9. ECONOMICS

9.1 OVERVIEW OF ECONOMICS RESEARCH FOR BUILDING AND FIRE PROGRAMS

The goal of the Office of Applied Economics (OAE), of the Building and Fire Research Laboratory, has been to bring state-of-the-art economic decision tools and data to decision makers in a form that they can understand and use. The focus has been on delivering useful economics research that would provide the maximum impact for the available research budget. Several strategic principles were followed: (1) conduct research in areas of high national interest (e.g., energy economics starting in the 1970s); (2) transfer research findings and tools to users in the building community via multiple routes-through professional societies and standards organizations (e.g., American Society for Testing and Materials (ASTM)), training, and publishing; and (3) adapt the format of OAE products to the technology and customer attitudes in the current market (e.g., switching over time from technical reports to user-friendly, decision-support software).

The OAE has provided economic products and services through research and consulting to industry and government agencies in support of productivity enhancement, economic growth, and international competitiveness, with a focus on improving the life-cycle quality and economy of constructed facilities. The focus of OAE's research and technical assistance is microeconomic analysis. The OAE provides information to decision makers in the public and private sectors who are faced with choices among new technologies and policies.

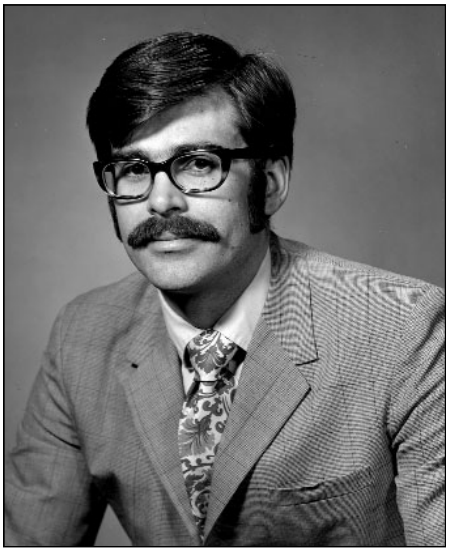
The OAE staff have competence in economics, financial analysis, operations research, cost engineering, and software development. Benefit-cost analysis, life-cycle costing, multicriteria decision analysis, risk analysis, linear programming, statistical modeling, and econometrics are techniques the OAE has used in evaluating new technologies, processes, governmental programs, legislation, and codes and standards to determine efficient alternatives. Research areas include energy conservation in buildings, fire safety, automation, seismic design, and building economics. Products include

Office of Applied Economics, October 2001

reports and articles on research findings; standard methods and guidelines for making economic evaluations; audiovisuals that teach and illustrate methods in practice; training programs; and decision-support software with documentation.

During the period 1967-1973, several economists and cost engineers supported various programs in the Center for Building Technology (CBT). The establishment of a separate building economics group, however, came with the hiring of economist Harold Marshall as Group Leader in 1973. Over the next 27-years, the group varied in size, increasing to 20 persons prior to the Reagan administration personnel cuts, and becoming stable in recent years at about 10-12 permanent employees. The group used two strategies to attract and retain productive employees. It organized the group by discipline to encourage economists to join and stay with the research team, and it provided research opportunities in areas of national importance that excited employees about the chance to do meaningful work.

Harold Marshall, leader, Office of Applied Economics.



The name of the group changed from Building Economics to Office of Applied Economics (OAE), and the group moved in 1981 to the Computing and Applied Mathematics Laboratory for a 14-year period. While the OAE had the charter to work in any industrial sector, the staff's expertise and client history continued to focus research on the building industry area. The group returned to the Building and Fire Research Laboratory in 1995.

Funds for the operation of the OAE come in part from Federally appropriated money through NIST and in part from other government agencies that enter into agreements with OAE for research services. While virtually all of OAE funds come from Federal sources, in some years as much as 85 percent has come from non-NIST agencies.

Examples of other agency sponsors of OAE work are the Department of Energy, Public Health Service, General Services Administration, National Institute of Justice, Environmental Protection Agency, and the Department of Housing and Urban Development. The OAE also provides economic support for other major operating units within NIST, the two largest efforts being for the Advanced Technology Program and the Manufacturing Extension Partnership Program.

All work done by the OAE is in the public domain. While some private sector clients want proprietary control over their research, and are therefore reluctant to fund OAE research directly, OAE does collaborate with private interests in identifying industry needs and in creating research agendas. In addition, since many of the products are economic evaluation methods and user-friendly software, non-government, as well as government, organizations benefit directly from OAE research.

The OAE has collaborated with researchers from every Office and Group within BFRL. Economists typically work with professionals from other disciplines, so it was natural to capitalize on multidisciplinary, and ultimately interdisciplinary, arrangements to treat building industry problems from multiple perspectives. This ability to work with other disciplines made it possible for the OAE to find other agency clients to support OAE research consistent with the BFRL and NIST missions. Moreover, the collaboration required of other agency work has helped focus OAE efforts on areas of high national interest that offer significant research payoffs.

Overviews of Major Projects

Nine major projects epitomize OAE's responsiveness to significant economic measurement needs of the building community. Following is a brief overview of each of the nine projects that describes project accomplishments and identifies the principal investigators. In the sections that follow the overviews are more detailed descriptions of each of the nine projects.

Economics of Energy Conservation–The energy crisis in the 1970s spurred the OAE to address the problem of how to measure and evaluate the appropriate level of investment in energy conservation in buildings. Scarcity and rising prices of energy forced the world to revise traditional approaches to construction, maintenance, and operation of buildings. Stephen Petersen's pathbreaking report on retrofitting existing housing for energy conservation redirected the U.S. Department of Energy's (DOE's) policy from promoting Btu budgets exclusively to seeking economically efficient levels of energy conservation investment. His BLCC 4.0 computer program for evaluating energy conservation investments has been used nationwide. For 20 years, Harold Marshall, Rosalie Ruegg, and Stephen Petersen developed and taught life-cycle cost workshops and produced reports in support of DOE's energy conservation program. Sieglinde Fuller and Amy Rushing continue that tradition today; in 2000 an enhanced, graphical version of BLCC was completed and has become the premier life-cycle costing software in energy conservation.

Standard Economic Methods in Building Economics–This project started with BFRL's suggestion to ASTM's Building Performance and Constructions Committee that a new subcommittee called Building Economics be established. Harold Marshall became the first chairman in 1979 and remains so today. For 20 years this subcommittee has helped shape the research agenda for the OAE and provided a forum for presenting to the building industry OAE research results. Robert Chapman, Harold Marshall, Stephen Petersen, and Rosalie Ruegg made substantial contributions to economic measurement by drafting for and guiding through the ASTM balloting process 13 standard economic methods, guides, and adjuncts based on their research. The subcommittee continues today to be an excellent link to industry, academia, and government users of OAE products.

Cost-Effective Compliance with Life Safety Codes–The Life Safety Code for fire protection in buildings is a prescriptive code that specifies solutions. It allows, however, for equivalent solutions to be substituted. In 1978, NIST fire researchers Harold Nelson and A. J. Shibe developed a system of assigning points that would help the designer choose equivalent, alternative building solutions to the prescribed solution for health care occupancies. Robert Chapman and William Hall, in 1982, developed software that allowed the user to find many alternatives close to the least-cost solution that would satisfy the code requirements. Stephen Weber and Barbara Lippiatt, in 1994, enhanced the software, now called ALARM, to greatly facilitate its application. Stephen Weber and Laura Schultz extended ALARM to make it applicable to correction and detention facilities. Conservative estimates of the cost savings from applying ALARM to the design of military hospitals over a 10-year period exceed $100 million.

Economic Impacts of BFRL Research–NIST and other research institutions need quantitative measures of research impacts to efficiently allocate their budgets among competing research projects and to evaluate the success of past projects. Harold Marshall and Rosalie Ruegg published the first such impact study in CBT in 1979. Four subsequent reports, authored by Robert Chapman, Stephen Weber, and Sieglinde Fuller, were published between 1996 and 2000. Robert Chapman's application of these methods to the estimation of cost savings to the public from BFRL investments in cybernetic building systems, for example, showed cost savings of almost eight dollars for every dollar of BFRL investment. In addition to showing significant net dollar impacts from selected NIST research projects, this series of reports provided (1) a standard framework for categorizing research benefits and costs and (2) standard methods for measuring and evaluating those benefits and costs.

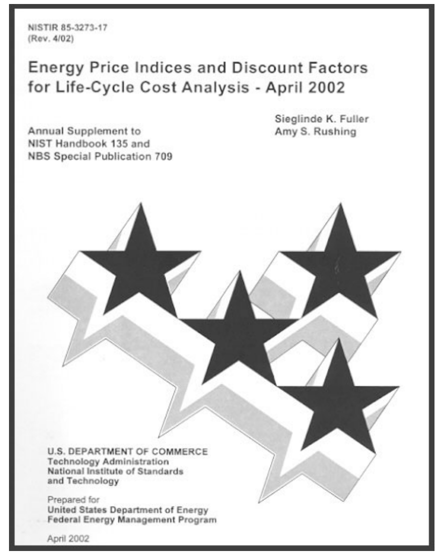
Applications of the Analytical Hierarchy Process (AHP)–The AHP is a method that considers non-financial characteristics and economic measures in evaluating investments. Economists in OAE have applied the AHP method to decisions in automated manufacturing, fire sprinklers in residences, green-building investments (BEES), and in the choices of building design and location. Robert Chapman and Harold Marshall worked with ASTM and Expert Choice, Inc. to produce an AHP software product that supports ASTM standard methods for economic evaluation. For fiscal years FY 1998-2000, BFRL management used the AHP with a series of resource allocation models developed by Robert Chapman to rate budget proposals and to allocate the BFRL research budget.

BEES: Building for Environmental and Economic Sustainability–BEES, developed by Barbara Lippiatt, is a cradle-to-grave life-cycle assessment tool that helps users measure and evaluate the environmental and economic performance of building products over their lifetimes. A traditional life-cycle cost comparison of products may reveal the most cost-effective choice, but it fails to account for related environmental impacts such as resource depletion, global warming, and acid rain. BEES fills this gap by providing the developer, owner, manufacturer, and architect with software for measuring and comparing both environmental and economic performance of building products using a single performance score. Two hundred building products can now be evaluated with the software, and additional products continue to be added.

UNIFORMAT II Elemental Classification for Building Specifications, Cost Estimating, and Cost Analysis–Building elements are major components, common to all buildings, that perform a given function regardless of design specifications, construction, method, or materials. Examples of elements are foundations, exterior walls, and lighting. A standard elemental classification of buildings is needed to provide a consistent reference for the description, economic analysis, and management of buildings during all phases of their life cycle. Harold Marshall, in collaboration with consultants Robert Charette and Brian Bowen, developed a standard set of elements called UNIFORMAT II. It became an ASTM standard classification and has been embraced widely in the United States by the Construction Specifications Institute, the Design-Build Institute of America, R.S. Means Company, Inc., Whitestone Research, and government agencies responsible for constructing buildings. Since elemental cost estimates are faster and less costly to make, UNIFORMAT II is making possible cost savings from informed design tradeoffs early in the planning process when the greatest savings from design choices are possible.

Baselines and Measures for the National Construction Goals–The Subcommittee on Construction and Building of the National Science and Technology Council developed seven National Construction Goals at its founding in 1994. The goals were intended to attract the support and cooperation of policy makers in federal agencies and in the private sector to the subcommittee's efforts to focus and coordinate federal R&D, to enhance the competitiveness of U.S. industry, and to promote public safety and environmental quality through research and development to improve the life-cycle performance of constructed facilities. Robert Chapman drew upon his experience assisting the Construction Industry Institute to establish baselines and measures for progress on its related goals to define baselines and measures for the National Construction Goals.

BridgeLCC–BridgeLCC, developed by Mark Ehlen, is a user-friendly, life-cycle costing software tool. It is used to evaluate the economic performance of new/alternative construction materials as compared with conventional materials in the construction of bridges. While the tool is specially tailored to compare new and conventional bridge materials, such as high-performance concrete vs. conventional concrete, it can also be used to compare alternative conventional materials and for the analysis of civil infrastructure other than bridges.


NISTIR 85-3273-17
(Rev. 4/02)

Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis - April 2002

Sieglinde K. Fuller
Amy S. Rushing

Annual Supplement to
NIST Handbook 135 and
NBS Special Publication 709

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

Prepared for
United States Department of Energy
Federal Energy Management Program

April 2002

BLCC version 5.1, and the discount factors annual supplement to the software.

9.2 ECONOMICS OF ENERGY CONSERVATION

The energy crisis of the early 1970s focused the attention of the building community on the high consumption of energy rather than on simply providing adequate cooling and heating, lighting, water heating, and other energy-related building services. Energy shortages, increasing energy prices, and significant media coverage encouraged conservation nationwide. Government and private sector facility managers as well as homeowners needed guidance regarding what conservation investments were economically justified given higher energy costs and forecasts of more increases to come. When the Building Economics Group (the forerunner of the Office of Applied Economics) was established in BFRL in 1973, its first major undertaking was to take a leadership role under the sponsorship of DOE in working with researchers from other disciplines to measure the life-cycle net savings from alternative approaches to energy conservation in buildings. The National Energy Conservation Policy Act, signed by President Carter in 1978, called upon the Secretary of The Department of Energy (DOE), in consultation with NBS, "...to (1) establish practical and effective methods for estimating and comparing life-cycle costs for Federal buildings, and (2) develop and prescribe the procedures to be followed in applying and implementing the methods so established."

The first challenge was how to provide useful, unbiased, information to building owners, the building trades, and government agencies on the economic tradeoffs between energy conservation and energy consumption in the design and retrofit of new and existing buildings.

Stephen Petersen's BSS 64 report *Retrofitting Existing Housing for Energy Conservation* [1] provided specific guidelines for determining economically optimal retrofit strategies for installing insulation and storm windows in existing houses based on site-specific energy prices, climate factors, heating and cooling equipment efficiencies, and retrofit costs. This report, with an initial dissemination of over 1,000 copies, showed energy policy makers that significantly larger investments in energy conservation (than had been made up to that time in most housing units) were cost effective based on a life-cycle cost analysis.

Making the Most of Your Energy Dollars, a consumer-oriented pamphlet [2] by Madeleine Jacobs and Petersen, was adapted from the BSS 64 report. The pamphlet, with a distribution of over a half-million copies, helped homeowners determine the best combination of energy conservation improvements for their home's unique design, climate, and fuel costs so as to provide the highest, long-run, net savings in home heating and cooling costs.

Petersen's *Building Life-Cycle Cost* (BLCC) computer program [3], expanding on the economic methodology used in BSS 64, helped owners and managers of all building types make more cost-effective choices related to energy conservation and energy use in buildings. The BLCC computer program, ultimately adopted by ASTM as a product in their software series, implemented the life-cycle cost methods introduced in BSS 64. The DOE, along with a number of public and private sector software vendors, distributed annually up to 5,000 copies of the software. The Java version, BLCC 5.1, is now available directly on the internet.

Petersen's Zip-Code Insulation Program [4] provided specific recommendations for insulation levels in houses based on local energy prices and climate factors (keyed to Postal Zip Codes) for the entire country.

A second challenge was to redirect DOE away from promoting BTU energy budgets to seeking economically efficient levels of energy conservation. BSS 64 made it clear that overinvestment as well as underinvestment in energy conservation was economically inefficient.

In the late 1970s, solar economics became a part of the group's research. Rosalie Ruegg, and Jeanne Powell published reports [5,6] on the economic evaluation of solar heating and cooling technologies for home and commercial environments. OAE's solar work was well received and widely used during the period when alternative energy sources were explored intensely.

In the early 1990's, DOE added renewable energy projects and water conservation to its portfolio of conservation strategies. The economics group at the OAE adapted its life-cycle cost methods, software, and instructional materials to accommodate new legislation and user requirements.

Another significant effort for DOE provided by the economics group was the teaching of 2-3 day life-cycle cost (LCC) workshops around the U.S. and abroad. In support of those workshops, Harold Marshall, Rosalie Ruegg, and Stephen Petersen developed reports, workbooks, case studies, and three instructional videos for helping government facility planners and private consultants evaluate the cost effectiveness of alternative energy-conservation investments and policies [7]. In recent years, Sieglinde Fuller and Amy Rushing continue to support DOE with reports, workshops, and a BLCC software product programmed in Java [8].

OAE workshops, taught in person around the world and via teleconferencing, have presented to users these methodologies, tools, and data for evaluating energy conservation investments to well over 2000 seminar attendees over the last 20 years. The internet makes OAE products even more accessible.

OAE participation in ASTM has been particularly effective in transmitting standard economic methods and software to the building community concerned with energy and water conservation and renewable energy. The first standard published by the ASTM's Building Economics Subcommittee was the Life-Cycle Cost standard. It was drafted by OAE staff in response to the subcommittee's plea for a way of evaluating energy conservation investments.

A major impact of economics work in energy conservation was a shift in philosophy from merely minimizing building energy consumption to optimizing on economic grounds the level of energy conservation investment and energy consumption. The public policy result was a shift from codes and standards based solely on energy budgets to a more flexible policy that takes into account the dollar cost of energy. NBS Director Richard Roberts, in his annual "state of the NBS" address in 1975, declared the CIS pamphlet on Energy Dollars to be the outstanding NBS publication for the year because it successfully addressed the energy crisis in the large stock of U.S. housing. It received the Society for Technical Communication Award for "outstanding government publication" in 1976.

Stephen Petersen (1976) and Rosalie Ruegg (1977) each received the Department of Commerce Silver Medal Award for their outstanding work in the economics of energy conservation. In 1998 Sieglinde Fuller was selected by DOE as an "Energy Champion" for the Department of Commerce for her work in developing and updating the life-cycle cost methodology and software for the Federal Energy Management Program.

NIST has become the de facto authority in software (BLCC), Life-Cycle Cost training, and methods for economic analysis of energy conservation investments, as indicated by the widespread adoption of OAE products by ASHRAE, ASTM, private companies, the federal government, numerous state governments, and other countries, such as Canada and Australia.

References

1. Steven R. Petersen, *Retrofitting Existing Housing for Energy Conservation: An Economic Analysis*, BSS 64, National Bureau of Standards, 1974.
2. Madeline Jacobs and Steven R. Petersen, *Making the Most of Your Energy Dollars*, CIS 8, National Bureau of Standards, 1975.
3. Steven R. Petersen, *BLCC-The original NIST Building Life-Cycle Cost Computer Program*, National Bureau of Standards, 1985.
4. *ZIP--The Zip Code Insulation Program*, NISTIR 88-3801, originally published by Oak Ridge National Laboratory in 1989.
5. Rosalie T. Ruegg, *Solar Heating and Cooling in Buildings: Methods of Economic Evaluation*, NBSIR 75-712, National Bureau of Standards, 1975.
6. Jeanne W. Powell, *An Economic Model for Passive Solar Designs in Commercial Environments*, NBS BSS 119, National Bureau of Standards, 1980.
7. Harold Marshall and Rosalie T. Ruegg, Audiovisual Series of 3 tapes on *Least-Cost Energy Decisions for Buildings--Life-Cycle Costing* (1990), *Uncertainty and Risk* (1992), and *Choosing Economic Evaluation Methods* (1993), National Institute of Standards and Technology.
8. Sieglinde K. Fuller and Amy Rushing, *Revised BLCC Computer Program written in Java format*, E-Publication National Institute of Standards and Technology, 2000.

9.3 STANDARD ECONOMIC METHODS

The building community needs standard methods for evaluating the economic performance of investments in buildings and building systems. For example, typical decisions facing investors are whether to accept or reject a building investment, what design or size to choose for a building system, and how to establish priority among investment choices when budgets are limited. Users of economic methods want to know that the methods have been tested, approved, and accepted in the standards process by all stakeholders in the building industry. While sophisticated economic methods are needed to guide these users towards cost-effective building choices, the methods must be understandable to the non-economists who typically use them. Thus two major challenges in implementing standard economic methods are (1) developing technically sound methods in a format that building professionals can understand and (2) educating industry representatives on the standards committee so that they will endorse and adopt the recommended standard methods.

Harold E. Marshall, Rosalie T. Ruegg, Stephen R. Petersen, and Robert E. Chapman of the Office of Applied Economics in BFRL played major authorship, educational, and leadership roles in writing and shepherding successfully 16 standards and two software products through the ASTM standardization process. ASTM has published all of the economics standards in a compilation of building economics standards [1]. BFRL management targeted ASTM as the organization for development of the economic standards because it had the consensus balloting process important in creating widespread acceptance and it dominated the standards field (current membership includes 32,000 members from over 100 countries). BFRL proposed an ASTM subcommittee on Building Economics and succeeded in having it formally established in 1979. Harold Marshall was named the original chairman and remains so today.

BFRL economists wrote NIST reports that were the bases for standard methods on life-cycle cost [2], benefit-to-cost and savings-to-investment ratios [3], internal rates of return [4], net benefits [4], multi-attribute decision analysis [5], and payback [6]. They wrote two guides: one recommending techniques for treating uncertainty and risk [7], and one to help users match technically appropriate economic methods with the different types of design and system decisions that require economic analysis [8]. They wrote a standard classification of building elements [9, 10] to facilitate cost analysis and the electronic tracking of buildings. Finally, ASTM based its Life-Cycle Cost and Analytical Hierarchy Process software products on BFRL work [11].

The ASTM Subcommittee on Building Economics has been the preeminent forum for BFRL's Office of Applied Economics to identify industry's economic measurement needs, to create collaboratively with industry the standard measurement practices to answer those needs, and to implement standard measurement practices through the voluntary consensus standards process. Users of such standards include manufacturers and producers; federal, state, and local government agencies; builders; building code bodies; architectural and engineering firms; consumer groups; trade associations; research groups; consulting firms; and universities. Examples of specific applications of the standards are (1) manufacturers using the Life-Cycle Cost Standard Practice to customize energy-conservation products to economically efficient performance levels (e.g., insulation batt resistance levels and heat pump efficiencies); (2) building owners and designers using the UNIFORMAT II Elemental Classification Standard as the basis for bidding, tracking, and analyzing costs in all phases of the building's life cycle; and (3) federal and state governments using the Savings-to-Investment Ratio and Adjusted Internal Rate of Return to choose among multiple building investment options when the available budget is insufficient to fund all economically feasible projects.

Reduced life-cycle cost for any given level of building performance is the significant impact resulting from BFRL developing economic measurement methods and supporting them through the ASTM standards process.

1. Consumers (private and public) save money by purchasing building products (roofs, heating and cooling equipment, multiple-pane glazing) that are life-cycle cost effective.
2. Manufacturers can increase profits by designing and offering for sale building products that are most cost effective for their customers.
3. While the standards focus on buildings and building components, they have also been used widely to reduce life-cycle costs in nonbuilding investments. Economic evaluation algorithms in commercial spreadsheet software that are based on the standard economic methods, for example, help their users achieve life-cycle savings when choosing among investment alternatives.

Harold Marshall received the Department of Commerce Silver Medal Award in 1978 for his leadership in developing the building economics program and pioneering the development of standard methods in building economics.

References

1. *ASTM Standards on Building Economics*, BLDGEC99, American Society for Testing and Materials, West Conshohocken, PA, 1999. (Compilation of all ASTM standards on building economics)
2. Rosalie T. Ruegg, Stephen, R. Petersen, and Harold E. Marshall, *Recommended Practice for Measuring Life-Cycle Costs of Buildings and Building Systems*, NBSIR 80-2040, National Bureau of Standards, 1980.
3. Harold E. Marshall and Rosalie T. Ruegg, *Recommended Practice for Measuring Benefit/Cost and Savings-to-Investment Ratios for Buildings and Building Systems*, NBSIR 81-2397, National Bureau of Standards, 1981.
4. Harold E. Marshall, *Recommended Practice for Measuring Net Benefits and Internal Rates of Return for Investments in Buildings and Building Systems*, NBSIR 83-2657, National Bureau of Standards, 1983.
5. Gregory A. Norris and Harold E. Marshall, *Multiattribute Decision Analysis Method for Evaluating Buildings and Building Systems*, NISTIR 5663, National Institute of Standards and Technology, 1995.
6. Harold E. Marshall, *Recommended Practice for Measuring Simple and Discounted Payback for Investments in Buildings and Building Systems*, NBSIR 84-2850, National Bureau of Standards, 1984.
7. Harold E. Marshall, *Techniques for Treating Uncertainty and Risk*, NIST SP 757, National Institute of Standards and Technology, 1988.
8. Harold E. Marshall, *Least-Cost Energy Decisions for Buildings—Part III: Choosing Economic Evaluation Methods Video Training Workbook*, NISTIR 5604, National Institute of Standards and Technology, 1995.
9. Harold E. Marshall and Robert Charette, *UNIFORMAT II Elemental Classification for Building Specifications, Cost Estimating, and Cost Analysis*, NISTIR 6389, National Institute of Standards and Technology, 1999.
10. Brian Bowen, Robert P. Charette, and Harold E. Marshall, *UNIFORMAT II—A Recommended Classification for Building Elements and Related Sitework*, NIST SP 841, National Institute of Standards and Technology, 1992.
11. Robert E. Chapman and Harold E. Marshall, *Users Guide to AHP/Expert Choice for ASTM Building Evaluation, #MNL29*, ASTM, West Conshohocken, PA, 1998.

9.4 COST-EFFECTIVE COMPLIANCE WITH LIFE SAFETY CODES

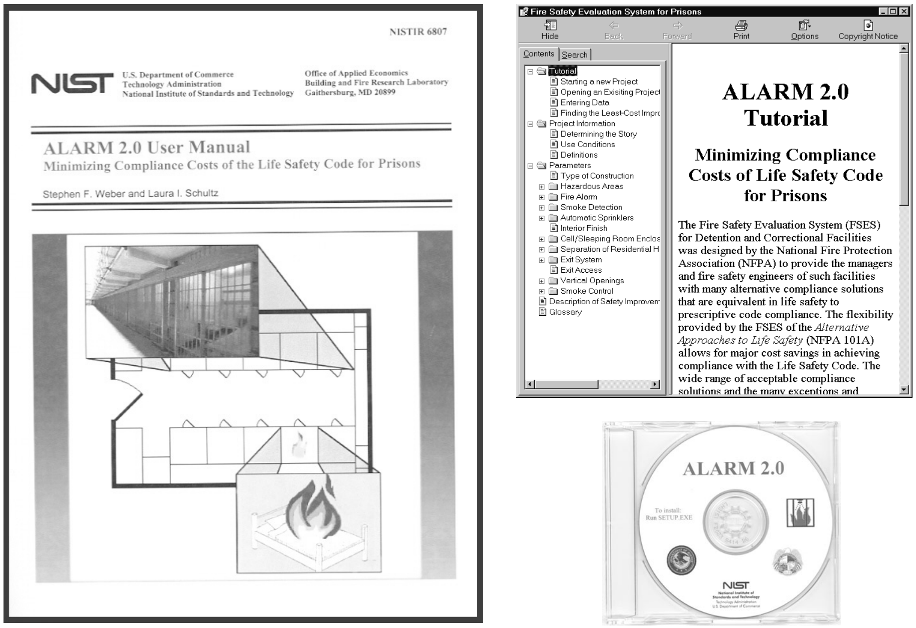
Although the Life Safety Code (LSC) for fire protection in buildings published by the National Fire Protection Association (NFPA) is primarily a prescriptive code specifying explicitly defined solutions to assure compliance, a special provision of the code has long allowed for substitution of equivalent solutions. In the late 1970s, Center for Fire Research (CFR) scientists worked with a panel of fire safety experts using the Delphi method to develop a point scoring system to assure that proposed safety improvements would provide a level of safety equivalent to the prescriptive code. This system was called the Fire Safety Evaluation System (FSES) and was first developed for health care facilities. The flexibility of the FSES made possible major cost savings when achieving compliance with the LSC. Because the FSES offers so many qualifying solutions, however, the most cost-effective solutions cannot be found by simple trial and error. What was needed was a method for finding a practical set of low-cost, safety-equivalent solutions from which facility managers could choose. The objective of this research was to develop systematic procedures for finding low-cost, safety-equivalent solutions compliant with the LSC for various building occupancies and to incorporate those procedures into software.

In 1978 Harold Nelson and A. J. Shibe of CFR led the effort to develop the first FSES [1], a flexible alternative to the prescriptive provisions of the LSC for health care facilities. Application of this alternative was initially made possible by language in the code allowing for equivalent solutions. Later the 1981 edition of the LSC formally adopted the FSES for health care facilities as an explicit part of the LSC. All editions since then have included the original FSES as well as others developed for a wide variety of building types, including offices and prisons.

Optimization based on the FSES scoring table of alternative safety states for each safety parameter is most directly formulated as a zero-one integer programming problem [2]. In 1982, Robert Chapman and William Hall developed an alternative formulation [3] based on solving the linear programming relaxation of the zero-one problem for the FSES of the 1981 edition of the LSC. The software exploited the “staircase” structure of the problem, a structure, which guaranteed that almost all variables in the solution would take on values of one or zero, and the advanced starting feature of the revised simplex algorithm. A post processor was used to select a single state when the solution fell between two states and to address any interdependencies caused by the footnotes to the FSES scoring table. The software, now called ALARM, contained a procedure for systematically finding many alternative, near least-cost solutions and then organizing them to ensure design compatibility across fire zones. The procedure usually produced about five to fifteen consistent strategies for the entire building. To facilitate comparisons, the costs of all alternatives are compared to and ranked against the costs of prescriptive compliance. Robert Chapman received the NIST Bronze Medal Award in 1982 for this work.

In 1994 Stephen Weber and Barbara Lippiatt [4] updated the cost data and cost algorithms, incorporated the changes in the point scores, and introduced new interdependent footnotes in the 1994 edition of the LSC. They also developed a menu-driven user interface for ALARM to assist users in preparing data files for the optimizer.

From 1998 to 2000, the National Institute of Justice funded Stephen Weber and Laura Schultz to extend the Alarm technology to cover the FSES for Correction and Detention facilities. They incorporated a new optimization model using zero-one integer programming to directly find the least-cost solution without the need to integerize the floating point solution of the simplex method [5]. They also developed an explicit Boolean model of all of the interdependencies in the footnotes and integrated it into the integer programming model. This model has the advantage of finding the true cost minimizing solution, taking into account all interdependencies, with a single optimization run without any post processing. They then developed ALARM 2.0, a 32-bit Windows software program with a user interface that intuitively leads the user through



ALARM 2.0 User Manual, screen shot, and software CD.

the FSES process. The interface graphically presents the main FSES scoring table with all the safety parameters and safety states and uses pop-up menus and color coding to guide the user in identifying current safety states, considering possible safety improvements, entering quantity data, and optimizing costs. The beta version of ALARM 2.0 was released in 2001.

The original version of the cost minimizer was used extensively by the U.S. Public Health Service (PHS). Between 1985 and 1995, fire safety engineers of the PHS conducted on-site surveys of 89 hospitals (53 Air Force, 33 Army, one Indian Health Service, and two community hospitals). They applied the cost minimizer software to all of these hospitals and used the results to prepare recommendations for safety improvements to the facility managers. The Alarm 1.0 software was published in 1994 and widely distributed by the NFPA through their One-Stop Data Shop.

The NIST Office of Applied Economics has published a detailed study of the economic impacts of this research in the hospital sector [6]. The economists based their impact estimates on the 86 military hospitals analyzed by PHS from 1985 to 1995, expert judgments of the use of the FSES for each type of hospital, and national statistics on the number of hospitals and beds in each type. The average cost savings of the optimized FSES solution found by the software compared with the prescriptive solution was about $2,200 per bed. Using a conservative twenty-year study period (1975-1995) and a thorough sensitivity analysis, the economists found that the present value of the net savings in hospitals from the FSES and the cost minimization software ranged from $119 million to $1,335 million. Large savings for FSES applications in prisons and commercial office facilities are anticipated in the future.

References

1. Harold E. Nelson and A. J. Shibe, *A System for Fire Safety Evaluation of Health Care Facilities*, NBSIR 78-1555, National Bureau of Standards, 1980.
2. Robert E. Chapman, "Cost-Effective Methods for Achieving Compliance with Firesafety Codes," *Fire Journal,* Vol. *123*, September, pp. 30-39, 1979.
3. Robert E. Chapman and William G. Hall, "Code Compliance at Lower Costs: A Mathematical Programming Approach," *Fire Technology*, Vol. 18, No. 1, February, pp. 77-89, 1982.
4. Stephen F. Weber and Barbara C. Lippiatt, "Cost-Effective Compliance with Fire Safety Codes," *Fire Technology*, Vol. 32, Nov/Dec, Number 4, pp. 291-296, 1996.
5. Stephen F. Weber and Laura I. Schultz, software and manual entitled, *Alarm 2.0 Users Manual: Minimizing Compliance Costs of the Life Safety Code for Prisons*, NISTIR 6807, National Institute of Standards and Technology, 2001.
6. Robert E. Chapman and Stephen F. Weber, *Benefits and Costs of Research: A Case Study of the Fire Safety Evaluation System*, NISTIR 5863, National Institute of Standards and Technology, 1996.

9.5 ECONOMIC IMPACTS OF BFRL RESEARCH

A formal resource allocation process for funding future 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. Economic impact studies help management set priorities and define new research opportunities. By revealing the "voice of the customer," such studies strengthen BFRL's ties to industry and identify opportunities for leveraging its federal research investments. Improved methods for measuring economic impacts are essential for BFRL to select the "best" among competing research programs, to evaluate the cost effectiveness of existing research programs, and to defend or terminate programs on the basis of their economic impact.

BFRL has long recognized the value of measuring the impacts of its research programs. A seminal study by Harold Marshall and Rosalie Ruegg in 1979 [1] demonstrated that even modest research efforts within BFRL are capable of producing significant impacts. More recently, BFRL has committed to a formal program for evaluating the impacts of not only past research efforts but also ongoing and planned research efforts as well.

A series of four reports published between 1996 and 2000 by Robert Chapman, Stephen Weber, and Sieglinde Fuller [2, 3, 4, 5] illustrate how to apply standardized methods to evaluate and compare the economic impacts of alternative research investments. The standardized methods employed in these reports make use of standard practices published by ASTM. In addition, the results of the economic impact assessments are summarized in a structured format, which ASTM has adopted as a standard format.

Two of the four economic impact studies deal with past BFRL research efforts for which a well-defined stream of benefits had been historically documented. These studies generated considerable interest from NIST senior management on how to apply the same approach to ongoing and planned research efforts. The two most recently published economic impact studies, and those planned for the future, are prospective in that the bulk of the impacts will occur in the future. These studies are designed to help BFRL shape its research efforts to better serve its constituency and to move its research results towards the marketplace.

The four recent economic impact studies have documented BFRL's role in some of the most significant research challenges facing the construction industry: energy conservation standards, fire safety in healthcare facilities, building automation and control functions, and construction systems integration and automation technologies. BFRL has successfully employed professional societies, standards and codes organizations, and public-private partnerships to move its research from the laboratory to a multitude of users.

BFRL's research is having a lasting impact on the construction industry. Without BFRL's customer-focused research, promising technologies would not have moved into the commercial marketplace as quickly as key construction industry stakeholders desired. The four recent reports document reductions in time-to-market for a variety of promising technologies of at least two years in all cases. The timelier introduction of new and innovative technologies into the construction industry has resulted in hundreds of millions of dollars of cost savings to construction industry stakeholders. For example:

1. Products and services based on BFRL's cybernetic building systems (CBS) research efforts are expected to result in cost savings in excess of $1.1 billion to owners, managers, and occupants of office buildings. BFRL's role in moving these products and services into the commercial marketplace in a timelier manner is valued at approximately $90 million. These expected gains are a direct result of the public sector's CBS-related research investment of approximately $11.5 million. In this case, every public dollar invested in BFRL's CBS-related research is expected to generate $7.90 in cost savings to the public.
2. BFRL's research on construction systems integration and automation technologies (CONSIAT) will generate substantial cost savings to

industrial facility owners and managers and to contractors engaged in the construction of those facilities. The present value of these cost savings is expected to be approximately $150 million. These cost savings measure the value of BFRL's contribution for its CONSIAT-related investment costs of approximately $30 million.

References

1. Harold E. Marshall and Rosalie T. Ruegg, *Efficient Allocation of Research Funds: Economic Evaluation Methods with Case Studies in Building Technology*, NBS Special Publication 558, National Bureau of Standards, 1979.
2. Robert E. Chapman and Sieglinde K. Fuller, *Benefits and Costs of Research: Two Case Studies in Building Technology*, NISTIR 5840, National Institute of Standards and Technology, 1996.
3. Robert E. Chapman and Stephen F. Weber, *Benefits and Costs of Research: A Case Study of the Fire Safety Evaluation System*, NISTIR 5863, National Institute of Standards and Technology, 1996.
4. Robert E. Chapman, *Benefits and Costs of Research: A Case Study of Cybernetic Building Systems*, NISTIR 6303, National Institute of Standards and Technology, 1999.
5. Robert E. Chapman, *Benefits and Costs of Research: A Case Study of Construction Systems Integration and Automation Technologies in Industrial Facilities*, NISTIR 6501, National Institute of Standards and Technology, 2000.

9.6 APPLICATIONS OF THE ANALYTICAL HIERARCHY PROCESS

Many research and building investment alternatives differ in characteristics that decision makers consider important but that are not readily expressed in monetary terms. To choose the best means for achieving the desired outcome or goal when non-financial characteristics are important, decision makers need a method that accounts for these characteristics when choosing among investment alternatives. A class of methods that accommodates non-financial characteristics is multi-attribute decision analysis (MADA). The analytical hierarchy process (AHP) is a MADA method that considers non-financial characteristics, in addition to common economic evaluation measures, when evaluating investment alternatives against a stated goal. In the context of the AHP, non-financial characteristics, economic evaluation measures, and other key factors are referred to as criteria. For complex decision problems, the criteria are divided into their constituent parts, referred to as sub-criteria.

Economists in the Office of Applied Economics have produced innovative AHP applications for a broad class of users in the construction industry, the research community, and in manufacturing.

Sieglinde Fuller explored the use of the AHP [1] by integrating quantifiable and qualitative variables to arrive at a preference ordering of fire protection systems in residential dwellings. The AHP hierarchy was structured to allow homeowners to include their personal risk attitudes and risk exposures, compared with an 'average' level of fire risk as indicated by U.S. fire statistics, when deciding whether or not to invest in a sprinkler system. The study included recommendations for developing customized decision-support software to meet the special needs of homeowner decisions. The AHP application to fire protection systems was met with interest by builders, municipalities, and fire research labs in the U.S., England, and Australia, whose task it is to promote the implementation of fire protection measures.

Stephen Weber and Barbara Lippiatt developed the AutoMan software [2, 3] designed to support multi-criteria decisions about automated manufacturing investments. The program permits users to combine quantitative and qualitative criteria in evaluating investment alternatives. Quantitative criteria could include such traditional financial measures as Life-Cycle Cost and Net Present Value as well as such engineering performance measures as throughput and setup time. Qualitative criteria could include criteria requiring judgments like flexibility and product quality. AutoMan includes a graphical system for conducting sensitivity analysis so users can easily visualize how results vary as criteria weights are changed. For two years, AutoMan made the NTIS list of Best-Selling Software from the U.S. Government. AutoMan also made the bestseller list of the Defense Technical Information Center, which began distributing AutoMan 2.0 in June 1992. The Institute for Management Accountants widely distributed AutoMan 2.0. The DoD Director for Defense Information adopted AutoMan as a tool for investment decisions on information systems. The software company, Foresight Science and Technology, signed a CRADA with NIST to incorporate AutoMan decision technology into an expert system for automation planning.

In 1995, Gregory Norris and Harold Marshall published a technical report that reviewed 14 classes of methods for performing MADA [4]. The report summarizes each method's usefulness for screening, ranking, and choosing among projects; its data input requirements; and its method for scoring project alternatives. The section of the report dealing with the AHP was used as the basis for ASTM Standard Practice E 1765.

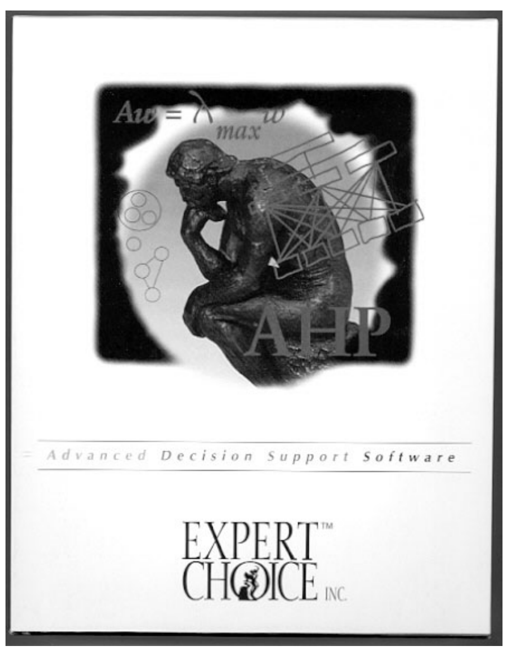
Harold Marshall and Robert Chapman, in collaboration with ASTM and Expert Choice, Inc., produced a software product [5], which contains a comprehensive list of building-related attributes. These attributes are drawn from standards produced by ASTM Subcommittees E06.25, Whole Buildings and Facilities, and E06.81, Building Economics. Marshall and Chapman revised ASTM's AHP Standard Practice E 1765 to incorporate enhancements resulting from the production of an ASTM-supported, AHP-based software product. The revisions promoted a broader use of both ASTM Standard Practice E 1765 and the software product.

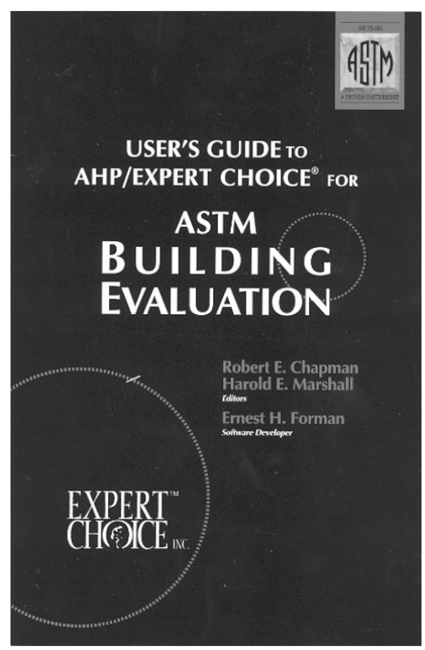
Robert Chapman, Karthy Kasi, and Julia Rhoten employed the AHP to produce a series of resource allocation models that were used by BFRL management to rate and produce budget allocations for BFRL projects in FY 1998, FY 1999, and FY 2000. Evaluation criteria and sub-criteria that were deemed important by BFRL's Management Council and Management Group were used with the models and were described in white papers. The NIST Visiting Committee recognized BFRL's use of AHP-based resource allocation models as an exemplary process that offers potential for significant and sustained performance improvements. BFRL Director Jack Snell described the process to several other NIST Laboratory Directors and their management teams, recommending its use as a contribution towards NIST compliance with the Government Performance and Results Act.

References

1. Sieglinde K. Fuller, *Risk Exposure and Risk Attitude of Homeowners in Fire Protection Investment Decisions*, NISTIR 4212, National Institute of Standards and Technology, 1989.
2. Stephen F. Weber, and Barbara C. Lippiatt, *AutoMan 2.0: Decision Support Software for Automated Manufacturing Investments: User Manual*, NISTIR 4543, National Institute of Standards and Technology, 1991.
3. Stephen F. Webber, "A Modified Analytic Hierarchy Process for Automated Manufacturing Decisions," *Interfaces*, Vol. 23, Number 4, pp. 75-84, July-August 1993.
4. Gregory A. Norris and Harold E. Marshall, *Multiattribute Decision Analysis Method for Evaluating Buildings and Building Systems*, NISTIR 5663, National Institute of Standards and Technology, 1995.

The User's Guide to the Expert Choice Software was authored by Robert Chapman and Harold Marshall.





5. Robert E. Chapman, Harold E. Marshall, and Ernest H. Forman, "User's Guide to AHP/Expert Choice® for ASTM Building Evaluation," MNL 29, *American Society for Testing and Materials*, West Conshohocken, PA, 1998.

9.7 BEES: BUILDING FOR ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY

The building industry needs a tool to measure and balance the environmental and economic performance of building products, covering multiple environmental and economic impacts over the entire life of the product. Many product claims and strategies are now based on a single life-cycle stage or a single impact. A product is claimed to be green simply because it has recycled content, or cost-effective simply because it has a low first cost. These single-attribute claims may be misleading because they ignore the possibility that other life-cycle stages, or other environmental impacts, may yield offsetting impacts. For example, the recycled content product may have a high embodied energy content, leading to resource depletion, global warming, and acid rain impacts during the raw materials acquisition, manufacturing, and transportation life-cycle stages. Or the low-first-cost product may have a short, maintenance-intensive life, leading to a high life-cycle cost.

The BEES methodology, first developed by Barbara Lippiatt in the summer of 1994, takes a multidimensional, life-cycle approach [1, 2]. It is relatively straightforward to select products based on minimum life-cycle economic impacts because building products are bought and sold in the marketplace. But how do we include life-cycle environmental impacts in our purchase decisions? Environmental impacts such as global warming, water pollution, and resource depletion are for the most part economic externalities. That is, their costs are not reflected in the market prices of the products that generated the impacts. Moreover, even if there were a mandate today to include environmental "costs" in market prices, it would be nearly impossible to do so due to difficulties in assessing these impacts in economic terms. How do you put a price on clean air and clean water? What is the value of human life? Economists have debated these questions for decades, and consensus does not appear likely.

While environmental performance cannot be measured on a monetary scale, it can be quantified using the evolving, multi-disciplinary approach known as environmental life-cycle assessment (LCA). The BEES methodology measures environmental performance using an LCA approach, following guidance in the International Standards Organization 14040 series of standards for LCA. LCA is a "cradle-to-grave," systems approach for measuring environmental performance. The approach is based on the belief that all stages in the life of a product generate environmental impacts and must therefore be analyzed, including raw materials acquisition, product manufacture, transportation, installation, operation and maintenance, and ultimately recycling and waste management. An analysis that excludes any of these stages is limited because it ignores the full range of upstream and downstream impacts of stage-specific processes. LCA thus broadens the environmental discussion by accounting for shifts of environmental problems from one life-cycle stage to another, or one environmental medium (land, air, water) to another. The benefit of the LCA approach is in implementing a trade-off analysis to achieve a genuine reduction in overall environmental impact, rather than a simple shift of impact.

Economic performance is separately measured using ASTM standard E 917 life-cycle cost (LCC) approach. The environmental and economic performance measures are then synthesized into an overall performance measure using ASTM standard E 1765 for Multi-attribute Decision Analysis. For the entire BEES analysis, building products are defined and classified based on UNIFORMAT II, the ASTM E 1557 standard classification for building elements.

The BEES approach is applied to 200 building products in the Windows-based decision support software, BEES 3.0 [3]. It evaluates generic products for 23 building elements, including framing, exterior and interior wall finishes, wall and roof sheathing, ceiling and wall insulation, and roof and floor

Barbara Lippiatt, developer of BEES.

BEES 3.0®

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coverings. Each product category contains detailed performance data for competing products. For example, the "floor covering" category surveys cork flooring, ceramic tile, linoleum, vinyl tile, and different types of carpets, marble, and terrazzo. Environmental performance data are collected under contract by Environmental Strategies and Solutions, Inc. and PricewaterhouseCoopers.

The environmental impact analysis measures the product's impact on global warming, acidification, eutrophication (the unwanted addition of mineral nutrients to the soil and water), indoor air quality, fossil fuel depletion, habitat alteration, criteria air pollutants, water intake, ozone depletion, smog, and ecological toxicity. The BEES user specifies the relative importance weights used to combine environmental and economic performance scores and may test the sensitivity of the overall scores to different sets of relative importance weights.

In the first week after BEES 3.0 was released, over 1,000 copies were requested. Users represent a broad spectrum on interests including design, construction, manufacturing, research, Federal/state/local government, and education. BEES is prominently listed and described as a key tool for carrying out Executive Order 13101, "Greening the Federal Government" in the Final Guidance issued by the EPA Environmentally Preferable Purchasing Program. This guidance document applies to the $200 billion in annual Federal purchases. In addition, BEES is currently taught at the University of Michigan, University of Florida, Georgia Tech, Texas A&M, Air Force Institute, and in Korea, Saudi Arabia, and Indonesia.

References

1. Barbara C. Lippiatt, BEES: Balancing Environmental and Economic Performance, *The Construction Specifier*, Vol. 51, pp. 35-42, 1998.
2. Barbara C. Lippiatt, "Selecting Cost-Effective Green Building Products: BEES Approach," *Journal of Construction Engineering and Management*, Vol. 125, pp. 448-455, 1999.
3. Barbara C. Lippiatt, *BEES 3.0: Building for Environmental and Economic Sustainability Technical Manual and User Guide*, NISTIR 6916, National Institute of Standards and Technology, 2002.

9.8 UNIFORMAT II ELEMENTAL CLASSIFICATION FOR BUILDING SPECIFICATIONS, COST ESTIMATION, AND COST ANALYSIS

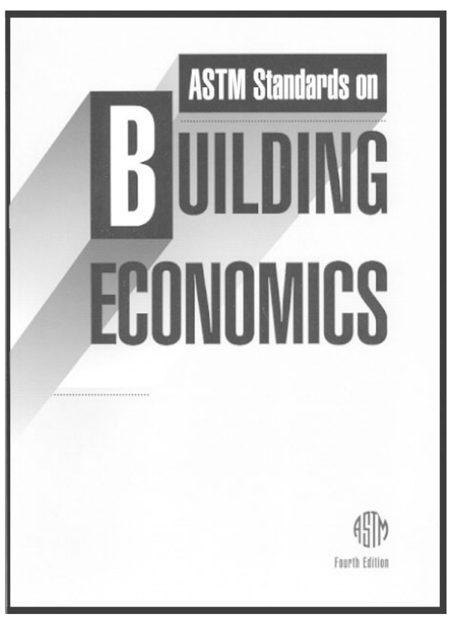
The building community needs a classification framework to provide a consistent reference for the description, economic analysis, and management of buildings during all phases of their life cycle. This includes planning, programming, design, construction, operation, and disposal. An elemental classification best meets these needs. Elements are major components, common to all buildings, that usually perform a given function regardless of design specification, construction method, or materials. Examples of elements are foundations, exterior walls, sprinkler systems, and lighting. The need for an elemental classification is most apparent in the economic evaluation of building alternatives at the design stage. Cost estimates based on lists of products and materials are time consuming and costly in early design. Yet it is in the early stages of design that economic analysis is most helpful in establishing economically efficient choices among building alternatives. An elemental classification can provide needed cost information in the most cost-effective manner.

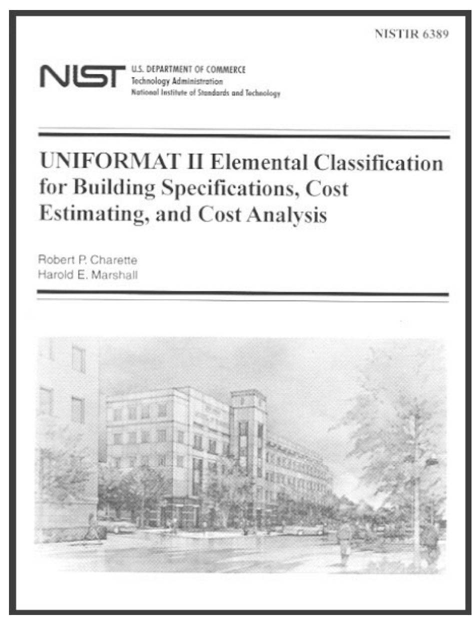
The major challenge to implementing an elemental format for building evaluations is to move the industry beyond the traditional practice of estimating costs of alternative designs via detailed quantity takeoffs of all materials and tasks associated with construction. For example, MasterFormat 95™, a classification published by the Construction Specifications Institute (CSI), is based on products and materials. While this is a logical format when preparing detailed cost estimates of the final design choice, it is time consuming and costly to apply early in the design process when establishing economically efficient choices among building alternatives. An alternative format is needed that is elemental-based and widely accepted in the construction industry.

Robert Charette, a Value Engineering Specialist in Canada, Harold Marshall of the Office of Applied Economics in BFRL, and Brian Bowen of Hanscomb Ltd. teamed up to develop an elemental classification of building elements for ASTM's consideration as a standard classification. ASTM was chosen as the organization for delivery of the new format because it has the consensus balloting process important in creating widespread acceptance, a standing committee on building economics with interest in the standard, and a prospective customer base of 32,000 members from over 100 countries.

The authors call their three-level hierarchical format UNIFORMAT II. It is based in part on a 1973 elemental classification developed for the General Services Administration (GSA) and the American Institute of Architects (AIA), in part on formats used by U.S. defense agencies, and in part on the team's judgment as to what kind of classification is needed in the modern electronic era. The team's initial NIST report [1] became the basis for ASTM's UNIFORMAT II standard classification, E 1557 [2] first issued in 1993. Representatives from CSI, AIA, R. S. Means, Department of Defense, GSA, and the American Association of Cost Engineers were invited to the ASTM work sessions to ensure that the standard met their needs. CSI became the secretariat to the ASTM task Group on UNIFORMAT II to ensure that CSI's forthcoming UniFormat™ would be compatible with ASTM's UNIFORMAT II.

The ASTM UNIFORMAT II standard classification has been adopted by the U.S. State Department for embassy bids worldwide; Whitestone Research in its Building Maintenance and Repair Cost Manuals; Hydro Quebec for the condition assessment of its 700 buildings; state governments such as Kansas and Massachusetts for building budgeting and programming; R. S. Means for Structuring its Assemblies Cost Data





UNIFORMAT II, co-authored by Harold Marshall, was adopted as an ASTM standard.

(in 2002); and by software products dealing with costs of construction-NIST's Building for Environmental and Economic Sustainability (BEES), NIST's BridgeLCC, and HPT-Buildwrite's Schematic Phase Elemental Project Template. The GSA has adopted a slightly modified version for cost estimates of U. S. government office buildings. CSI and the Design-Build Institute of America have developed jointly a software product for design-build estimating called PerSpective™ that is based on a slightly modified UNIFORMAT II and CSI's UniFormat™ hardcopy and software versions are generally consistent with UNIFORMAT II.

Adoption of UNIFORMAT II is reducing life-cycle costs in all phases of the building life cycle. And as owners and builders use commercial cost databases, e.g., from R. S. Means, that are structured according to UNIFORMAT II, these cost reductions will magnify. Some specific benefits from UNIFORMAT II are as follows:

1. Elemental cost estimates are faster and less costly to generate than detailed estimates. This yields savings in preparing the estimates and encourages the consideration of design tradeoffs early in the design process, when the greatest savings are possible from efficient design choices.
2. Data entered in a consistent format will never have to be reentered again, allowing cradle-to-grave electronic tracking of the building and its components.
3. All stakeholders in the construction process will share better information, generated at lower cost, because data are linked to a common, standardized structure.
4. Using a standardized format for collecting and analyzing historical data for use in budgeting and estimating future projects will save time and produce better estimates.
5. Tracking building condition assessments will help facility managers be more efficient in maintaining buildings.
6. Making performance specifications in standard elemental terms promotes the use of design-build contracts by making them more understandable to the participating parties.

References

1. Brian Bowen, R. P. Charette, and Harold E. Marshall, *UNIFORMAT II-A Recommended Classification for Building Elements and Related Sitework*, NIST Special Publication 841, National Institute of Standards and Technology, 1992.
2. *Standard Classification for Building Elements and Related Sitework-UNIFORMAT II, ASTM E 1557*, American Society for Testing and Materials, West Conshohocken, PA, 1997.

9.9 BASELINE MEASURES FOR THE NATIONAL CONSTRUCTION GOALS

The National Science and Technology Council, a cabinet-level group chaired by the president, is charged with setting federal technology policy and coordinating R&D strategies across a broad cross-section of public and private interests. It has established nine research and development committees, including the Committee on Technology, to collaborate with the private sector in developing a comprehensive national technology policy. The purpose of the Committee on Technology is to enhance the international competitiveness of U.S. industry through federal technology policies and programs. The Subcommittee on Construction and Building of the Committee on 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.

The mission of the Subcommittee on Construction and Building-in cooperation with U.S. industry, labor, and academia-is to enhance the competitiveness of U.S. industry and promote public safety and environmental quality through research and development, and to improve the life-cycle performance of constructed facilities. To accomplish its mission, the Subcommittee on Construction and Building has established seven National Construction Goals in collaboration with a broad cross-section of the construction industry. The goals are focused on the four major sectors of the construction industry-residential, commercial/institutional, industrial, and public works.

Data describing current practices of the U.S. construction industry are needed to establish baselines against which the industry can measure its progress towards achieving the seven National Construction Goals. The seven National Construction Goals are concerned with: (1) reductions in the delivery time of constructed facilities; (2) reductions in operations, maintenance, and energy costs; (3) increases in occupant productivity and comfort; (4) reductions in occupant-related illnesses and injuries; (5) reductions in waste and pollution; (6) increases in the durability and flexibility of constructed facilities; and (7) reductions in construction worker illnesses and injuries.

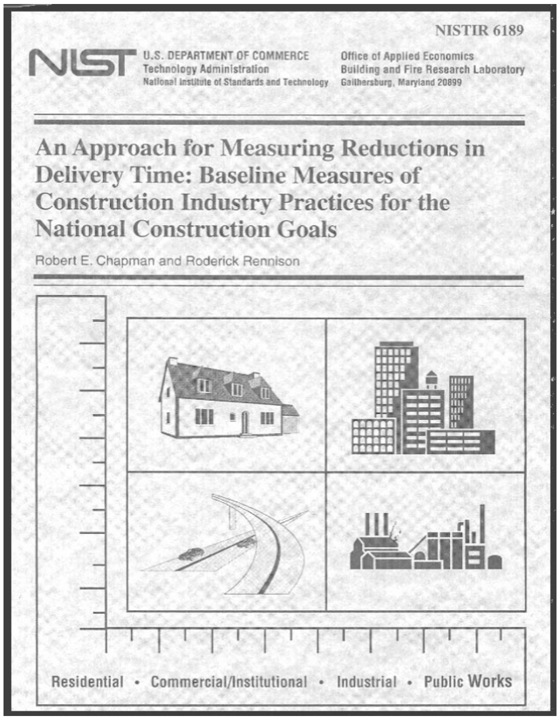
Goals 1, 2, and 7 were identified as the highest priority National Construction Goals by the construction industry. Robert Chapman and Roderick Rennison, a visiting researcher from the UK firm of WS Atkins PLC, with funding from the Subcommittee on Construction and Building, produced three reports that provide baseline measures and characterize current industry performance for Goals 1, 2, and 7. Industry performance in 1994 was used as the reference point from which the values of the baseline measures are calculated.

Delivery time is defined as the elapsed time from the decision to construct a new facility until its readiness for service. The report [1] on delivery time explains how delivery time issues affect both industrial competitiveness and project costs. During the initial planning, design, procurement, construction, and start-up process, the needs of the client are not being met. Furthermore, the client's needs evolve over time, so a facility long in delivery may be uncompetitive or partially unsuitable when finally finished. Delays almost always translate into increased project costs due to inflationary effects, higher financial holding costs, and reduced productivity. Furthermore, the investments in producing the facility cannot be recouped until the facility is operational. Owners, users, designers, and constructors are among the groups who will benefit from technologies and practices that reduce delivery time.

The report describes how a well-defined set of metrics is used to develop the baseline measures and measures of progress. Two data classification schemes are used to construct data hierarchies from which key metrics are derived and used to develop baseline measures for the residential sector and three non-residential sectors-commercial/institutional, industrial, and public works. These measures are based primarily on aggregated, project-level data made available by the Construction Industry Institute. A discontinued data series published by the U.S. Bureau of the Census is included as a reference point and for purposes of comparison.

The report [2] on operations, maintenance, and energy (OM&E) costs shows that OM&E is a major factor in the life-cycle costs of a constructed facility. In some cases, OM&E costs over the life of a facility exceed its first cost. However, because reductions in OM&E costs are often associated with increased first costs, facility owners and managers may under-invest in cost-saving technologies. Furthermore, undue attention on minimizing first costs may result in a facility which is expensive to operate and maintain, wastes energy resources, is inflexible, and rapidly becomes obsolete. Finally, because OM&E costs tend to increase more rapidly than the general rate of inflation, facility owners and operators are often forced to reallocate funds to cover OM&E costs. Reductions in OM&E costs produce two types of benefits. First, constructed facilities become more affordable because facility owners and operators are making more cost-effective choices among investments (e.g., design configurations) that affect life-cycle costs. Second, these same facilities better conserve scarce energy resources.

Like the delivery time report, this report describes how a well-defined set of metrics is used to develop the baseline measures and measures of progress. Two data classification schemes are used to construct data hierarchies from which key metrics are derived and used to develop the baseline measures for each of four construction industry sectors: residential sector, commercial/institutional sector, industrial sector, and public works sector. The overview of each sector examines sector size, changes in the sector, and key sector characteristics. Detailed


NISTIR 6189

NIST 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

An Approach for Measuring Reductions in Delivery Time: Baseline Measures of Construction Industry Practices for the National Construction Goals

Robert E. Chapman and Roderick Rennison

Residential • Commercial/Institutional • Industrial • Public Works

NISTIR 6189, co-authored by Robert Chapman.

baseline measures examine operations, maintenance, and energy categories separately. The key OM&E baseline measures for each sector are summarized in tabular form at the end of that sector's chapter.

The third report [3] is on health and safety issues. It shows that health and safety exert a major effect on the competitiveness of the U.S. construction industry. Construction workers die as a result of work-related trauma at a rate higher than all other industries except mining and agriculture. Construction workers also experience a higher incidence of lost workday injuries than workers in other industries do. Although the construction workforce represents less than five percent of the nation's workforce, it is estimated that the construction industry pays about 15 percent of the nation's workers' compensation.

The report describes a well-defined set of metrics used to develop baseline measures, which are based on data published by the Bureau of Labor Statistics. The data cover both nonfatal construction worker illnesses and injuries and construction-related fatalities. The report introduces the concept of a safety practice and gives several examples of safety practices currently in use within the construction industry. An analysis of the impact of safety practice use on reducing nonfatal construction worker illnesses and injuries is based on data provided to NIST by the Construction Industry Institute. The report concludes with a discussion of why the aggressive use of safety practices is a key instrument for achieving the 50 percent reduction in construction worker illnesses and injuries set forth in National Construction Goal 7.

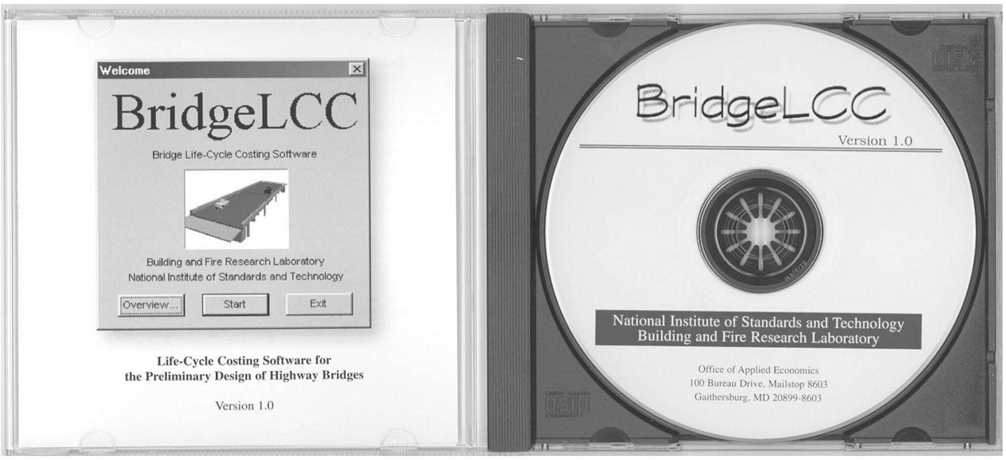
References

1. Robert E. Chapman and Roderick Rennison, *An Approach for Measuring Reductions in Delivery Time: Baseline Measures of Construction Industry Practices for the National Construction Goals*, NISTIR 6189, National Institute of Standards and Technology, 1998.
2. Robert E. Chapman and Roderick Rennison, *An Approach for Measuring Reductions in Operations, Maintenance and Energy Costs: Baseline Measures of Construction Industry Practices for the National Construction Goals*, NISTIR 6185, National Institute of Standards and Technology, 1998.
3. Robert E. Chapman, *An Approach for Measuring Reductions in Construction Worker Illnesses and Injuries: Baseline Measures of Construction Industry Practices for the National Construction Goals*, NISTIR 6473, National Institute of Standards and Technology, 2000.

9.10 BRIDGE LCC

Engineers, designers, and builders need a user-friendly software tool to compare the life-cycle cost of new and alternative construction materials with conventional materials. Mark Ehlen and Harold Marshall developed the theoretical basis for such a tool in a 1996 report [1] on the economics of new technology materials. BridgeLCC [2] was developed in 1999 by Mark Ehlen to provide this type of decision support in software form. Even though the software was specially tailored to compare new and conventional bridge materials, it can be used in comparing alternative conventional materials and for the analysis of civil infrastructures other than bridges.

The first step of a BridgeLCC analysis is for the user to determine construction, maintenance, and disposal costs for the alternatives being evaluated. The user enters this information into BridgeLCC and the software calculates life-cycle costs. Graphs of life-cycle costs by bearer, life-cycle period, and project component can be displayed. This allows for a comprehensive assessment of the advantages and disadvantages, in life-cycle cost terms, of each alternative. If one or more costs are highly uncertain, individual costs can be assigned probability distributions and Monte Carlo simulations performed to examine the likelihood that one of the alternative structures will be cost effective over the range of possible cost outcomes.



BridgeLCC, version 1.0, helps designers evaluate the cost-effectiveness of new construction materials such as high-performance steel and fiber-reinforced-polymer composites.

BridgeLCC 1.0 was released in May 1999. The program had registered users in approximately 40 states and 16 countries. Mark Ehlen received the Department of Commerce Bronze Medal Award in 2000 for his development of BridgeLCC.

BridgeLCC 2.0, by Amy Rushing and Mark Ehlen, is an expanded version of the software. It includes improved Monte Carlo simulation capability, context-sensitive help, a concrete service life prediction tool, and the addition of a Terrorist Risk Management module. BridgeLCC 2.0 is available for download under "software" at http://www.bfrl.nist.gov/oae/oae.html.

References

1. Mark A. Ehlen and Harold E. Marshall, *Economics of New-Technology Materials: A Case Study of FRP Bridge Decking*, NISTIR 5864, National Institute of Standards and Technology, 1996.
2. Mark A. Ehlen, *BridgeLCC 1.0 Users Manual*, NISTIR 6298, National Institute of Standards and Technology, 1999.