches to Life Safety.* NFPA 101A. Quincy, MA: National Fire Protection Association.

National Fire Protection Association (NFPA). 1994. *Life Safety Code.* NFPA 101, 1994 Edition. Quincy, MA: National Fire Protection Association.

National Fire Protection Association (NFPA). 1992. *Alternative Approaches to Life Safety.* NFPA 101M. Quincy, MA: National Fire Protection Association.

Nelson, H.E., and A.J. Shibe. 1980. *A System for Fire Safety Evaluation of Health-Care Facilities.* NBSIR 78-1555-1. Gaithersburg, MD: National Bureau of Standards.

Nelson, H.E., and A.J. Shibe. 1978. *A System for Fire Safety Evaluation of Health-Care Facilities.* NBSIR 78-1555. Gaithersburg, MD: National Bureau of Standards.

Norris, Gregory A., and Harold E. Marshall. 1995. *Multiattribute Decision Analysis Method for Evaluating Buildings and Building Systems.* NISTIR 5663. Gaithersburg, MD: National Institute of Standards and Technology.

Reich, Robert W. 1989. "The Quiet Path to Technological Preeminence." *Scientific American* (October), pp. 41-7.

Ruegg, Rosalie T., and Harold E. Marshall. 1990. *Building Economics: Theory and Practice.* New York, NY: Chapman and Hall.

Weber, Stephen F., and Barbara C. Lippiatt. 1994. *ALARM 1.0—Decision Support Software for Cost-Effective Compliance with Fire Safety Codes.* NISTIR 5554. Gaithersburg, MD: National Institute of Standards and Technology.

References (continued)

Wright, Richard N., Arthur H. Rosenfeld, and Andrew J. Fowell. 1995. *Construction and Building: Federal Research and Development in Support of the U.S. Construction Industry.* Washington, DC: National Science and Technology Council.