Designation: E2204 – 15

Standard Guide for Summarizing the Economic Impacts of Building-Related Projects[1]

This standard is issued under the fixed designation E2204; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Quantitative descriptions of economic impacts are a basic requirement in many organizations for evaluating budget requests and the value of a project to the organization. Several measures of economic performance are available for evaluating building-related investments. These measures include, but are not limited to, life-cycle cost, the benefit-to-cost ratio, adjusted internal rate of return, and net benefits. This guide provides a generic format for presenting these economic measures of building-related investments.

1. Scope

1.1 This guide covers a generic format for summarizing the economic impacts of building-related projects.

1.2 The guide provides technical persons, analysts, and researchers a tool for communicating project impacts in a condensed format to management and non-technical persons.

1.3 The generic format described in this guide calls for a description of the significance of the project, the analysis strategy, a listing of data and assumptions, and a presentation of the key economic measures of project impact.

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E631 Terminology of Building Constructions
E833 Terminology of Building Economics
E917 Practice for Measuring Life-Cycle Costs of Buildings and Building Systems
E964 Practice for Measuring Benefit-to-Cost and Savings-to-Investment Ratios for Buildings and Building Systems
E1057 Practice for Measuring Internal Rate of Return and Adjusted Internal Rate of Return for Investments in Buildings and Building Systems
E1074 Practice for Measuring Net Benefits and Net Savings for Investments in Buildings and Building Systems
E1121 Practice for Measuring Payback for Investments in Buildings and Building Systems
E1369 Guide for Selecting Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Buildings and Building Systems
E1699 Practice for Performing Value Engineering (VE)/Value Analysis (VA) of Projects, Products and Processes
E1765 Practice for Applying Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems
E2506 Guide for Developing a Cost-Effective Risk Mitigation Plan for New and Existing Constructed Facilities

2.2 *Adjuncts:*

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

2.3 *ASTM Software Product:*

MNL 29 Software to Support ASTM E1765: Standard Practice for Applying Analytical Hierarchy Process (AHP) to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems[2]

3. Terminology

3.1 *Definitions*—For definitions of general terms related to building construction used in this guide, refer to Terminology

[1] This guide is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.81 on Building Economics.

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

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

E631; and for general terms related to building economics, refer to Terminology E833.

4. Summary of Guide

4.1 This guide presents a standard format for presenting the economic impacts of building-related projects. It includes the entire range of private and public construction projects, as well as research related to those projects.

4.2 The generic format provided in this guide helps decision makers and managers understand the background and objectives of a project, the data from which impacts were calculated, how impact was measured, and the significance of the project's measures of worth.

5. Significance and Use

5.1 This guide reduces the time and effort to communicate the findings of project impact studies and improves the quality of communication between those who measure economic impacts and those who evaluate and interpret them.

5.2 Following the guide assures the user that relevant economic information on the project is included in a summary format that is understandable to both the preparer and user.

5.3 Since the standard guide provides a consistent approach to reporting the economic impacts of projects, it facilitates the comparison of economic studies across projects and over time.

5.4 The guide focuses on projects in construction and building-related research. It applies to government as well as private projects. And while the examples treat building-related projects, the guide is applicable to non-building-related projects as well.

5.5 Building-sector users of this guide include building owners and managers, private-sector construction companies, research groups in building and construction industry trade associations, parties to public-sector construction projects, and government laboratories conducting building-related research.

5.6 Use the guide to summarize the results of economic impact studies that use Practices E917 (Life-Cycle Costs), E964 (Benefit-to-Cost and Savings-to-Investment Ratios), E1057 (Internal Rate of Return and Adjusted Internal Rate of Return), E1074 (Net Benefits and Net Savings), E1121 (Payback), E1699 (Value Engineering/Value Analysis), and E1765 (Analytical Hierarchy Process for Multiattribute Decision Analysis).

5.7 Use this guide in conjunction with Guide E1369 to summarize the results of economic impact studies involving natural or man-made hazards, or both, that occur infrequently but have significant consequences.

5.8 Use the guide to summarize the impacts of projects that affect exclusively initial costs, benefits, or savings, as well as projects that affect life-cycle costs, benefits, or savings.

NOTE 1—Examples of projects dealing exclusively with initial costs, benefits, or savings include design modifications or innovative construction practices that reduce labor or material costs, reduce construction duration, or increase construction productivity, but leave future costs, benefits, or savings unchanged.

5.9 Use the guide to summarize the impacts of projects that affect parties that are internal to the organization preparing the summary as well as projects that affect not only the organization preparing the summary but also groups external to the organization.

NOTE 2—Projects whose impacts are internal only correspond to situations where the organization preparing the summary bears all of the costs and receives all of the benefits or savings, or both, from the project. Examples include, but are not limited to, the use of innovative construction practices or alternative building materials, components, or systems that reduce initial costs or future costs, or both, to the building owner.

NOTE 3—Projects with a public-sector component frequently have impacts that reach beyond the organization preparing the summary. Examples include, but are not limited to, building-related research conducted by government laboratories, projects aimed at mitigating the consequences of natural or man-made hazards, or both, that have the potential to cause collateral damage, and highway and bridge constructions that affect traffic patterns.

5.10 There is no limitation to the use of the guide in facilitating communication between project analysts and project managers and other decision makers. Substantial benefits from using the guide, however, are likely to come from its application in a large institution, such as a federal agency, where many projects are competing for funding, and a systematic presentation of results that can be compared across projects and agencies is needed to allocate efficiently scarce funds.

6. How to Use This Guide

6.1 The generic format for summarizing project impacts is outlined in Fig. 1.

6.1.1 To promote a better understanding of the information called for in Fig. 1, the numbered headings in the table are cross-referenced to the subsections of 6.2. Specifically, the information called for under Headings 1.a and 1.b is covered in 6.2.1, the information called for under Heading 2 is covered in 6.2.2, and the information called for under Headings 3.a, 3.b, and 3.c is covered in 6.2.3.

6.2 *Presentation and Analysis of the Results of an Economic Impact Assessment*—The presentation and analysis of the results of an economic impact assessment 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 will stand up under close scrutiny. This section describes a generic format and procedure for summarizing the results of an economic impact assessment that meets the two previously cited conditions. The generic format is built upon the following three factors: (*1*) why the project is important; (*2*) how the analysis strategy was employed; and (*3*) how the key measures are calculated, summarized, and traced to relevant standards, codes, and regulations. These factors, taken together, constitute a three-step procedure for summarizing the results of an economic impact assessment. Six case studies are used to illustrate what a completed impact assessment using the generic format would look like. The six case studies were chosen so that there is at least one case study for each combination of affected parties (see 5.9) and affected costs, benefits, or savings (see 5.8), and at least one involving natural or man-made hazards, or both. The six case studies are presented in Appendix X1 – Appendix X6. Appendix X1 is

1.a Significance of the Project:

Describe why the project is important and how the organization became involved.

Describe the changes brought about by the organization.

1.b Key Points:

Highlight two or three key points which convey why this project is important.

2. Analysis Strategy:

Describe how the present value of ***total benefits (savings)*** *both internal and external stemming from all contributions to the project was determined.*

Describe how the present value of ***total costs*** *both internal and external stemming from all contributors to the project was determined.*

Describe how the present value of ***net benefits (savings)*** *both internal and external was determined.*

Describe how the present value of ***total benefits (savings)*** *attributable to the organization was determined.*

Describe how the present value of ***total costs*** *attributable to the organization was determined.*

Describe how the present value of ***net benefits (savings)*** *attributable to the organization was determined.*

Describe how any ***additional measures*** *were calculated and how the organization's contribution was determined.*

Summarize key data and assumptions: (a) base year; (b) length of study period; (c) discount rate or minimum acceptable rate of return; (d) data; and (e) other.

3.a Calculation of Benefits, Costs, and Additional Measures:

Total Benefits (Savings):
Report the present value of the total benefits (savings) attributable to the organization.

Total Costs:
Report the present value of the total costs attributable to the organization.

Net Benefits (Savings):
Report the present value of net benefits (savings) attributable to the organization.

Additional Measures:
Report the values of any additional measures calculated.

3.b Key Measures:

Report the calculated value of the Present Value of Net Benefits **or** *the Present Value of Net Savings* attributable to the organization carrying out the project or conducting the research **and** at least one of the following:

- ❖ Benefit-to-Cost Ratio *or Savings-to-Investment Ratio*
- ❖ Adjusted Internal Rate of Return

3.c Traceability

Cite references to specific ASTM standard practices, ASTM adjuncts, or any other standards, codes, or regulations used.

FIG. 1 Format for Summarizing the Economic Impacts of Building-Related Projects

based on a private-sector commercial building application where all impacts are internal and only initial costs are relevant. Appendix X2 is based on a highway project where both internal and external impacts are important and only initial costs are relevant. Appendix X3 is based on an energy conservation project where all impacts are internal and both initial and future costs and future savings are included. Appendix X4 is based on a public-sector research application where both internal and external impacts are important and past, present, and future costs, benefits, and savings are included.[4] Appendix X5 is based on a case study on the application of life-cycle cost analysis to homeland security issues in constructed facilities, where both internal and external impacts are important and both initial and future costs and future savings are included.[5] Appendix X6 is based on a case-study example that was designed to illustrate the three-step protocol (Guide E2506), and summarizes a public evaluation of alternative approaches to minimizing the damage from intentionally-set fires in at-risk communities in Michigan, where both internal and external impacts are important, and both present and future costs, benefits, and savings are included.[6] While the case-study is based on a real-world example and uses actual data, its description, assumptions, and findings are meant to highlight elements of the three-step protocol rather than to justify certain actions or policies in Michigan. Appendix X6 is designed to demonstrate a summarization of the economic analysis resulting from the use of the three-step protocol.

6.2.1 *Why the Project Is Important:*

6.2.1.1 Headings 1.a and 1.b in Fig. 1 set the stage for summarizing the results that follow. The information called for under these headings provides the opportunity to discuss the objective of the project and why doing this project was noteworthy.

6.2.1.2 Heading 1.a in Fig. 1 calls for a short but concise summary of the project. Make the summary sufficiently detailed to enable senior management and non-technical readers to understand the significance of the project. The goal of the information presented under Heading 1.a is to clearly describe: (*1*) why the project is important and how the organization carrying out the project or conducting the research became involved; and (*2*) why some or all of the changes brought about were due to the organization's contribution.

6.2.1.3 The objective of Heading 1.b is to highlight two or three points which convey why this project is important. These points are intended for use as talking points by senior management when they make presentations to non-technical audiences or for use in press releases.

6.2.2 *How the Analysis Strategy Was Employed:*

6.2.2.1 Heading 2 of Fig. 1, analysis strategy, has two components. The first component focuses on documenting the steps taken to ensure that the analysis strategy is logical and complete. The second component places particular emphasis on summarizing the key data elements and associated assumptions needed to calculate the values reported under Headings 3.a and 3.b of Fig. 1.

6.2.2.2 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. Include any constraints that limited the scope of the study. The information called for under Heading 2 of Fig. 1 establishes an audit trail from the raw data, through data manipulations (for example, represented by equations and formulae), to the results. The audit trail consists of seven items that describe how to determine:

(1) The present value of total benefits (savings) both internal and external stemming from all contributors to the project under study, any benefits (savings) to users of products (materials, equipment, software, or procedures) stemming from the project under study, and any third parties affected positively by either the project or the use of products stemming from the project (see Practice E917 for instructions on how to compute present values);

(2) The present value of total costs for all contributors to the project under study, any costs to users of products stemming from the project under study, and any third parties affected negatively by either the project or the use of products stemming from the project;

(3) The present value of net benefits (savings) both internal and external stemming from all contributors to the project under study, any users of products stemming from the project under study, and any third parties affected by either the project or the use of products stemming from the project;

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

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

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

(7) The way in which any additional measures were calculated and how the organization's contribution was determined.

NOTE 4—If the focus of the analysis is on initial costs, benefits, and savings only, then all costs, benefits, and savings are already expressed in present value terms. Therefore, it is not necessary to discount costs, benefits, and savings to a present value, unless the base year for reporting the results is different from the year in which the costs, benefits, and savings occurred.

NOTE 5—If all impacts are internal to the organization preparing the summary, then items (*4*) through (*7*) suffice to establish the audit trail.

NOTE 6—If the focus of the analysis is on mitigating the consequences of natural or man-made hazards, or both, summarize how uncertainty was incorporated into the economic evaluation, and provide ranges of values or computed statistics for key measures of economic performance.

6.2.3 *How Key Measures Are Calculated, Summarized, and Traced:*

6.2.3.1 Heading 3.a of Fig. 1 calls for information that provides enough detail on the calculations of the key measures for others to understand how the calculated values were produced. Report summaries (for example, using text, mathematical expressions, tables, graphs, comparative statistics) of the following information:

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[4] Chapman, R. E., *Benefits and Costs of Research: A Case Study of Construction Systems Integration and Automation Technologies in Industrial Facilities*, NISTIR 6501, Gaithersburg, MD: National Institute of Standards and Technology, 2000.

[5] Chapman, R. E., *Application of Life-Cycle Cost Analysis to Homeland Security Issues in Constructed Facilities: A Case Study*, NISTIR 7025, Gaithersburg, MD: National Institute of Standards and Technology, 2003.

[6] Butry, D.T., "Economic Performance of Residential Fire Sprinkler Systems." *Fire Technology*, Vol 45, 2009, pp. 117–143.

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

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

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

(4) The values of any additional measures calculated.

6.2.3.2 Heading 3.b of Fig. 1 calls for the calculated values of the key benefit and cost measures, as well as any additional measures that are deemed appropriate. Report the calculated value of the present value of net benefits or the present value of net savings attributable to the organization's contribution and at least one of the following:

(1) The benefit-to-cost ratio or the savings-to-investment ratio; or

(2) The adjusted internal rate of return.

NOTE 7—If the focus of the analysis is on initial costs, benefits, and savings only, then report only the present value of net benefits or the present value of net savings attributable to the organization's contribution.

6.2.3.3 To ensure traceability, cite references to specific ASTM standard practices, ASTM adjuncts, or any other standards, codes, or regulations used. This information is called for under Heading 3.c of Fig. 1.

7. Report

7.1 The report for this guide is the summary impact statement outlined in Fig. 1 and described in 6.2. It is a stand-alone document designed to summarize the most important elements of a project impact study.

7.2 Attach the detailed technical study that underlies the summary impact statement to your report if the user requests complete background information on the project.

7.3 If you follow one of the standard economic practices listed in 5.6 for measuring economic impacts, establish traceability of your methodology by citing in your report the specific ASTM standard practice that you used.

8. Keywords

8.1 adjusted internal rate of return; analytical hierarchy process; benefit-to-cost ratio; building economics; economic evaluation methods; economic impacts; engineering economics; homeland security; impact assessment; internal rate of return; life-cycle costs; man-made hazards; measures of worth; multiattribute decision analysis; natural hazards; net benefits; net savings; payback; savings-to-investment ratio; value engineering

APPENDIXES

(Nonmandatory Information)

X1. PRIVATE-SECTOR COMMERCIAL BUILDING APPLICATION

X1.1 See Fig. X1.1.

1.a Significance of the Project:

In order to better evaluate alternative column designs during the Value Engineering Workshop Effort, a computer program was developed to design and estimate the cost of concrete columns. The primary purpose of the program was to enable design engineers to understand the cost implications of column shapes, concrete strengths, and reinforcement patterns.

Cost savings calculated by the computer program are limited to reductions in first cost to the client. The program does not estimate life-cycle costs or impacts to other stakeholders.

To test the new program, a high-rise office building, which had been designed but not yet constructed, was selected as a case study. The original design of the office building's structural system used a conventional strength and serviceability approach for square columns based upon prevailing industry practice. Trial runs of the program indicated that there might be substantial cost savings from a design with round columns and high-strength concrete. These cost savings were confirmed through a comparative cost analysis.

1.b Key Points:

The traditional approach to concrete column design is to use square columns. Since alternative column shapes may be more cost effective than square columns, a computer program was developed to evaluate the cost consequences of alternative concrete column shapes.

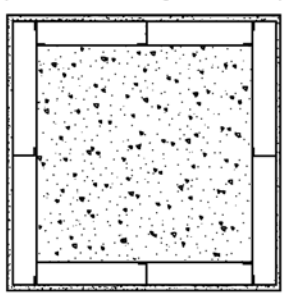
The computer program evaluates the implications of the following shape-related variables on total column cost:

- the use of high-strength concrete rather than conventional-strength concrete;
- the reinforcing pattern, including the main vertical elements as well as dowels and ties;
- the type of formwork; and
- the framing requirements or "furring out" to the finished surface.

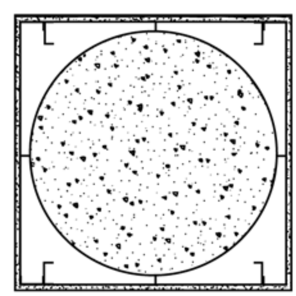
Application of the computer program to a high-rise office building found that a design with round columns and high-strength concrete might result in substantial cost savings vis-à-vis a traditional approach based on square columns.

2. Analysis Strategy:

Comparison of furring cost for square vs. round columns:



Square column with support framing



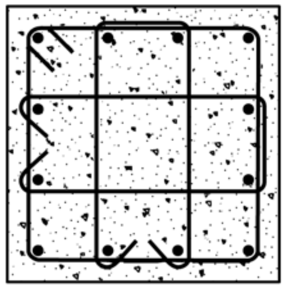
Round column with support framing

There is a misconception that round columns need framework (furring) to support drywall whereas drywall can be mounted directly on square columns. Since the concrete finish does not yield a plumb surface, contractors must build frameworks for square columns as well. ***Thus, there is no additional furring cost for round columns.***

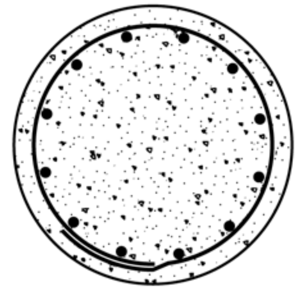
FIG. X1.1 Computer Program for Evaluating Concrete Column Shapes

2. Analysis Strategy (continued):

Reinforcing pattern for square vs. round column:



Ties for square columns are elaborate.



Ties for round columns are simpler.

3.a Calculation of Benefits, Costs and Additional Measures:

As Designed – Square Column 0.91 m × 0.91 m (36 in. × 36 in.)
Strength (KSI) 6.0 Percent Steel 1.92

	Cost	%
Concrete	$269.9	31.2
Formwork	$259.2	29.9
Reinforcing		
Main Vertical	$248.2	28.6
Dowels	$ 44.6	5.2
Ties	$ 44.5	5.1
Total Cost	$866.4	100.0

Recommended – Round Column 0.91 m dia. (36 in. dia.)
Strength (KSI) 9.0 Percent Steel 0.99

	Cost	%
Concrete	$295.1	52.8
Formwork	$ 93.6	16.8
Reinforcing		
Main Vertical	$108.5	19.5
Dowels	$ 46.9	8.4
Ties	$ 13.8	2.5
Total Cost	$557.9	100.0

Net Savings Calculations

Net Savings Per Column Per Floor: $866.40 – $557.90 = $308.50
Number of Floors = 35
Number of Columns Per Floor = 40

Total Net Savings: 35 × 40 × $308.50 = $431,900

3.b Key Measures:

Net Savings Attributable to the Use of Round Columns:

$431,900

Additional Benefits:

1. **Construction time with this change will be reduced by 40%.**
2. **It is safer to build round column forms than square column forms.**

3.c Traceability

- ACI Building Code ACI 318-83
- Chicago Building Code
- CRSI Handbook
- ASTM E1699 (Value Engineering)

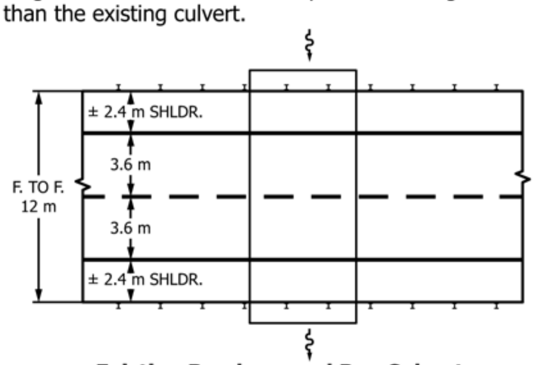
FIG. X1.1 Computer Program for Evaluating Concrete Column Shapes *(continued)*

X2. HIGHWAY PROJECT

X2.1 See Fig. X2.1.

1.a Significance of the Project:

An existing box culvert (see diagram below) is to be replaced with a new structure. The application of value engineering concepts chose use of precast culvert sections over a traditional cast-in-place concrete culvert. The reason for using precast culvert sections is to reduce the construction time and associated driver inconvenience. Due to the availability of discrete standard sizes for the precast culvert sections, the length of the culvert when completed will be greater than the existing culvert.



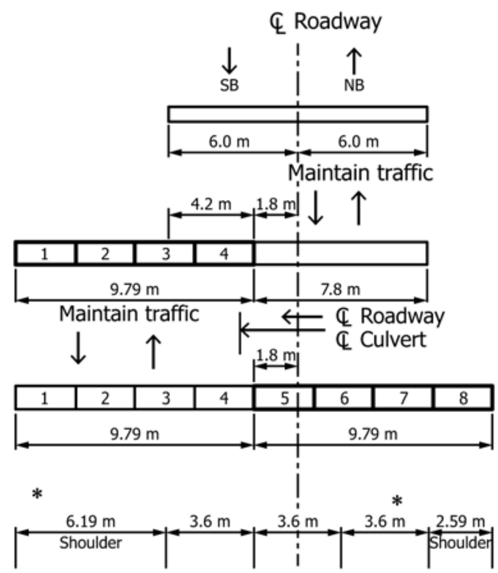
Existing Roadway and Box Culvert

Two methods are under consideration. The first method, referred to as the "As Designed," replaces each half of the existing culvert with four precast culvert sections. The second method, referred to as the "Alternative," first shifts the centerline of the roadway and then replaces the existing culvert in two stages; four precast culvert sections in the first stage, and four precast culvert sections in the second stage.

As Designed: Maintaining half of the existing culvert in the beginning will not give sufficient road width (7.8 m) to accommodate traffic during construction. Therefore, the roadway will be completely closed to traffic for 40 days and a 2.4 kilometre (1.5 mile) detour will be provided to accommodate traffic.

Alternative: The Alternative to the As Designed method is to shift the centerline of the new culvert 1.8 m west of the existing roadway centerline. Remove (12.0 – 7.8 = 4.2 m) of existing culvert and install four precast sections (half the width of new culvert). Maintain 7.8 m of existing roadway to accommodate traffic. Shift traffic and remove the remaining 7.8 m of the existing culvert and replace it with four precast sections.

Both the As Designed method and the Alternative method use eight precast sections to construct the new culvert. Thus, there is no difference in construction costs for the two methods. Both methods are estimated to cost $618,000. The construction sequence and traffic flow patterns for the Alternative method are illustrated in the diagram that appears below.



* Minimum required shoulder = 2.4 m

Alternative

1.b Key Points:

- Construction with precast culvert sections is faster than a traditional cast-in-place concrete culvert.
- Both methods use eight precast culvert sections, so there no change in design.
- Both methods have the same construction cost.
- The Alternative method does not require traffic to detour.

FIG. X2.1 Format for Summarizing the Design and Construction of Box Culverts

2. Analysis Strategy:

Driver Delay Costs = $(L / S_d) \times ADT \times N \times w$ (1)

Where,
L is the length of the detour,
S_d is the traffic speed over the detour route,
ADT is the average daily traffic,
N is the number of days of road work, and
w is the hourly time value of drivers.

Vehicle Operating Costs = $(L / S_d) \times ADT \times N \times r$ (2)

Where r is a weighted-average hourly vehicle cost similar to the hourly time value of drivers in equation (1), and the remaining parameters are the same as those in equation (1).

3.a Calculation of Benefits, Costs, and Additional Measures:

The As Designed method involves both the initial construction cost and user costs associated with the detour required to accommodate traffic during construction. Applying the equations for driver delay costs and vehicle operating costs, the user costs for the As Designed method are as follows:

Key Parameters:
- ADT: 12,800
- Detour Traffic: 2.4 kilometres (1.5 miles), For 40 days, Posted speed 48 kph (30 mph)
- Hourly time value of drivers: $10.73
- Hourly vehicle cost: $8.85

User Costs:
- Driver Delay Costs: (2.4/48) × 12,800 × 40 x $10.73 = $274,700
- Vehicle Operating Costs: (2.4/48) × 12,800 × 40 × $8.85 = $226,560
- Total User Costs: $501,260

As Designed:

Construction Cost:	$618,000
User Costs:	$501,260
Total Cost:	$1,119,260

Alternative:

Construction Cost:	$618,000
User Costs:	$0
Total Cost:	$618,000

Benefits and Additional Measures:

- Alternative method allows maintenance of traffic during construction.
- Detour road has restriction on load limits. Alternative method has no load restriction.
- User savings of $501,260 can be realized if the Alternative method is employed.

3.b Key Measures:

- No change in design.
- No increase in construction cost.
- Traffic is maintained.
- User cost savings = $501,260

3.c Traceability:

- AASHTO Guidelines
- MDOT Standards
- ASTM E1699 (Value Engineering)

FIG. X2.1 Format for Summarizing the Design and Construction of Box Culverts *(continued)*

X3. ENERGY CONSERVATION PROJECT

X3.1 See Fig. X3.1.

1.a Significance of the Project:

A 752.5 square metre (8100 square feet) NAVFAC office building in Dahlgren, VA, provides administrative space, counseling rooms, and records and research areas. Over time, the increased use of devices such as individual workstations and printers has increased the cooling requirements of the building.

The existing cooling system is still functional and could be maintained for another 20 years, but it requires frequent maintenance and consumes excessive amounts of energy. On very hot days it cannot meet the cooling demand, which results in loss of staff productivity. Therefore, it is not a viable long-term option.

The two upgrade alternatives considered are (1) a DX Split System central air conditioning unit with a new air distribution system, and (2) a connection to the central chilled water plant on the site, which would allow centralized maintenance. Electric baseboard heating will continue to be used for the facility. Given that the capital cost is lower for the DX Split System, we will use it as the base case.

1.b Key Points:

1. The objective of the project is to provide economical and effective air conditioning for the family housing office at the Dahlgren, VA, Naval Station.
2. Excessive consumption of energy, high operations, maintenance and repair (OM&R) costs, and reduced staff productivity make it imperative to replace the existing air-conditioning system.
3. Two upgrade alternatives are proposed:
   - a DX Split System and
   - connection to central chilled water plant

2. Analysis Strategy: How Key Measures are Estimated

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

(1) **Total Life-Cycle Costs** (PVLCC) for the Base Case (DX Split System (DX SS)) and for the alternative (Central Plant Connection (CPC)), including all costs of acquiring and operating the systems over the length of the study period. The selection criterion is lowest LCC.

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

Additional measures:

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

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

Data and Assumptions:

- The Base Date is June 2001.
- The existing cooling system is not a viable long-term option.
- The alternative with the lower first cost is designated the base case.
- The study period is 21 years and ends in May 2022. Savings and future costs begin to accrue after a one-year installation period.
- The discount or hurdle rate is 3.3% real, which is the US Department of Energy (DOE) discount rate in effect in 2001 for federal energy conservation projects.
- Electricity price is $0.08711/kWh
- DOE energy price escalation rates apply to electricity used in Virginia.

FIG. X3.1 Summary of Life-Cycle Cost Analysis of Air-Conditioning System

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

Savings and Costs

PV of Investment Costs	**DX SS**	**CPC**
Capital Requirements at Base Date	210,000	265,000
Capital Replacement	18,517	0
Residual Value at end of Study	(10,549)	0
	$217,968	$265,000

Increased Total PV Investment for CPC $47,032

PV of Non-Investment Costs	**DX SS**	**CPC**
Energy Consumption Costs	186,590	134,141
Recurring and Non-recurring OM&R Costs	20,888	4,393
	$207,478	$138,534

PV of Non-Investment Savings for CPC $68,944

PVLCC	**DX SS**	**CPC**
PV of Investment Costs	217,968	265,000
PV of Non-Investment Costs	207,478	138,534
	$425,446	$403,534

PVNS from CPC **$21,912**

Savings-to-Investment Ratio (SIR)

PV of Non-Investment Savings $68,944
Divided by PV of Incr. Investment 47,032
SIR = 1.47

Adjusted Internal Rate of Return (AIRR)

$(1+0.033)\ 1.47^{1/21} - 1 = 0.052$

AIRR = 5.2%

which exceeds the hurdle rate of 3.3%

3.b Key Results:

- **PVLCC**
  - DX Split System $425,446
  - CPC 403,534
- **PVNS from CPC** $21,912
- **SIR** 1.47
- **AIRR** 5.2%

3.c Traceability:

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

Energy price escalation rates used are projected annually by DOE's Energy Information Agency.

FIG. X3.1 Summary of Life-Cycle Cost Analysis of Air-Conditioning System *(continued)*

X4. PUBLIC-SECTOR RESEARCH APPLICATION

X4.1 See Fig. X4.1.

1.a Significance of Research Effort:

Owners of industrial facilities and contractors engaged in the construction of those facilities are pressing for reductions in delivery time as a means of improving their competitive positions. Owner concerns over both the first costs and life-cycle costs of industrial facilities and tightening profit margins for contractors are also affecting the competitive positions of each stakeholder. One means of improving the competitive positions of each industrial sector stakeholder is through the development, adoption, and use of fully-integrated and automated project process (FIAPP) products and services. Characteristics of FIAPP products and services include one-time data entry; interoperability with design, construction, and operation processes; and user-friendly input/output techniques. The Building and Fire Research Laboratory's (BFRL's) focused research efforts, its collaboration with the Construction Industry Institute (CII), and its participation in the FIATECH Consortium are designed to deliver FIAPP products and services to CII members and the rest of the construction industry.
BFRL's focused research on Plant STEP, construction metrology, and economic analysis led BFRL to form the construction systems integration and automation program in 1997. In addition, BFRL is uniquely positioned to collaborate with industry on the development of FIAPP products and services and to provide a forum for conducting interoperability testing. BFRL is working towards a prototype FIAPP being tested and deployed by 2004. To achieve this goal, BFRL is working with facility owners, contractors, equipment and systems manufacturers and service providers, software developers, facility operators, trade associations, professional societies, standards organizations, university researchers, and other government agencies. Without BFRL's participation, it is likely that the introduction of FIAPP products and services will be delayed for at least four years.

1.b Key Points:

- Pressure to reduce delivery time and life-cycle costs has created a potential market for FIAPP products and services.
- BFRL is uniquely positioned to collaborate with industry on the development of FIAPP products and services and to provide a forum for conducting interoperability testing.
- Without BFRL's participation, it is likely that the introduction of FIAPP products and services will be delayed for at least four years.

2. Analysis Strategy: How Key Measures are Estimated

The objective of the study is to (1) evaluate, for the period 1993 through 2017, the net cost savings due to the adoption and use of FIAPP products and services in industrial facilities, and (2) estimate BFRL's contribution to these net cost savings. *The approach is to estimate in 1997 present value (PV) dollars:*
Present Value Cost Savings Nationwide (PVCSN) in industrial facilities that employ FIAPP products and services. PV cost savings nationwide are estimated for each year from 1993 to 2017 and summed.
Present Value Savings (PVS) attributable to BFRL by including the savings only for those years that accrued due to BFRL's participation (i.e., 1993 to 2008).
Present Value Net Savings (PVNS) attributable to BFRL by subtracting from BFRL PVS the present value of BFRL's investment costs (PV Costs). A PVNS >0 indicates an economically worthwhile project.
Two additional measures are also estimated:
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.
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.

FIG. X4.1 Summary of Economic Impacts of a Government Research Project

2. Analysis Strategy: Data and Assumptions

- The period over which costs and savings are measured begins in 1993 and ends in 2017. Hence the length of the study period is 25 years.
- The base year is 1997, and all amounts are calculated in PV 1997 dollars.
- The discount rate is 7 percent (real).
- Estimates of cost savings associated with the adoption and use of FIAPP products and services are based on construction industry data and information provided by industry experts.
- Without BFRL's participation, the introduction of FIAPP products and services will be delayed by four years.

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

Savings and Costs

Present Value Cost Savings Nationwide (PVCSN):
Sum from 1993 to 2017 the present values of cost savings nationwide by year
= $2,043.2 million

Present Value Savings (PVS) Attributable to BFRL:
Sum from 1993 to 2008 the present values of cost savings nationwide by year
= $149.0 million

Present Value Investment Costs (PV Costs) to BFRL:
Sum from 1993 to 2017 the present values of investment cost to BFRL by year
= $30.1 million

Present Value Net Savings (PVNS) Attributable to BFRL:
Difference between present value savings (PVS) attributable to BFRL and present value of investment costs (PV Costs) to BFRL

= $149.0 - $30.1 = $118.9 million

Additional Measures

SIR of BFRL Contribution:
Savings-to-Investment Ratio on BFRL investment
= $149.0/$30.1 = 4.95

AIRR of BFRL Contribution:
Adjusted Internal Rate of Return on BFRL investment
$= (1+ 0.07) * 4.95^{1/25} - 1 = 0.141$

3.b Key Results:

1997 Dollars
($ amounts in millions)

Cost Savings Nationwide:

$2,043.2

Savings Attributable to BFRL:

PVS	**$149.0**
PV Costs	**$30.1**
PVNS	**$118.9**
SIR	**4.95**
AIRR	**14.1%**

3.c Traceability:

ASTM *Discount Factor Tables* (PVCSN and PVS)

ASTM E 917 (PV Costs)

ASTM E 1074 (PVNS)

ASTM E 964 (SIR)

ASTM E 1057 (AIRR)

FIG. X4.1 Summary of Economic Impacts of a Government Research Project *(continued)*

X5. HOMELAND SECURITY APPLICATION

X5.1 See Fig. X5.1.

1.a Significance of the Project:	**1.b Key Points:**
The data center undergoing renovation is a single-story structure located in a suburban community. The floor area of the data center is 40,000 ft^2 (3,716 m^2). The replacement value of the data center is $20 million for the structure plus its contents. The data center contains financial records that are in constant use by the firm and its customers. Thus, any interruption of service will result in both lost revenues to the firm and potential financial hardship for the firm's customers. The building owners employ two different renovation strategies. The first, referred to as the Base Case, employs upgrades that meet the minimum building performance and security requirements. The second, referred to as the Proposed Alternative, results in enhanced security as well as selected improvements in building performance. Both alternatives recognize that in the post-9/11 environment the data center faces heightened risks in two areas. These risks are associated with the vulnerability of information technology resources and the potential for damage to the facility and its contents from chemical, biological, radiological, and explosive (CBRE) hazards. Two scenarios—the potential for a cyber attack and the potential for a CBRE attack—are used to highlight these risks.	1. The objective of the renovation project is to provide cost-effective operations and security protection for the data center. 2. The renovation is to upgrade the data center's HVAC, telecommunications and data processing systems and several security-related functions. 3. Two upgrade alternatives are proposed: - Base Case (Basic Renovation) and - Proposed Alternative (Enhanced Renovation), which augments the Base Case by strengthening portions of the exterior envelope, limiting vehicle access to the data center site, significantly improving the building's HVAC, data processing and telecommunications systems, and providing better linkage of security personnel to the telecommunications network.

2. Analysis Strategy: How Key Measures are Estimated

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

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

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

Additional measures:

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

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

Data and Assumptions:

- The Base Date is 2003.
- The alternative with the lower first cost (Basic Renovation) is designated the Base Case.
- The study period is 25 years and ends in 2027.
- The discount rate is 4.0 % real.
- The minimum acceptable rate of return is 4.0 % real.
- Annual probabilities for the outcomes for each attack scenario are given along with outcome costs.
- Annual probabilities and outcome costs differ by renovation strategy.
- Uncertainty in the values of 21 key input variables was analyzed via Monte Carlo Simulation.

FIG. X5.1 Summary of the Data Center Case Study

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

Savings and Costs in Thousands of Dollars ($K)

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

PV of Increased Investment Costs for Proposed Alt. $604K

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

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

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

PVNS from Proposed Alternative **$682K**

Savings-to-Investment Ratio (SIR)
PV of Non-Investment Savings $1,286K
Divided by PV of Incr. Investment 604K
SIR = 2.13

Adjusted Internal Rate of Return (AIRR)
$(1+0.04)\ 2.13^{1/25} - 1 = 0.072$
AIRR = 7.2 %
which exceeds the minimum acceptable rate of return of 4.0 %

3.b Key Results:

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

3.c Traceability:

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

Treatment of uncertainty and measures of project risk were calculated according to ASTM standard E 1369.

Results of Monte Carlo Simulation

Economic Measure	**Computed Statistics**				
	minimum	**median**	**maximum**	**mean**	**standard deviation**
LCC_{BC}	$4,344K	$6,008K	$9,023K	$6,216K	$1,301K
LCC_{ALT}	$4,012K	$5,320K	$7,429K	$5,451K	$926K
PVNS	$46K	$708K	$1,884K	$765K	$396K
SIR	1.06	2.20	6.14	2.36	0.83
AIRR	4.2 %	7.3 %	11.8 %	7.4 %	1.4 %

FIG. X5.1 Summary of the Data Center Case Study *(continued)*

X6. RISK MITIGATION PLAN APPLICATION

X6.1 See Fig. X6.1.

1.a Significance of the Project

The risk mitigation objective for this analysis is to limit intentionally-set fires in at-risk communities of Michigan. The risk of intentionally-set fire is assessed using (A) a statistical model to estimate the occurrence of neighborhood-based intentionally-set fire (intentionally-set structure and vehicle ignitions), and (B) loss estimates (life and property) derived from reported fire incident data.

The total impact per reported intentionally-set fire is measured as the combined economic loss from property damage plus the economic value of fatalities and injuries. The total impact was larger for intentionally-set residential fires, because they involved more loss of life than did non-residential and vehicles fires. Reported intentionally-set residential fires averaged in cost $94 thousand per fire. Reported intentionally-set non-residential and vehicle fires averaged $27 thousand and $43 thousand in cost per fire, respectively. A weighted average over all incident types (based on likelihood) was used in the benefit estimation ($64 thousand).

The three mitigation strategies offer communities with very different mechanisms to affect intentionally-set fires in structures and vehicles. Increased policing by law enforcement and neighborhood activists provides communities with increased detection of potential firesetters, as well as means to apprehend and punish setters of illegal fires. Law enforcement policing also provides a deterrent effect. The demolition of vacant structures limits the number of possible "good" targets for firesetters.

1.b Key Points

1. The objective of the analysis is to develop a cost-effective risk mitigation plan for at-risk Michigan communities seeking to protect themselves from intentionally-set fires.
2. The three-step protocol (ASTM E 2506)—perform a risk assessment, specify combinations of risk mitigation strategies for evaluation, and conduct an economic evaluation—is used to develop a community-based mitigation strategy limiting undue exposure to intentionally-set fires.
3. Three mitigation strategies are individually evaluated: (1) an increase in policing; (2) a decrease in the vacancy rate; and (3) an increase in community surveillance activity by local residents, labeled here as "neighborhood watch activity," which causes a decrease in physical and social measures of disorder.

2. Analysis Strategy: How Key Measures are Estimated

The following economic measure is calculated as present-value (PV) amounts:

1. **Present Value Net Benefits** (PVNB) are the net benefits remaining from subtracting the PV costs from PV benefits. A PVNB > 0 implies an economically worthwhile project.

Additional Measures of Economic Performance:

1. **Benefit-to-Cost Ratio** (BCR) is the ratio of project benefits to project costs. A BCR > 1.0 implies an economically worthwhile project.
2. **Adjusted Internal Rate of Return** (AIRR) is the annual return on project investment over the study period. An AIRR > minimum acceptable rate of return implies an economically worthwhile project.

Data and Assumptions:

- The study period is 5 years and ends in 2008.
- The discount rate is 7.0 % real.
- The minimum acceptable rate of return is 7.0 % real.
- Risk of intentionally-set fires is estimated using a statistical model of ignition occurrence and loss estimates derived from reported fire incident data.
- Risk mitigation effectiveness (number of fires avoided) varied by risk mitigation strategy, but the distribution of incident types avoided is assumed to be the same (i.e., 100 avoided fires = 49 avoided residential fires + 29 avoided vehicle fires + 22 avoided non-residential fires) regardless of the mitigation strategy.
- Uncertainty in the values of five key input variables was analyzed using Monte Carlo Simulation.
- The value of a statistical life used was $8.75 million and value of a statistical injury used was $190 thousand. These were inflation-adjusted ($ 2008) based on the values discussed in Butry.[6]
- Only demolition costs were considered in the benefit-cost analysis of removing vacant structures. Including any legal or associated process costs would diminish the PVNB, BCR, and AIRR.

FIG. X6.1 Summary of Risk Mitigation Plan Application

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

Benefits and Costs in Thousands of Dollars ($K)

PV of Benefits and Investment Costs

Alternative	PV of Benefits	PV of Costs
Police	3,276	1,849
Vacant Houses	44,440	22,564
Neighborhood Watch	11,843	5,244

PVNB of Alternative Mitigation Strategies

Alternative	Calculation	PVNB
Police	= 3,276 – 1,849	1,418
Vacant Houses	= 44,440 – 22,546	21,876
Neighborhood Watch	= 11,843 – 5,244	6,600

Each benefit exceeds the associated cost

Benefit-to-Cost Ratio (BCR) of Alternative Mitigation Strategies

Alternative	Calculation	BCR
Police	= 3,276 / 1,849	1.76
Vacant Houses	= 44,440 / 22,546	1.97
Neighborhood Watch	= 11,843 / 5,244	2.26

Each exceeds the BCR of 1.0

Adjusted Internal Rate of Return (AIRR) of Alternative Mitigation Strategies

Alternative	Calculation	AIRR
Police	$= (1 + 0.07)\ 1.76^{1/5} - 1$	0.20
Vacant Houses	$= (1 + 0.07)\ 1.97^{1/5} - 1$	0.23
Neighborhood Watch	$= (1 + 0.07)\ 2.26^{1/5} - 1$	0.26

Each exceeds the minimum acceptable rate of return of 7.0 %

Results of Monte Carlo Simulation

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

3.b Key Results:

- **Largest PVNB**
  Vacant Houses: 21,876
- **Largest BCR**
  Neighborhood Watch: 2.26
- **Largest AIRR**
  Neighborhood Watch: 0.26

3.c Traceability:

Present value net benefits, benefit-to-cost ratio, and adjusted internal rate of return were calculated according to ASTM standards E 1074, E 964, and E 1057, respectively.

Treatment of uncertainty and measures of project risk were calculated according to ASTM standard E 1369.

FIG. X6.1 Summary of Risk Mitigation Plan Application *(continued)*