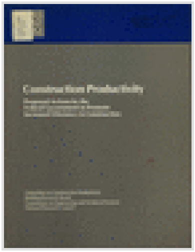

# Construction Productivity: Proposed Actions by the Federal Government to Promote Increased Efficiency in Construction (1986)

Pages
93

Size
7 x 10

ISBN
0309311438

Committee on Construction Productivity; Building Research Board; Commission on Engineering and Technical Systems; National Research Council

# Construction Productivity

## Proposed Actions by the Federal Government to Promote Increased Efficiency in Construction

Committee on Construction Productivit
Building Research Board
Commission on Engineering and Technical Systems
National Research Council (U.S.)



Order from
National Technical
Information Service,
Springfield, Va
22161
Order No. PB 88-183592

NATIONAL ACADEMY PRESS
Washington, D.C. 1986

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competencies and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purpose of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

---

This report was prepared as part of the technical program of the Federal Construction Council (FCC). The FCC is a continuing activity of the Building Research Board (formerly the Advisory Board on the Built Environment), which is a unit of the Commission on Engineering and Technical Systems of the National Research Council. The purpose of the FCC is to promote cooperation among federal construction agencies and between such agencies and other elements of the building community in addressing technical issues of mutual concern. The FCC program is supported by 13 federal agencies: the Department of the Air Force, the Department of the Army, the Department of Commerce, the Department of Energy, the Department of Health and Human Services, the Department of the Navy, the Department of State, the General Services Administration, the National Aeronautics and Space Administration, the National Endowment for the Arts, the National Science Foundation, the U.S. Postal Service, and the Veterans Administration.

Funding for the FCC program was provided through the following agreements between the indicated federal agency and the National Academy of Sciences: Department of Commerce Contract No. 50SBN5C3528; National Endowment for the Arts Grant No. 42-4253-0091; National Aeronautics and Space Administration Contract No. NASW-4029; National Science Foundation Grant No. MSM-8501109, under master agreement 82-05615; and U.S. Postal Service grant, unnumbered.

For information regarding this document, write the Director, Building Research Board, National Research Council, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

Printed in the United States of America

# COMMITTEE ON CONSTRUCTION PRODUCTIVITY

Chairman

DAVID S. HAVILAND, Rensselaer Polytechnic Institute, Troy, New York

Members

LOUIS E. ALFELD, Decision Dynamics Inc. Clayton, Missouri
STEVEN G. ALLEN, North Carolina State University, Raleigh, North Carolina
DONALD S. BARRIE, G. M. Consultants Inc., Diablo, California
HOMER JOHNSTONE, Program Management Associates, San Francisco, California
DORIS LACKEY, International Union of Bricklayers and Allied Craftsmen, Washington, D.C.
CHARLES MERICA, The Pennsylvania State University, University Park, Pennsylvania
MARTIN D. ROBBINS, Colorado School of Mines, Golden, Colorado
RICHARD L. TUCKER, University of Texas, Austin, Texas

Agency Liaison Members

DONALD BOYLE, U.S. Public Health Service, Rockville, Maryland
JOHN A. COOK, Veterans Administration, Washington, D.C.
JIM CHOROMOKOS, Department of the Army, Washington, D.C.
CHARLES CULVER, National Bureau of Standards, Gaithersburg, Maryland
THOMAS R. GANNON, Department of the Navy, Washington, D.C.
DONALD McGARRY, Department of the Air Force, Washington, D.C.
JOHN LANDAHL, Department of the Army, Washington, D.C.
PAUL PLAISANCE, Department of the Navy, Alexandria, Virginia
ROBERT SHERIDAN, National Institutes of Health, Bethesda, Maryland

Staff

HENRY A. BORGER, Executive Secretary, Federal Construction Council
JUDITH G. SCOTT, Editorial Consultant
LENA B. GRAYSON, Senior Secretary
JOANN CURRY, Senior Secretary

# PREFACE

As we seek to best use our national resources and to maintain our international competitiveness, the productivity of the American economy is of major concern to all Americans.

Building--the planning, design and construction of new facilities as well as the ongoing repair and rehabilitation of existing facilities--is especially important. We invest over $300 billion in newly-constructed homes, nonresidential buildings of all kinds, industrial and utility plants, highways and other transportation facilities each year. The productivity of the construction industry directly influences the productivity of <u>every</u> segment of the American economy.

A visit to any construction site, however, will confirm that building is a complex, slow and stubborn business. The products of the construction industry are bulky, complex and expensive. Most are one-of-a-kind designs and, in most cases, the factors of production must be brought to and assembled at a unique site. For each project a temporary multi-organization of people and firms who have different interests and values, who have not worked together, and may not work together again, is brought into being. It is no wonder that there have been so many allegations of low productivity in this critically important industry.

With an estimated $50 billion annual outlay in construction-related expenditures, there is no larger stake-holder in this problem than the federal government itself. Given this reality, the agencies that sponsor the Federal Construction Council asked the Building Research Board to determine what they can do, if anything, to stimulate increased productivity. This is the report of the BRB study committee.

Our charge led us directly into a problem of measurement. As important as construction productivity may be, establishing measures for it has been vexacious. There is not agreement on how best to measure the inputs and the outputs, and easily-understood single-factor measures are inappropriate. The federal government's own measure, which is flawed and no longer published, suggests dramatic decreases in construction productivity over the past 20 years. Some analysts suggest that the situation is not as bad as that. Our conclusion: Depending on who you wish to believe, productivity is poor, or at best, not improving. By any measure it is trailing productivity gains in other sectors of the economy and, given our annual national investment in building, that is a problem.

Solutions? There are no easy ones. Given the nature of the construction process and the lack of concentration in the building industry, we sought an underlying issue which, when substantively addressed, might yield the hope of improvement for all construction projects. Since investments in research and development are generally considered to be effective in improving productivity, we have focused on R&D in all of its forms--from basic research to dissemination and demonstration of what is already known--as a strategy for improving construction productivity in the United States.

In this report, we examine who undertakes construction research in the United States, for what reasons and at what levels of investment. We look at how it compares with R&D investments in other industries and, briefly, with construction R&D in other countries. We critically review past efforts by the federal government to stimulate research or innovation, both in building and in other areas. Finally, we suggest a strategy for significantly increasing the level of research and development committed to construction in general and to construction productivity specifically.

This was a short study done without benefit of vast resources. The study committee acknowledges the contributions made by our federal agency liaison members and most especially by Henry Borger of the BRB staff.

David S. Haviland
Committee Chairman

# CONTENTS

# 1

## EXECUTIVE SUMMARY

During the past 2 decades many individuals and organizations have expressed alarm about an apparent decline in the productivity of the U.S. construction industry, and there have been numerous calls for the federal government to take action to reverse the trend.

The federal agencies that sponsor the Federal Construction Council asked the Building Research Board to assemble a committee of knowledgeable individuals to assess the current state of technology and research related to construction productivity in the United States and to explore the possible roles of federal construction agencies in fostering research and the development of new construction techniques. The committee was formed and conducted its investigation during calendar year 1985. This report presents the results of the committee's work.

The committee affirmed that the federal government has a legitimate interest in the health and productivity of the construction industry, both because the industry is a huge and vitally important element of the national economy (it accounts for more than 8 percent of the gross national product and has a major impact on most other elements of the economy) and because the federal government funds a significant percentage of all U.S. construction work. The committee also affirmed, however, that the construction industry is highly decentralized and complex and is not easily influenced by federal action.

On the basis of a review of the literature and its own analysis, the committee found that it is difficult to show conclusively that construction productivity has actually decreased in recent years or, if it has decreased, to show the magnitude of the decrease. However, most evidence suggests that even if construction productivity has not actually decreased, it probably has not increased very much either. Futhermore, it is almost certain that productivity growth in construction has been slower than in other industries in the United States. The committee concluded that although there is a need for more comprehensive and accurate measurement of construction productivity, efforts to improve productivity need not be deferred until more accurate estimates are available. There is already sufficient evidence that a productivity problem exists to justify action.

Because it has been clearly demonstrated that, as a general rule, productivity is increased through investments in R&D, one of the reasons often given for the current productivity problems of the construction industry is insufficient R&D.* On the basis of its analysis, the committee determined that:

- The total annual investment in R&D by all elements of the construction community probably amounts to about 0.39 percent of the annual value of construction put in place. Manufacturers of construction materials, products, and equipment probably account for almost 69 percent of all construction-related R&D in the United States, government agencies for about 18 percent, contractors for about 4 percent, and all other elements of the building community (e.g., labor unions, architects, and various engineering disciplines) for about 9 percent.
- The U.S. construction community, including users, manufacturers, contractors, government agencies, and others, probably invest proportionally less in R&D than other U.S. industries and also less than the construction industries in some foreign countries, notably Japan.
- The federal government invests less in construction R&D than in R&D in other fields.

Based on the lack of increase in U.S. construction productivity over the past 20 years and the low rate of investment in construction-related R&D, the committee concluded that construction-related R&D has been inadequate in the United States and needs to be increased. Because of the complexity and diversity of the construction industry, it is impossible to determine precisely how much of an increase in R&D is needed. It is apparent, however, that the current level of investments in R&D is sufficiently low that the amount of R&D could easily be increased several fold before the point of diminishing returns is reached.

The committee also concluded that there is little reason to hope that the needed increase will come from the private sector. Although the existence of a construction-productivity problem has been recognized and discussed for many years, the amount spent on R&D by private

---

*Various economic and sociological factors that are outside of the control of the construction community also have been cited as reasons for the productivity problems of the construction industry (e.g., fluctuations in interest rates, a shift in the nature of the output of the construction industry, and a drop in the average age of construction workers). While such factors probably have contributed to the productivity problem, the committee has focused on the technical and managerial aspects of the construction process itself (i.e., the planning, design, and construction of buildings and similar facilities) because that was its charge and out of conviction that problems with the construction process have been the major cause of the productivity problems, though possibly not the only cause.

members of the construction community (except manufacturers) has remained low. It seems unlikely that the factors that have caused this situation (e.g., the attitudes of those involved and/or the structure of the industry) would change now. Therefore, if there is to be an increase in construction R&D, some direct action by the federal government will be required.

As part of its review of construction-related R&D in the United States, the committee explored whether the current supply of researchers would permit an expanded R&D effort. The committee concluded that while an increase in spending for construction-related R&D might produce a temporary shortage of researchers in various fields who are familiar with the construction process, the shortage would not persist for very long.

The committee next reviewed the history of previous government efforts to promote technological innovation to determine what type of federal construction R&D program (if any) might succeed. The committee concluded that with currently available statistics and analytical tools, it is impossible to determine in terms of macro-economics how federal R&D programs affect the overall economy. Most economists seem to believe intuitively that such programs are beneficial; however, they cannot prove it. Most also believe that federal R&D expenditures do not cause a decrease in private R&D investments.

The committee also found that the results of previous and ongoing federal R&D programs are varied. Some programs have been highly successful, others have failed. Whether a program succeeds or fails seems to depend more on nontechnical considerations than technical ones. Where a federal construction-related R&D program is carefully crafted, it has a good chance of succeeding.

The keys to a successful federal R&D program, the committee concluded, are the following:

- Involve representatives of all segments of the building community in the process of formulating the program, and design the program to address a broad spectrum of needs. For example, the concerns of federal agencies that procure buildings as well as those of agencies that are interested in broader issues should be recognized.
- Concentrate on generic (non-proprietary) problems, opportunities, and issues; avoid involvement in the design, development, manufacturing, or marketing of proprietary products or concepts.
- Try to get a long term commitment to the program from Congress.
- Design the program to generate numerous small payoffs over an indefinite period of time; do not promise big results quickly.
- Design the program to cover the full spectrum of R&D projects, from the discovery of new basic knowledge to the development of better methods of disseminating known technology.
- Design the program to permit researchers and research organizations from various segments of the industry to participate.

- Include a mechanism for promoting continuous two-way communications between users of technology (e.g., owners, contractors, designers) and researchers. R&D is of little value if it does not address real problems and important issues and if the results are not widely disseminated.
- Keep the size of the program large enough to ensure that many members of the building community can be involved and that the results of R&D will have widespread inpact, but not so large that it becomes a target for budget cutting.
- Find a mechanism for funding the program that helps give it stability and continuity.

The committee also concluded that it would be unrealistic to expect operational agencies to take the lead in performing or funding R&D of a generic nature. Agencies are under almost constant pressure to reduce budgets and expenditures, and most are unwilling to try to defend requests for funds that are not clearly related to their missions. Therefore, the committee concluded that the initiative would have to come from the Congress, and toward this end it offered the following recommendations:

1. The Congress should formally acknowledge the need for federal leadership in conducting, funding, and coordinating general construction-related R&D, just as it has in agriculture, medicine, transportation, and many other fields. This acknowledged leadership should be reflected in a federal program.
2. In order to ensure the stability of the program, the Congress should consider methods of funding a strong federal R&D program that would provide stability and continuity. Numerous options are available. Congress might consider, for example, providing multi-year authorization and appropriation for the program, establishing a program trust fund of some type, or funding the program through an automatic surcharge on all federal construction appropriations--like the approach that has been used for many years to fund highway research and planning.*
3. In order to ensure that a broad spectrum of construction R&D needs are met, the Congress should provide for the distribution of program funds to the various federal agencies that have construction-related responsibilities; for example, some funds could be allocated to

---

*In FY 1984 the federal government spent a total of almost $44 billion on construction (see Chapter 3). If, for example, a 1.0 percent surcharge had been added to each construction appropriation that year, approximately $440 million would have been generated for construction related research. Inasmuch as federal agencies actually spent about $220 million in FY 1984 on construction R&D, the 1.0 percent surcharge would have increased the FY 1984 budget by only $220 million.

the agencies that are responsible for procuring federal facilities for R&D on the design and construction of such facilities; some funds could be allocated to agencies like the National Bureau of Standards and the National Science Foundation for generic R&D for the entire construction community; and some funds could be allocated to information-generating agencies like the Bureau of the Census and the Bureau of Labor Statistics for the development and publication of more accurate construction statistics.

4. In formulating the program, the Congress should provide a mechanism to ensure that the construction R&D activities of the various federal agencies are coordinated and that information and technology produced through such activities are widely disseminated. To accomplish this, the Congress might consider giving a particular agency overall responsibility for managing the program and distributing R&D funds to other agencies. Alternatively, Congress might permit the various agencies to manage their own R&D programs, but require them to participate in a cooperative, coordination body (either public or private) that would do for construction R&D what the National Research Council's Transportation Research Board has done for highway research for many years. (See Appendix C for a discussion of federal highway research programs and the Transportation Research Board's role in those programs.)

# 2

## INTRODUCTION

For more than a decade, various individuals and organizations have expressed concern and in some cases alarm about declining productivity in the U.S. construction industry. The Business Roundtable (1983)* described the situation as follows:

> Since the closing years of the sixties, productivity in construction has been declining at a rate many industry leaders find appalling. The figures should not be regarded as precise because of statistical deficiencies in the data on which they are based... but they all contain the same disturbing message: A large and increasing gap has opened between the performance of construction and that of U.S. industry as a whole. In 1981, for example, the Commerce Department reported that productivity in new construction put in place had dropped from an index number of 100 in 1972 to an index of 82.9 in 1979--a debilitating decline of nearly 20 percent. The Houston-based American Productivity Center, measuring labor productivity in 11 large sectors of the U.S. economy over a span of three decades, found construction to be the most laggard performer by a wide margin. Since 1965, according to the Center, construction has been the only industry with consistently negative productivity growth. The average annual rate of change was minus 0.9 percent from 1965 to 1973, then dropped 3 percent a year from 1973 to 1979 and an alarming 8 percent a year in 1979-80.

As a reflection of its concern about declining construction productivity, the Business Roundtable published a series of 23 detailed

*The Business Roundtable is a New York City based association in which the chief executive officers of some 200 major corporations meet to address a wide variety of public issues. It began in 1969 as The Construction Users Anti-Inflation Roundtable.

reports (plus two summary reports) presenting 223 specific recommendations for improving the performance of the construction industry--the majority of which were directed entirely or partially at owners (the consumers of the construction industry).

Concern about low construction productivity is not a recent development. It was one of the reasons offered by the Building Research Advisory Board in 1962 in support of a recommended expansion of the building research program of the National Bureau of Standards.

Subsequently, concern about low construction industry productivity was expressed at a number of conferences, including a joint conference of the National Commission on Productivity and the Construction Industry Collective Bargaining Commission in 1972 (National Commission on Productivity, 1972); a conference sponsored by the Stanford Construction Institute in 1975 (Paulson, 1975); a National Research Council (NRC) conference in 1979 (Building Research Advisory Board, 1980); a conference at the National Bureau of Standards in 1981 (Center for Building Technology, 1981); a workshop sponsored by the American Society of Civil Engineers in 1983 (Steering Committee on Civil Engineering Productivity, 1983); and a workshop sponsored by the National Science Foundation in 1984 (Ashley and Tucker, 1984). Numerous recommendations for improving productivity in the construction industry also were made at the conferences.

One way to improve construction productivity mentioned in many of the documents cited above is through increased research and development (R&D). Those recommending more R&D have usually justified it on the grounds that the construction industry currently spends very little on R&D by almost any standard: total dollars, as a percentage of construction expenditures, or when compared to other industries. Among the reasons that have been given for this situation are the fragmented/decentralized nature of the building industry and the uneven demand for construction services. However, it is often asserted that the construction industry will not significantly increase its investment in R&D without some special incentive. The Business Roundtable (1982b) was so skeptical of the industry's willingness to undertake a significant amount of R&D that it recommended the establishment of a new owner-funded R&D organization.

The federal agencies that sponsor the Federal Construction Council (FCC)* have participated in many of the recent conferences and studies on construction productivity, frequently concurring with the resulting conclusions and recommendations. Nevertheless, most of the agencies have hesitated to undertake or fund research aimed at improving construction productivity for several reasons: concern that such research

---

*Department of the Air Force; Department of the Army; Department of Energy; Department of the Navy; Department of State; General Services Administration; National Aeronautics and Space Administration; National Bureau of Standards; National Endowment for the Arts; National Science Foundation; Public Health Service; U.S. Postal Service; Veterans Administration.

would be inappropriate because it is not directly related to the agency's mission; uncertainty about what kind of research is needed; and apprehension that government involvement would be resented by the construction industry. However because the agencies that sponsor the FCC are either construction-industry consumers or sponsors of construction-related research, they feel an obligation to assist the construction industry if their assistance is needed and wanted--particularly if by doing so they can help the government get more construction for the dollar. Thus, the agency sponsors of the FCC requested that the Building Research Board (BRB) of the NRC form a committee to undertake a study of the matter, with the following objectives:

- To assess the current state of technology and research related to construction productivity in the United States.
- To explore the possible roles of federal construction agencies in fostering research and the development of new construction techniques.

## STUDY METHODS

To carry out the study, the BRB appointed an advisory committee with expertise in the organization and operation of the construction industry, construction productivity, and federal and private R&D programs. The committee's membership included representatives from the industry (builders, organized labor, construction management consultants), from academic institutions (representing economics, construction, and architecture), and liaison members from the sponsoring federal agencies.

The committee was asked to complete its study within 9 months. To meet this tight schedule, the committee adopted a number of clear boundaries for its work (see "Scope and Focus of The Study" below) and proceeded at a fast pace. Consequently, the committee could not thoroughly study some aspects of the problem.

The committee met four times in the course of the study. It reviewed and analyzed the current situation in the U.S. construction industry, including the size and nature of the industry, its productivity and technological sophistication, and the amount of research and development performed by and for the industry. It also received briefings on the nature and status of the design and construction research programs of various federal agencies and on related studies carried out by other NRC committees. Finally, the committee discussed and recommended actions that the federal government might take to improve construction productivity. Individual committee members wrote or provided background material for various sections of the report. The complete report was reviewed and edited by the entire committee.

## SCOPE AND FOCUS OF THE STUDY

Before beginning its work, the committee defined several key concepts that would provide necessary and appropriate boundaries to its broad study of construction technology and R&D in the United States.

### Range of Construction Projects Considered

This study considers the full range of construction projects undertaken by and for federal construction agencies rather than focusing on one segment of the industry (e.g., residential buildings, commercial buildings, industrial buildings, road construction, or utility construction). The construction industry is often divided into such segments, for it involves various people, skills, organizations, technologies, contracting methods, financing arrangements, and regulatory mechanisms. However, because the predominant audience for this report is the federal government and since federal agencies collectively manage all types of construction projects, the committee decided to consider the whole range of construction projects.

### Phases of the Construction Cycle Considered

Although this study focuses on the construction phase in the life of a facility, other phases in the life cycle also are considered. There are many phases in the life of a building or similar facility. They are conceived, planned, designed, and built; then they are used, operated, maintained, repaired, and renovated; and eventually they are demolished or replaced. Thus, in looking for productivity improvements in construction, all phases of the life cycle of facilities need to be considered. Indeed it can be argued that the most significant productivity gains often stem from efforts taken during the early phases of a project. Consequently, although this study is primarily concerned with construction productivity improvements--and especially R&D to improve productivity during construction--other phases of the process also have been considered to the extent that they directly affect the construction phase.

### Aspects of Construction Considered

This study considers both the technical and nontechnical aspects of the construction process. Often, construction productivity is discussed from a narrow perspective, for example in terms of one of the following: the design of the facility, its component parts, the technology of construction, the management of the design and construction process, or legal considerations in construction. However, because the committee believes that construction productivity is affected by many factors simultaneously, it agreed that this study should not ignore any aspect of the design and construction process. On the other hand, the committee did not focus on broad economic and sociological factors like fluctuations in the money supply and the average age of construction workers, which may affect construction productivity but are outside of the control of the construction community.

## Nature of R&D Activities Considered

This study takes a broad view of research and development activity. Over the years there have been heated debates about the nature of the R&D process and the appropriate type of R&D activity. The committee takes the view that R&D is a broad activity that includes basic research (the discovery of new insights and concepts) and the demonstration, application, and dissemination of known technology.

# 3

# SIZE AND NATURE OF THE U.S. CONSTRUCTION INDUSTRY

Construction productivity is or should be a matter of national concern by virtue of the size of the industry and its importance to the national economy. Because the industry is tremendously complex and diverse, however, efforts at the national level to influence its course may be hindered.

## SIZE OF THE INDUSTRY

Defining and measuring the size of the construction industry is difficult because of its fragmented nature and because construction activities frequently overlap or can be included as part of another industry. For example, construction contracts frequently call for the installation of such items as carpeting, home appliances, production equipment, and telephone systems, which are not usually considered construction products and which could be installed independently of the construction process. The question arises: Should the purchase and installation costs of such items be included in construction industry statistics? There are countless interfaces like these between the construction industry and other industries that create statistical grey areas. The problem is complicated by the fact that national statistics on construction are based mainly on data from construction contracts, which vary widely in what they include. Consequently, experts often disagree about the size of the construction industry.

One measure of the size of the U.S. construction industry is the dollar value of construction work. The most widely used statistics on construction volume are those on the value of new construction put in place in the United States, which are developed by the Bureau of the Census of the U.S. Department of Commerce. Table 1 shows the value of new construction put in place in the United States in 1984 for various categories of facilities. Of the 1984 total of almost $313 billion, approximately $258 billion was private construction and $55 billion was public (federal, state, and local government) construction.

TABLE 1 Value of New Construction Put in Place in 1984 (millions of current dollars)

| Type of Construction | Value |
|---|---|
| **Private Construction** | |
| Residential buildings: | |
| New housing units | 114,620 |
| Non housekeeping (e.g. hotels) | 7,000 |
| Additions and alterations | 23,440 |
| Total | 145,059 |
| Nonresidential buildings: | |
| Industrial | 13,745 |
| Office | 25,940 |
| Other commercial | 22,167 |
| Religious | 2,132 |
| Educational | 1,411 |
| Hospital and institutional | 6,297 |
| Miscellaneous | 2,455 |
| Total | 74,147 |
| Farm nonresidential | 2,860 |
| Public utilities: | |
| Telephone and telegraph | 7,174 |
| Railroads | 3,671 |
| Electric light and power | 19,473 |
| Gas | 3,233 |
| Petroleum pipelines | 271 |
| Total | 33,822 |
| All other private | 1,912 |
| Total, private construction | 257,801 |
| **Public Construction** | |
| Buildings: | |
| Housing and redevelopment | 1,636 |
| Industrial | 1,828 |
| Educational | 5,557 |
| Hospital | 2,039 |
| Other | 6,822 |
| Total | 17,883 |
| Highways and streets | 16,294 |
| Military facilities | 2,839 |
| Conservation and development | 4,654 |
| Sewer systems | 6,241 |
| Water supply facilities | 2,621 |
| Miscellaneous public | 4,654 |
| Total, public construction | 55,186 |
| Total, all construction | 312,987 |

SOURCE: Bureau of the Census (1985).

The size of the construction industry also can be expressed as a percentage of the Gross National Product (GNP). Using the latest figures available from the Department of Commerce, the construction industry accounted for 8.1 percent of the GNP in 1983 and 8.5 percent in 1984.

Another measure of the size of the industry is employment. Data collected by the Bureau of Labor Statistics (BLS) (1985) show that employment in the U.S. construction industry in July 1985 was 4.99 million, which amounted to 4.6 percent of those employed in the United States. However, the BLS data only include people employed by construction companies; they do not include, for example, workers employed by manufacturers of building products, construction workers in non-construction companies (e.g., "force account" workers), or architects, engineers, and others employed by design firms. If these workers had been included, construction industry employment would probably be in proportion to the industry's share of the GNP; thus it would probably total more than 8 percent of the national work force--more than 8.6 million workers.

The Department of Commerce and BLS statistics cited here demonstrate conclusively that the construction industry is a huge and vitally important part of the U.S. economy. However, the industry may be even larger than the government statistics indicate. The Business Roundtable (1982d) believes that the Department of Commerce statistics understate the size of the construction industry by failing to include some projects or portions of projects, particularly industrial. Specifically, the Roundtable has presented evidence that the Department of Commerce statistics for 1979 understated industrial construction volume by almost 79 percent ($54 billion) and total construction volume by almost 24 percent ($71 billion).

## NATURE OF THE INDUSTRY

The most notable characteristic of the U.S. construction industry is its diversity and decentralization, which some refer to as fragmentation. There are almost 1 million general and specialty contractors in construction, (Business Roundtable, 1983), over 50,000 architect and consulting engineering firms (American Business Lists, 1985), over 25,000 building material dealers (American Business Lists, 1985), 15 major building and construction unions with more than 7,000 U.S. locals (personal communications with the various unions, 1985), at least 180 construction-related trade associations (Columbia Books, 1984), and more than 10,000 building code jurisdictions (Council of American Building Officials, personal communication, 1985).

### Elements of the Industry

The construction industry, like all large institutions, can be subdivided into parts, and there are various ways of doing so. As discussed under "Size of the Industry," one method of subdivision is on the basis of the type of facility constructed: residential buildings, residential additions, industrial buildings, office buildings, religious buildings, educational buildings, warehouses, hospitals and other institutional buildings, farm construction, telephone and telegraph facilities, gas distribution systems, electric power systems, railroads, petroleum pipelines, highways and streets, military facilities, conservation and development projects, sewer systems, and water supply facilities.

Because of the decentralized nature of the industry, it is sometimes asserted that there is not a single U.S. construction industry but several separate industries, each organized to construct a particular type of facility. For example, a specialized group of contractors, architects, material suppliers, and developers finance, design, and construct most single family residences. Their methods, materials, and contractual arrangements are different from those used for other types of construction. The construction of highways and streets, certain types of industrial facilities, and some utility work usually is also handled by specialist groups.

Another way to subdivide the construction industry is by services performed in the construction process. These include services by developers and owners, architects, engineers of various kinds, general contractors and construction managers, specialty (sub-) contractors, material and product manufacturers, material and product dealers, construction equipment manufacturers, construction equipment dealers, construction workers, labor unions, and government regulatory bodies.

Occasionally, the construction industry is described in terms of the phases in the life cycle of a facility, for example, programming and planning, design, bidding, construction, operation and maintenance, and demolition. Or in some cases, the industry is subdivided on the basis of the construction techniques used (e.g., "stick" building, prefabrication, modular construction, curtain wall construction, systems building) or the structural materials used (e.g., brick, stone, reinforced concrete, steel, concrete blocks, bricks and blocks, and wood).

## Size of Construction Firms

Although the construction industry is highly fragmented and composed of thousands of independent businesses, not all construction-related firms are small. In 1984, for example, 210 U.S. construction companies had contracts totaling more than $100 million each, and 18 companies had contracts totaling more than $1 billion each, just for work in the United States (Engineering News Record, April 18, 1985). Furthermore, the largest 25 construction firms accounted for almost one third of all non residential construction. Some design firms (engineers and architects) also are quite large; 17 firms had billings totaling $100 million or more in 1984, and another 24 firms had billings totaling $50 million or more (Engineering News Record, May 16, 1985).

TABLE 2 Profiles of Typical Construction Projects

| Craft | Buildings[a] | Light Industrial[b] | Heavy Industrial[c] | Power[d] |
|---|---|---|---|---|
| | Labor Shares (percent) | | | |
| Boilermakers | 1 | 1 | 2 | 11 |
| Carpenters | 16 | 14 | 8 | 9 |
| Cement finishers | 7 | 4 | 2 | 1 |
| Electricians | 11 | 10 | 18 | 15 |
| Equipment operators | 4 | 5 | 5 | 7 |
| Insulators | 1 | 2 | 4 | 2 |
| Instrument | 1 | 3 | 5 | 1 |
| Ironworkers | 14 | 9 | 7 | 10 |
| Masons | 4 | 6 | 1 | 1 |
| Millrights | 1 | 3 | 4 | 3 |
| Laborers/helpers | 17 | 14 | 10 | 13 |
| Painters | 4 | 3 | 2 | 2 |
| Pipefitters | 9 | 14 | 22 | 18 |
| Riggers | 1 | 1 | 2 | 0 |
| Roofers | 2 | 3 | 1 | 1 |
| Teamsters | 1 | 3 | 2 | 2 |
| Welders | 1 | 2 | 4 | 1 |
| Others | 5 | 3 | 1 | 3 |
| | Cost Distribution (percent) | | | |
| Civil | | | | |
| Earthwork | 4.8 | 4.3 | 3.3 | 6.2 |
| Foundations | 3.3 | 7.2 | 7.5 | 10.4 |
| Structure | 26.9 | 17.2 | 8.2 | 9.7 |
| Enclosure skin | 15.2 | 7.0 | 1.7 | 1.8 |
| Interior finishing | 11.6 | 8.5 | 1.6 | 2.2 |
| Roofing | 2.1 | 3.9 | 1.1 | 0.8 |
| Mechanical | | | | |
| Piping | 3.4 | 11.6 | 23.9 | 16.1 |
| Plumbing | 2.2 | 3.7 | 1.5 | 1.4 |
| Vessels | 2.0 | 1.4 | 7.3 | 3.9 |
| Heating, ventilation, air conditioning | 6.5 | 8.4 | 2.3 | 2.9 |
| Mechanical equipment | 5.4 | 6.0 | 9.9 | 18.5 |
| Other | | | | |
| Special equipment installation | 1.4 | 5.7 | 3.0 | 5.3 |
| Electrical | 8.5 | 11.3 | 15.0 | 14.1 |
| Instrumentation | 1.6 | 2.1 | 6.4 | 2.9 |
| Insulation | 0.8 | 0.9 | 3.8 | 1.6 |
| Coatings, painting | 2.0 | 1.0 | 2.1 | 1.6 |
| Fireproofing | 2.0 | 2.5 | 1.4 | 0.6 |

[a] Average project cost = $25 million; average peak work force = 300.
[b] Average project cost = $120 million; average peak work force = 600.
[c] Average project cost = $190 million; average peak work force = 900.
[d] Average project cost = $470 million; average peak work force = 1,600.

SOURCE: Business Roundtable (1982c).

## Nature of Construction Projects

There is also considerable variety in the nature of construction projects. Table 2 summarizes the results of a survey conducted by the Business Roundtable (1982c) to develop profiles of four types of construction projects in terms of their costs and the work forces used. The four types were buildings, light and heavy industrial projects, and power plants. Many differences were found. For example, whereas civil construction (earthworks, foundation, structure, enclosure skin, interior finishing, and roofing) constitutes two-thirds of the cost of constructing a building, it is less than one-third of the cost of constructing a heavy industrial or power plant project. For those projects, the majority of cost is for mechanical and electrical work. Similarly, whereas almost two-thirds of the craftsmen on building projects perform civil and architectural work, the majority of workers on heavy industrial and power plant projects perform mechanical and electrical work.

## Other Features

Other features distinguish the construction industry from most other industries. Among the most important are the seasonal and weather-sensitive nature of the work (see Employment Standards Administration, 1979), the wide swings in the demand for construction due to the industry's high sensitivity to fluctuation in interest rates; the location of every project at a different site, the fact that most projects involve the construction of one-of-a-kind facility, and finally, the degree to which voluntary standards (published by professional societies and trade associations) and mandatory regulations and building codes (promulgated by countless federal, state, and local government agencies) control construction.

The participants in the construction process, both individually and collectively, have accepted and adapted to these features. To a greater extent than in any other industry, construction workers move from job to job and from company to company with alacrity; firms expand, contract, and relocate with amazing speed; and diverse groups are able to organize quickly into an effective team to carry out a particular project.

# THE FEDERAL ROLE IN CONSTRUCTION

For many years, the federal government has funded a substantial portion of U.S. construction work. Patrick MacAuley (1985) in Construction Review discussed the size and composition of the construction portion of the federal budget for the years 1980 to 1986. Among the points highlighted in the paper were the following:

TABLE 3 Major Construction-Related Direct Federal Programs for Fiscal Years 1980-1986 (millions of dollars)[a]

| Direct Federal Programs[b] | 1980 (actual) | 1981 (actual) | 1982 (actual) | 1983 (actual) | 1984 (actual) | 1985 (estimated) | 1986 (budget) |
|---|---|---|---|---|---|---|---|
| Military construction (10 accounts) | 2,735 | 2,295 | 2,962 | 3,322 | 3,565 | 4,029 | 5,072 |
| Housing, defence family housing (4 accounts), total | 75 | 186 | 194 | 304 | 406 | 436 | 602 |
| Highways and roads | | | | | | | |
| BIA road construction | 76 | 70 | 47 | 45 | 23 | 11 | 3 |
| USFS forest roads and trails | 101 | | | | | | |
| USFS construction and land acquisition | 267 | 486 | 420 | 402 | 292 | 261 | 223 |
| USFS timber purchaser roads | 54 | 53 | 48 | 45 | 38 | 34 | 23 |
| Total | 498 | 609 | 515 | 492 | 353 | 306 | 249 |
| Hospitals and other health facilities | | | | | | | |
| H&HS indian health facilities | 87 | 89 | 65 | 66 | 69 | 58 | 70 |
| NIH building and facilities | 56 | 33 | 25 | 16 | 18 | 19 | 12 |
| VA construction, major projects | 190 | 308 | 345 | 338 | 353 | 425 | 581 |
| VA construction, minor projects | 105 | 96 | 83 | 91 | 123 | 140 | 157 |
| Total | 438 | 526 | 518 | 511 | 563 | 642 | 820 |
| Conservation and development | | | | | | | |
| COE civil construction, general | 1,659 | 1,536 | 1,453 | 1,258 | 1,103 | 1,100 | 980 |
| COE flood control, Mississippi River | 161 | 162 | 247 | 284 | 395 | 350 | 276 |
| COE rivers and harbors contributed funds | 34 | 84 | 65 | 45 | 50 | 56 | 96 |
| Bureau of Reclamation, construction | 437 | 591 | 569 | 600 | 656 | 703 | 700 |
| Fish and Wildlife Service, construction | 86 | 67 | 33 | 19 | 16 | 29 | 23 |
| National Park Service, construction | 137 | 134 | 87 | 106 | 104 | 96 | 93 |
| Tennessee Valley Authority fund | 1,758 | 2,103 | 1,178 | 1,244 | 518 | 1,310 | 1,286 |
| Bonneville Power Administration, construction | 104 | 148 | 192 | 160 | 206 | 234 | 201 |
| Western Area Power Administration, construction | 20 | 37 | 74 | 94 | 105 | 93 | 80 |
| Total | 4,396 | 4,862 | 3,898 | 3,810 | 3,153 | 3,971 | 3,735 |
| Federal industrial structures | | | | | | | |
| Atomic Energy Defense, structures | 397 | 470 | 852 | 920 | 908 | 1,242 | 1,322 |
| Fossil Energy R&D, structures | 137 | 161 | 52 | 10 | 13 | 14 | 4 |
| General science and Research, structures | 81 | 75 | 68 | 66 | 100 | 137 | 62 |
| Uranium enrichment, structures | 272 | 388 | 670 | 647 | 606 | 387 | — |
| Energy supply R&D, structures | 403 | 249 | 161 | 116 | 130 | 134 | 138 |
| Strategic petroleum reserve, structures | 254 | 200 | 158 | 178 | 192 | 241 | 161 |
| Total | 1,544 | 1,543 | 1,961 | 1,937 | 1,949 | 2,155 | 1,687 |
| Other construction-related programs | | | | | | | |
| FAA airport facilities and equipment | 230 | 252 | 292 | 248 | 268 | 500 | 845 |
| Coast Guard acquisition, structures | 32 | 29 | 30 | 55 | 54 | 62 | 61 |
| BIA general construction | 30 | 77 | 108 | 88 | 101 | 128 | 97 |
| FPS Prison building and facilities | 16 | 23 | 15 | 18 | 52 | 68 | 100 |
| Washington airport construction | 6 | 26 | 13 | 14 | 18 | 23 | 20 |
| Architect of Capitol, construction | 30 | 49 | 32 | 15 | 13 | 39 | 46 |
| NASA construction of facilities | 140 | 147 | 109 | 108 | 109 | 167 | 162 |
| Social Security Administration, construction | 32 | 16 | 33 | 48 | 38 | 44 | 37 |
| GSA federal buildings, construction | 11 | 34 | 43 | 179 | 122 | 202 | 49 |
| GSA federal buildings, repair | 87 | 139 | 148 | 168 | 265 | 279 | 357 |
| BIA energy conservation | 0 | [c] | 63 | 224 | 90 | 137 | 62 |
| Total | 614 | 792 | 886 | 1,165 | 1,130 | 1,649 | 1,836 |
| Total, 36 major direct federal programs | 10,300 | 10,813 | 10,934 | 11,541 | 11,119 | 13,188 | 14,001 |

[a]Does not include U.S. Postal Service construction, which totaled $232 million in 1982, $394 million in 1983, $585 million in 1984, and will total approximately $783 million in 1985.
[b]BIA, Bureau of Indian Affairs; USFS, U.S. Forest Service; H&HS, Health and Human Services; NIH, National Institutes of Health; VA, Veterans Administration; COE, Corps of Engineers; FAA, Federal Aviation Administration; FPS, Federal Prison System; NASA, National Aeronautics and Space Administration; GSA, General Services Administration.
[c]Less than $500,000.

SOURCE: Construction Review (March-April, 1985).

- Construction-related federal expenditures for fiscal year (FY) 1984 (which ended September 30, 1984) totaled almost $43.8 billion, of which approximately $11.1 billion were used for direct federal purchases (i.e., the 36 programs listed in Table 3), $21 billion were spent on 26 grant-in-aid programs (e.g., for highways, community development, and airports), and $11.6 billion were distributed under 30 construction-loan programs (e.g., for rural electrification, small businesses, and housing). Construction-related federal expenditures for FY 1985 are expected to total about $50.5 billion.
- During FY 1984, federal expenditures accounted for at least 15 percent of the value of all new construction put in place, and 65 percent of total public works construction. In addition to funding all federally-owned construction, the federal government also funded over 56 percent of state and local government-owned construction and at least 5 percent of all privately-owned construction (see Table 4).
- Federal spending for construction has grown most rapidly in the following categories: military facilities, highways, and rural electrification. Spending for federal hospitals, conservation and development, sewage treatment facilities, federal industrial facilities, and housing has remained level or has increased only modestly (see Table 5).
- Construction-related expenditures have accounted for a declining share of total federal expenditures in recent years. In FY 1980 they accounted for 7.9 percent of total federal spending plus lending, but by FY 1984 they accounted for only 4.9 percent.
- In addition to spending $43.8 billion on programs directly related to construction in FY 1984, the federal government also spent $38.8 billion on programs that are indirectly or only partially related to construction (e.g., the National Flood Insurance Fund, general revenue sharing grants, farm ownership loans, subsidized housing programs, General Services Administration real property operations, the hazardous waste superfund, and defense family housing maintenance). In FY 1984 the federal government also guaranteed $43.5 billion in construction-related loans for such things as housing, rural electrification, and energy resources development.

## SUMMARY

The construction industry is a huge and vitally important element of the national economy. It accounts for more than 8 percent of the GNP and has a major impact on most other elements of the economy. The federal government must be concerned with the health and productivity of the construction industry both because of the importance of the industry to the economy and because directly or indirectly the federal government funds a significant percentage of all U.S. construction work. However, the construction industry is extremely complex and decentralized; consequently, its basic structure and method of operation are not easily directed or influenced by federal actions.

TABLE 4 Federal Construction-Related Expenditures by Ownership Category for Fiscal Years 1980-1986 (millions of current dollars)

| Ownership Category | 1980 (actual) | 1981 (actual) | 1982 (actual) | 1983 (actual) | 1984 (actual) | 1985 (estimated) | 1986 (budget) |
|---|---|---|---|---|---|---|---|
| Government-owned | | | | | | | |
| Federal | 10,300 | 10,813 | 10,871 | 11,317 | 11,029 | 13,051 | 13,939 |
| State and local | 26,081 | 27,753 | 15,285 | 24,758 | 24,142 | 27,649 | 26,496 |
| Total | 36,381 | 38,566 | 36,156 | 36,075 | 35,171 | 40,700 | 40,435 |
| Privately-owned | | | | | | | |
| Residential | 7,539 | 8,321 | 8,115 | 8,437 | 6,044 | 6,264 | 3,666 |
| Nonresidential | 5,090 | 5,556 | 3,537 | 2,940 | 2,549 | 3,545 | 2,205 |
| Total | 12,629 | 13,877 | 11,652 | 11,377 | 8,593 | 9,809 | 5,871 |
| Total construction expenditures | 49,010 | 52,443 | 47,808 | 47,452 | 43,764 | 50,509 | 46,306 |

SOURCE: Construction Review (1985).

TABLE 5 Federal Construction-Related Expenditures by Types of Construction for Fiscal Years 1980-1986 (millions of current dollars)

| Type of Construction | 1980 (actual) | 1981 (actual) | 1982 (actual) | 1983 (actual) | 1984 (actual) | 1985 (estimated) | 1986 (actual) |
|---|---|---|---|---|---|---|---|
| Military construction | 2,735 | 2,295 | 2,962 | 3,332 | 3,565 | 4,029 | 5,072 |
| Highways and roads | 9,011 | 9,197 | 8,180 | 9,469 | 10,584 | 13,186 | 13,943 |
| Hospitals and other health facilities | 552 | 630 | 601 | 564 | 577 | 674 | 846 |
| Conservation and development | 4,708 | 5,261 | 4,287 | 4,147 | 3,538 | 4,438 | 3,970 |
| Sewage treatment facilities[a] | 4,343 | 3,881 | 3,756 | 2,983 | 2,623 | 2,740 | 2,650 |
| Federal industrial | 1,544 | 1,543 | 1,961 | 1,937 | 1,949 | 2,155 | 1,687 |
| Housing | 7,733 | 9,329 | 9,041 | 9,215 | 6,603 | 6,700 | 4,268 |
| Other construction-related | 18,384 | 20,307 | 17,020 | 15,815 | 14,325 | 16,587 | 13,870 |
| Total | 49,010 | 52,443 | 47,808 | 47,452 | 43,764 | 50,509 | 46,306 |

[a]FmHA water and sewer loans and grants are classified as "other construction-related."

SOURCE: Construction Review (1985).

# 4

# CONSTRUCTION PRODUCTIVITY IN THE UNITED STATES

## PRODUCTIVITY MEASURES

Productivity measures are used to make comparisons of technical efficiency across different production units for a given time period or across different time periods for given production units. Any production process can be viewed as transforming certain inputs (land, labor, capital, and materials) into a good or service (such as a building or a haircut). Productivity is defined as the ratio of output to inputs. Increasing productivity is an important economic objective because it allows more goods and services to be produced from the same set of inputs.

### Single-Factor and Multifactor Measures

There are two basic approaches to measuring productivity: single-factor and multifactor measures. Single-factor measures use only one input in the denominator. The most commonly used measure of productivity is labor productivity, the ratio of output to either employment or labor hours. In construction, square footage and dollar value put in place per hour are commonly used indicators of labor productivity. In certain situations, other single-factor measures might also be useful, such as capital productivity (the ratio of output to capital input) or land productivity (the ratio of output to land area).

When using any of these single-factor measures, care must be taken to avoid assigning causation of productivity change to whatever input happens to be in the denominator. Increases in labor productivity do not necessarily indicate that workers are becoming more skilled or putting forth greater effort. Higher labor productivity can also result from increases in the quantities of other inputs, especially capital, or changes in technology or organization. In fact, it is possible for labor productivity to increase while capital or land productivity decreases. In such cases, it is very difficult to determine what has actually happened to technical efficiency.

Because interpreting single-factor productivity measures is difficult, the multifactor approach was developed. Multifactor productivity measures use a weighted average of all inputs in the denominator. The weights usually correspond to each input's share of total expenditures. Multifactor measures reflect the joint impact of all inputs on productivity more accurately than single-factor measures because the quantities of all inputs are in effect held constant, whereas only one input is held constant in the single-factor approach. Multifactor measures do not seem to be widely used in construction.

One important conceptual limitation of productivity measures is that they ignore the cost of inputs. Even if a new production technique promises greater productivity, firms will not choose to adopt that technique unless it lowers their costs. One way to take input costs into account is to use a unit cost measure, the ratio of input costs to output. A unit cost measure that is used frequently in construction is cost per square foot.

## LIMITATIONS OF AVAILABLE DATA ON CONSTRUCTION PRODUCTIVITY

### The BLS Productivity Index

The federal government currently does not publish any data on construction productivity. The Bureau of Labor Statistics (BLS) does compute a productivity index for the entire industry, but it is considered to be so deficient that it is not published. Nevertheless, it is widely disseminated and discussed. In the past, BLS also conducted studies on the quantity of labor, equipment, and materials required to build certain types of projects, but this program was discontinued in 1981 to save money.

The unpublished index (Table 6) is computed by dividing value added (total revenue minus subcontracting and expenditures for materials) for all establishments classified as being in the construction industry under the Standard Industrial Code (SIC) system by labor hours for those establishments. In order to make comparisons over time, value added must be adjusted for price changes. Since 1967, this index has indicated that productivity in construction has fallen.

There are three major limitations to the BLS productivity index. The most important of these is the deflator used to adjust for price changes. True price deflators are available for only two types of construction: single family houses and highways. For all other types, which represent two-thirds of the industry, indices of labor and materials costs are used in place of price indices. This causes the deflator to systematically overestimate the rate at which prices are increasing and, thus, underestimate the growth in output and productivity. This happens because the rate of growth in wages is directly related to productivity growth as well as inflation.

A second serious limitation is that this index totally ignores construction work by establishments that are not classified as being in the construction industry. For instance, some power companies use their own crews to build new plants. Because they are classified as public utilities, their construction activity is excluded from the index.

**TABLE 6 Annual Index Values for Output per Employee Hour in the U.S. Construction Industry, 1947-1984 (1977 = 100)**

| Year | Index | Year | Index |
|---|---|---|---|
| 1947 | 71.4 | 1966 | 115.3 |
| 1948 | 77.1 | 1967 | 116.2 |
| 1949 | 77.5 | 1968 | 121.8 |
| 1950 | 81.8 | 1969 | 110.9 |
| 1951 | 83.0 | 1970 | 108.3 |
| 1952 | 84.9 | 1971 | 113.0 |
| 1953 | 89.1 | 1972 | 112.0 |
| 1954 | 93.2 | 1973 | 106.6 |
| 1955 | 93.6 | 1974 | 94.9 |
| 1956 | 93.6 | 1975 | 98.0 |
| 1957 | 96.5 | 1976 | 102.9 |
| 1958 | 103.9 | 1977 | 100.0 |
| 1959 | 105.9 | 1978 | 95.7 |
| 1960 | 109.9 | 1979 | 89.8 |
| 1961 | 112.8 | 1980 | 83.0 |
| 1962 | 114.6 | 1981 | 82.4 |
| 1963 | 114.9 | 1982 | 86.2 |
| 1964 | 117.1 | 1983 | 85.5 |
| 1965 | 118.3 | 1984 | 84.2 |

SOURCE: U.S. Department of Labor, Bureau of Labor Statistics.

The Business Roundtable's Construction Industry Cost Effectiveness (CICE) project recently reported another serious defect in the BLS index. The Business Roundtable (1982a) found that many projects, some costing $5 million or more, are not included in the tabulation of total output. In some cases, companies do not receive requests for data and in others, companies refuse to respond to requests because of the costs involved. Alan Blum (1980) of the Census Bureau presented corroborating evidence of this undercount. Blum found that the Census of Construction in 1977 reported 75 percent more industrial construction and 29 percent more hospital and institutional construction than the Value of New Construction Put in Place series used to estimate total output. The consequences of this undercount of output are not yet clear. If the labor hours used in the omitted projects are also not being counted, then the problems caused by the undercount are identical to those caused by the exclusion of construction work by establishments in other industries. If the labor hours in these projects are being counted, then this exclusion is resulting in an even greater systematic underestimation of output and productivity.

Even if the BLS index were not subject to these limitations, it would be useful mainly for the purposes of economic analysis, not for effective decision making by owners and managers of construction projects. It makes little sense to think that a single aggregate measure could apply to all types of construction; separate measures are needed for each of the major branches of the industry. Because the SIC system classifies establishments in construction as either general (e.g., building, highway) or special trade (e.g., plumbing, electrical) contractors, it is impossible for the federal government to use currently available data to construct measures for a representative spectrum of construction projects.

A few groups of construction company owners have begun to share productivity data collected from their own projects. Although this kind of information is no doubt better than no data at all, it is also likely to be of limited usefulness because it is not derived from random samples.

## IS CONSTRUCTION PRODUCTIVITY DOWN?

Most assertions that construction productivity has dropped in recent years have been based on the BLS productivity index (see Table 6), which, as indicated above, has shortcomings that diminish its value as an indicator of national productivity trends. This does not mean, however, that a construction productivity problem does not exist. Rather, it means that the BLS statistics used to demonstrate the existence of a productivity problem are flawed and must be used with extreme caution.

Several investigators have analyzed the BLS statistics and other data to determine the true magnitude and causes of productivity changes that have occurred. Allen (1985) concluded that the actual drop in labor productivity between 1968 and 1978 was 8.8 percent, not 21.4 percent as indicated by the BLS index. He found that the BLS index overstated the productivity drop primarily because it understated the real output of the construction industry. He attributed the productivity decline that occurred between 1968 and 1978 to "the reduction in skilled labor intensity resulting from the shift in the mix of output from large-scale commercial, industrial, and institutional projects to single-family houses" and, to a lesser extent, to "decline in the average number of employees per establishment, capital-labor ratio, percent union, and the average age of workers."

Stokes (1981) examined several possible reasons for the decline in construction productivity reported by the BLS: a shift in the nature of the output of the construction industry; a reduction in capital equipment used per worker, a drop in the average age of construction workers, changes in work rules, and problems relating to the measurement of productivity. He found that only about 25 percent of the productivity decrease indicated by the BLS index could be explained by these factors. He concluded, therefore, that "the productivity declines in the construction industry during the past decade are real."

Bourdon (1980) concluded that there has not been a severe drop in construction productivity. According to Bourdon, the BLS index is wrong because the deflator used by the Department of Commerce to adjust the value of construction put in place to constant dollars causes output (the numerator in the productivity equation) to be understated, and the fixed labor percentages used by BLS causes the input (the numerator) to be overstated.

Lange and Mills (1979) suggested that the problem is not that the BLS index is wrong per se. Rather, the index fails to account for the fact that facilities now being constructed by the industry are more complex and thus require more labor.

Schriver and Bowlby (1985) examined the causes of changes in square foot costs of buildings between 1972 and 1982. They concluded that there were "substantial declines in total factor productivity in [building] construction during 1980-1982 after adjusting for changes in the composition of output." However, they found no decrease in productivity during the 1972-1979 period.

Ball (1981), an economist in the BLS, used data from the BLS surveys of labor and material requirements for various types of construction activity (which were discontinued in 1981 due to budget cuts) to estimate changes in onsite employee-hour requirements between 1958 and 1976 per deflated dollar of construction for various categories of construction. He found that the number of site hours required had dropped (indicating a productivity increase) for all categories of construction. The average annual change (percent) in labor requirements for those categories in which sufficient data were available were as follows: federally-aided highways, 1958 to 1976, -1.5 percent; federal office buildings, 1959 to 1975, -2.2 percent; public housing, 1960 to 1975, -3.9 percent. For other categories of construction the span of years for which data were available was too narrow to be meaningful.

As an alternative to the BLS productivity index, the committee decided to use data from cost estimating manuals to determine construction productivity trends. Dunlop also suggested this method in 1972. Using manuals published by the Robert S. Means Company, the committee compared the productivity of members of construction crews performing 30 different randomly selected tasks in 1975 and 1985, based on Means' (1974, 1984) data. The results, which are presented in Appendix A, suggest that there was no definite trend in construction productivity between 1975 and 1985, either up or down. Over the 10 year period, output per crew member increased for 13 tasks, decreased for 11 tasks, and remained unchanged for 6 tasks.

Although it is generally agreed that the BLS construction productivity index per se is inaccurate, the index is nevertheless occasionally used to compare the performance of the construction industry with other industries and to track the performance of the industry over a long period of time. Table 7, prepared by Martin Baily (1981), illustrates such usage. The table indicates that productivity increased at a slower rate in the construction industry than in any other industry during the 30-year period from 1948 to 1979, and that problems with construction productivity apparently began in the late 1960s.

## CONCLUSIONS

It is difficult to show conclusively that construction productivity has actually decreased in recent years or, if it has decreased, to show the magnitude of the decrease. However, most evidence suggests that even if construction productivity has not actually decreased, it probably has not increased very much either, which is almost as bad. Furthermore, it is almost certain that productivity growth in construction has been slower than in other industries in the United States.

Undoubtedly, there is a need for more comprehensive and accurate measurement of construction productivity, not just at the macro-economic level, but also for various segments of the industry, types of enterprises, and individual tasks. However, efforts to improve productivity need not be deferred until more accurate estimates are available. There is already sufficient evidence that a productivity problem exists to justify action.

TABLE 7 Annual Growth Rates of Labor Productivity for the Nonfarm Business Sector and for Major Industries, Not Cyclically Adjusted, Selected Periods, 1948-1979

| | Annual Growth Rate of Labor Productivity (percent) | | | | |
|---|---|---|---|---|---|
| Sector and Industry | 1948-1957 | 1957-1968 | 1968-1973 | 1973-1979 | 1948-1979 |
| Nonfarm business[a] | | | | | |
| Manufacturing | 2.64 | 2.82 | 3.52 | 1.51 | 2.63 |
| Nonmanufacturing | 2.14 | 2.76 | 1.04 | 0.25 | 1.82 |
| Industries[b] | | | | | |
| Manufacturing | 2.57 | 2.84 | 2.72 | 1.41 | 2.47 |
| Agriculture | 5.58 | 4.76 | 5.12 | 2.81 | 4.68 |
| Communications | 4.62 | 5.71 | 4.57 | 6.06 | 5.28 |
| Construction | 2.50 | 2.98 | -5.15 | -2.49 | 0.47 |
| Utilities | 6.78 | 5.16 | 3.19 | -0.66 | 4.18 |
| Finance, insurance, and real estate | 2.42 | 1.70 | 0.07 | 0.89 | 1.49 |
| Mining | 4.11 | 4.29 | 0.20 | -5.19 | 1.75 |
| Retail trade | 2.36 | 2.63 | 1.70 | 0.78 | 2.04 |
| Wholesale trade | 2.65 | 3.71 | 3.15 | -0.44 | 2.51 |
| Transportation | 2.94 | 3.36 | 2.51 | 0.12 | 2.47 |
| Services | 1.19 | 1.82 | 2.01 | 0.14 | 1.34 |

[a]Data reflect the 1980 revision of the national income accounts.
[b]The 1980 revision is not yet available by industry, so these data are not directly comparable to other data in this paper.

SOURCE: Bureau of Labor Statistics.

# 5

# CONSTRUCTION-RELATED RESEARCH AND DEVELOPMENT IN THE UNITED STATES

Numerous studies have examined the relationship between productivity and R&D (e.g., see the volume edited by Griliches, 1984). Most researchers have expressed the relationship in terms of a rate of return on money invested in R&D. Although various researchers have calculated widely different rates of return, almost everyone has found that the rate of return is positive (i.e., money invested in R&D produces savings from increases in productivity that exceed the investment). For example, Clark and Griliches (1984) reported an overall rate of return on R&D of 20 percent while Griliches and Lichtenberg (1984) reported a 9 percent rate of return on R&D performed between 1959 and 1963, a 20 percent return on R&D performed between 1964 and 1968, and a 33 percent return on R&D performed between 1969 and 1973.

The fact that R&D can contribute to higher productivity has been recognized for many years. Thus, in the past when productivity problems of the construction industry have been analyzed and discussed, one frequently identified cause has been insufficient R&D (e.g., see Ashley and Tucker, 1984; and Business Roundtable, 1982b, c). However, because investments in R&D can contribute to productivity growth does not necessarily mean that the converse is true: that stagnant productivity is due to inadequate investment in R&D. In fact, various reasons besides insufficient R&D have been given for the lack of productivity growth in construction--for example, lack of investment in capital equipment, the fragmentation of the construction industry, out-of-date management practices, undertrained workers (especially foremen), slow adoption of new technology, jurisdictional disputes among unions, inefficient labor practices, and government regulations. Although such factors may have contributed to the productivity problems of the construction industry, the committee has concentrated on R&D both because that was its charge and out of conviction that inadequate R&D undoubtedly has been a major factor, though possibly not the only factor. Furthermore, it is possible that many of the contributing factors mentioned above would not have been present if more R&D had been performed, particularly R&D relating to the management of construction.

As part of its analysis of the current state of the U.S. construction industry, the committee decided to examine the nature and amount of construction-related R&D actually being conducted in the United States and to try to assess whether the amount is inadequate, as has been asserted. Because, as noted previously, the construction industry is composedof many elements or subgroups, each with special concerns and motivations, the committee examine the R&D activities of the various subgroups separately.

## R&D BY CONSTRUCTION CONTRACTORS

The committee found few statistics on R&D conducted by construction contractors--that is, general and specialty contractors involved in on-site construction. The National Science Foundation (NSF) prepares an annual report on R&D performed by industry (see NSF, 1983); however, the NSF combines R&D performed by construction contractors with R&D performed by other "non-manufacturing industries"--for example, agriculture, forestry, fisheries, mining and extraction, transportation, communications and other public utilities, wholesale and retail trade, finance, insurance, real estate, and selected service industries. Therefore, it is impossible to determine from the NSF data how much construction contractors spend on R&D.

Using data from the Federal Trade Commission's line of business survey of 1974, Scherer (1984) estimated that construction contractors spent $28 million on R&D in 1974, which represents about $54 million in 1984 dollars. (See "R&D by Manufacturers" below for further discussion of Scherer's work.) Although this is not an insignificant amount of money, it is minuscule for the size of the industry, and it does not invalidate the conclusion by many that construction contractors spend almost nothing on R&D (e.g., Business Roundtable, 1982b).

The committee is aware of only a few large contractors that have R&D offices, and many of these are concerned primarily with product evaluation. Some of the construction trade associations have R&D programs, but in general they do not receive much support from contractors. For example, the R&D arm of one of the largest associations, which has many thousands of members, spends only about $150,000/year on R&D requested and funded by association members. (This same association receives approximately $3 million/year for R&D through contracts with various government agencies and private manufacturing corporations.) Most trade associations spend even less or nothing on R&D.

One interesting recent development is the proposal of the International Union of Bricklayers and Allied Craftsmen to greatly increase the R&D program of the International Masonry Institute (which is jointly sponsored by the union and the Mason Contractors Association of America) through collectively bargained payments by masonry contractors. Under the proposal, the annual R&D budget of the Institute would increase from the current level of about $150,000 per year to $20 million per year in ten years. It is presumed that the payments to the Institute would be based on the number of hours worked by union members. (Project 2000 Committee, 1985)

The committee believes that contractors generally have not supported R&D for one or more of the following reasons:

- A belief that onsite construction is a service industry and that responsibility for conducting construction R&D rests primarily with the manufacturers of the equipment, products, and materials used by the industry.
- A belief that it seldom pays a construction contractor to conduct R&D because the results of construction-related R&D generally cannot be patented, and competitors will quickly learn of and use anything worthwhile that is developed.
- A belief that overhead expenses like R&D must be kept to a minimum in order for a construction firm to survive the periods of low activity that are common and inevitable in construction.
- A belief that only very large organizations can afford to conduct R&D.

Although construction contractors do not support R&D, there has been considerable innovation in onsite construction over the years. Much of the innovation, of course, has resulted from the introduction of new equipment and products by manufacturers. However, contractors themselves also have developed new and better work methods. In most cases, such developments have resulted from on-the-job experimentation rather than formal R&D programs; consequently, such developments do not show up in statistics, and their value and cost cannot be measured.

## R&D BY DESIGN PROFESSIONALS

The committee found no published statistics on R&D performed by design professionals (i.e., architects, engineers, and other professionals in private practice who specialize in the design of buildings and similar facilities). The most likely reason for the lack of statistics is that professionals probably spend very little of their own funds on R&D. Whatever the amount, the committee has no doubt that it represents a tiny percentage of annual expenditures on construction-related design services.*

The committee believes that many design professionals do some R&D as a normal part of the design process, and that some design firms occasionally undertake investigations for clients that could be considered R&D. However, it would be difficult to determine how much R&D work of this kind is performed throughout the country because most professional firms do not keep separate records on such work.

---

*The committee estimates that expenditures for construction-related design services average 5 percent of total construction expenditures. Thus for 1984, expenditures for design services probably totaled about $15 billion.

Many design professionals support the R&D programs of the professional societies to which they belong. However, such programs are very small. For example, contributions during the 1984-1985 fiscal year to the research program of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) totaled slightly less than $800,000, and a substantial percentage of that amount came from manufacturers (ASHRAE, 1985). ASHRAE membership totals almost 50,000; thus, the average individual member contributed less than $20. Other professional societies with R&D programs probably receive comparable support from their members.

## R&D BY MANUFACTURERS OF CONSTRUCTION PRODUCTS AND EQUIPMENT

Statistics on R&D by manufacturers are published by many organizations (see Business Week, July 8, 1985; Inside R&D, June 5, 1985; NSF, 1983). Unfortunately, such statistics are of limited value in this study because they show R&D expenditures by categories of products (e.g., appliances, automotive, chemicals, electrical, metals, paper, and steel), which are used partly by the construction industry and partly by other industries. Thus, except for products that are specifically associated with construction, the published statistics do not show how much manufacturers invest in R&D on products used by the construction industry.

The Business Week statistics include one product category, building materials, that is clearly linked to construction; corporations in this category spent $184.1 million on R&D in 1984. A portion of another product category, farm and construction machinery, is also clearly linked to construction; corporations in this category spent $769 million on R&D in 1984. However, it is not known how much of the latter amount was used for construction equipment R&D and how much was for farm equipment R&D.

Scherer (1982, 1984) developed an analytical technique for determining how the benefits of R&D performed by one industry flowed to various other industries. He presents his results in a matrix that shows the pro rata benefits that accrue to various industries from the R&D performed by other industries with which they do business. The starting points for the matrix were the 1972 input-output tables for the U.S. economy and the Federal Trade Commission's 1974 line of business survey. It includes only company financed R&D expenditures.

Scherer's analysis indicates that although the construction industry itself does little R&D, it uses and benefits from R&D performed by other industries (mostly manufacturing). For example, in 1974 the construction industry benefited from approximately $432 million in R&D expenditures from 33 other industries, as indicated in Table 8. In 1984 dollars, these expenditures total more than $838 million. In most cases the construction industry benefited indirectly from R&D performed by other industries through better products and services. It is not known whether such indirectly-acquired R&D has the same impact on productivity as R&D performed by an industry itself.

TABLE 8 Benefits Derived by the Construction Industry from R&D Performed by Other Industries (millions of 1974 dollars)

| Industry | Amount[a] |
| --- | --- |
| Food and tobacco products | 0.3 |
| Textile mill products | 0.8 |
| Lumber and wood products | 0.3 |
| Furniture | 0.6 |
| Paper mill products | 1.4 |
| Printing and publishing | 0.4 |
| Industrial inorganic chemicals | 1.0 |
| Industrial organic chemicals | 0.6 |
| Synthetic resins, fibers, rubber | 1.1 |
| Agricultural chemicals | 0.1 |
| Paints, toiletries, explosives and other chemical products | 16.3 |
| Petroleum extraction and refining | 6.1 |
| Rubber and plastic products | 9.7 |
| Stone, clay, and glass products | 9.0 |
| Ferrous metals | 1.6 |
| Nonferrous metals | 0.4 |
| Fabricated metal products | 17.1 |
| Engines and turbines | 10.2 |
| Farm machinery | 2.4 |
| Construction, mining and materials handling equipment | 154.4 |
| Metalworking machinery | 6.6 |
| Other machinery | 20.5 |
| Computers and office equipment | 2.3 |
| Industrial electrical equipment | 1.8 |
| Household appliances | 0.2 |
| Lamps, batteries, ignition, X-ray and other electrical equipment | 5.7 |
| Radio and communication equipment | 16.1 |
| Electronic components | 1.7 |
| Motor vehicles and equipment | 125.1 |
| Aircraft | 0.5 |
| Measuring and medical instruments, photo equipment and timepieces | 13.9 |
| Miscellaneous manufacturers | 1.6 |
| Construction and services, including R&D services | 2.2 |
| Total | 432.0 |

[a]Share of R&D performed by the indicated industries that benefited construction industry.

SOURCE: Scherer (1984).

## R&D BY CONSTRUCTION INDUSTRY CONSUMERS

Because almost everything man-made that remains stationary is either assembled, installed, or enclosed by the construction industry, almost every person and organization in the country is, at some time, a consumer of the industry. Of course, most individuals and organizations deal with the industry infrequently; consequently, they have no long-term interest in construction technology. There are many organizations,however, that have large, continuing construction programs, and some of these undertake construction-related R&D.

### Private Corporations

The committee found no published statistics on the amount of construction-related R&D by private corporations that are construction consumers. Although the committee knows that such organizations sometimes undertake R&D projects (often through contracts with professional firms and academic institutions), the committee does not know the amount invested in such work each year. The committee is certain, however, that the amount is small in comparison to the construction expenditures of large corporations. The committee also believes that such projects usually deal with problems concerning specific facilities rather than broad issues of concern to the construction industry. Thus, such R&D probably has little impact on construction productivity.

There is evidence, however, of growing interest on the part of large, private construction consumers in R&D on broad issues. For example, large consumers make up most of the membership of the Business Roundtable, which conducted the widely publicized Construction Industry Cost Effectiveness (CICE) study (see Business Roundtable, 1983). In addition, construction consumers comprise approximately one-half of the membership of the Construction Industry Institute (CII), which is undertaking studies of a number of basic issues. Currently, the CII, which is located at the University of Texas, has about 60 members, each of whom contributes $25,000/year.

### Government Organizations

The committee also could find no published statistics on construction-related R&D by state and local governmental organizations that procure construction, except for highway research, and most of the money spent for highway research by state and local governments actually comes from federal agencies.* Nevertheless, the committee is confident that state and local governments spend very little on other construction-related R&D. The committee is aware that several of the associations that serve state and local government officials (e.g., American Association of State Highway and Transportation Officials; and the American Public Works Association) conduct construction-related R&D projects. However, the nature and magnitude of these efforts is not known.

The committee found detailed R&D statistics for only one category of construction consumer--federal government agencies. These statistics are published regularly by the NSF; however, because NSF categorizes R&D by technical discipline, not by the purpose of the R&D, the statistics do not show federal expenditures on construction-related R&D per se.

The NSF R&D category that is most closely associated with construction is civil engineering, and although it is neither exclusively associated with construction, nor the only discipline involved in construction, it is close enough to provide some insight into federal expenditures on construction R&D.

The committee obtained additional information on the construction-related R&D efforts of several agencies through direct briefings (see Appendix B). Table 9 shows the estimated R&D expenditures of various agencies based in part on NSF data and in part on the briefings. On the basis of the briefings, the committee believes that most of the R&D work of the agencies listed deals with the design of agency facilities and not construction technology. Statistics indicate that the construction arms of some agencies (e.g., the Departments of the Army, the Air Force, and Energy) spend substantial amounts on R&D whereas other agencies spend little or nothing.

## R&D BY FEDERAL AGENCIES THAT ARE NOT CONSTRUCTION CONSUMERS

As noted in Chapter 3, several of the federal agencies that are not consumers of the construction industry have an interest in various aspects of construction and consequently conduct or fund some construction-related research. The NSF, for example, provides grants to academic institutions for a wide variety of R&D projects. Similarly, the National Bureau of Standards conducts R&D at its own laboratory on a broad spectrum of construction-related issues. Statistics on the R&D expenditures of these nonconsumer agencies are included in the NSF statistics on federal R&D (NSF, 1984a).

---

*Of the approximately $72 million spent on highway research in the United States in 1982, approximately $1 million was spent by cities and counties and $39 million was spent by state highway departments. However, all but $5 million of the money spent by the states actually came from the U.S. Department of Transportation. Federal agencies also directly funded almost $29 million in highway research directly. (Transportation Research Board, 1984).

TABLE 9 Estimated Annual Construction-Related R&D Expenditures of Federal Agencies Responsible for Procuring Construction (millions of dollars)

| Department/Agency | R&D Expenditures |
| --- | --- |
| Department of Agriculture, | |
| Forest Service | 1.9[a] |
| Department of Defense: | |
| Army Corps of Engineers | 42.7[b] |
| Naval Facilities Engineering Command | 4.0[b] |
| Air Force Civil Engineering | 33.0[b] |
| Department of Energy | 32.2[a] |
| Department of the Interior, | |
| Bureau of Reclamation | 3.3[a] |
| General Services Administration | .2[a] |
| National Aeronautics and Space Administration | 1.0[a] |
| Veterans Administration | 1.0[b] |
| Total | 119.3 |

[a]Source: National Science Foundation (1984a). Includes applied civil engineering research for 1983 and basic civil engineering research for 1984.
[b]Source: Briefings given to the committee (see Appendix B). Includes research, development, testing, and evaluation for FY 1985.

As discussed above, the NSF statistics on civil engineering R&D by federal agencies do not relate to construction per se; they do, however provide a general indication of the level of federal funding for construction-related R&D. Table 10 shows annual expenditures totaling greater than $100 million for civil engineering R&D by agencies that do not procure construction. The committee has no basis for estimating what percentages of that amount might be devoted to R&D on construction technology, on other construction-related matters like design, or on civil engineering topics unrelated to construction.

## R&D BY ACADEMIC INSTITUTIONS

In addition to statistics on R&D expenditures by industry and by federal agencies, the NSF also publishes statistics on R&D expenditures by academic institutions. Recently, NSF (1984b), reported that academic institutions spent almost $107 million on civil engineering research (both basic and applied) in 1983, the last year for which statistics were available. This total is misleading, however, because a substantial portion of the R&D funds spent by academic institutions are provided by federal agencies and private corporations. In fact, the committee believes that academic institutions spend very little of their own funds on construction-related R&D.

## OTHER SPONSORS OF CONSTRUCTION-RELATED R&D

A number of organizations that do not fit in any of the previously discussed categories also sponsor some construction-related R&D. For example, a few private charitable foundations (e.g., the Ford Foundation and the Pierce Charitable Trust) have funded some construction R&D, as have some labor unions. A notable example is International Union of Bricklayers and Allied Craftsmen, which (as discussed above in connection with R&D by contractors) supports R&D through the International Masonry Institute and the Masonry Research Foundation. The committee has no statistics on the total dollar amount of R&D funded by such organizations; however, it is probably not a large amount.

## THE ADEQUACY OF CONSTRUCTION-RELATED R&D

The key question regarding construction-related R&D is whether the current level of R&D is inadequate, as has been asserted. Since R&D for an entire industry like the construction industry is inherently an amorphous, open-ended activity, there are no clearly defined goals and milestones that can be used to judge the adequacy of the industrys R&D investments. The only way to make a judgment is through the use of various comparisons and indirect indicators. Since, as noted at the beginning of the chapter, economists have established a definite link

TABLE 10 Estimated Annual Expenditures on Civil Engineering R&D by Federal Agencies That Are Not Primarily Responsible for Procuring Construction (millions of dollars)[a]

| Department/Agency | R&D Expenditures |
|---|---|
| Department of Agriculture, | |
| Agricultural Research Service | 2.2 |
| Department of Commerce: | |
| National Bureau of Standards | 6.7 |
| National Oceanic and Atmospheric Administration | 2.1 |
| Department of Housing and Urban Development | 0.1 |
| Department of Interior: | |
| Geological Survey | 4.6 |
| Minerals Management Service | 0.9 |
| Office of Surface Mining Reclamation and Enforcement | 0.2 |
| Department of Transportation: | |
| Federal Aviation Administration | 8.1 |
| Federal Highway Administration | 2.5[b] |
| Federal Railroad Administration | 1.0 |
| Research and Special Programs Administration | .3 |
| Urban Mass Transportation Administration | 17.8 |
| Agency for International Development | 3.0 |
| Environmental Protection Agency | 22.0 |
| Federal Emergency Management Agency | 0.2 |
| National Science Foundation | 29.1 |
| Total | 100.8 |

[a]Includes applied research for 1983 and basic research for 1984.
[b]The Federal Highway Administration actually transferred more than $30 million to the states for highway planning and research. NSF reports only funds used for basic and applied research.

SOURCE: NSF (1984a).

between R&D investments and productivity, one indicator of the adequacy of the R&D investments of an industry is the productivity of that industry. Thus it can be argued that the mere presence of a productivity problem in construction is prima facie evidence of inadequate investments in construction R&D, and indeed that argument has been used frequently, either implicitly or explicitly, in previously cited reports on the subject to justify the need for more construction-related R&D. Without disputing the validity of that argument, the Committee decided to try to see if the comparisons discussed below would shed further light on the question of the adequay of the current level of investments in construction R&D in the United States.

## Working Estimate of Total Annual R&D Expenditures

In order to make comparisons, the committee needed an estimate of the total annual expenditures for construction R&D in the United States. Because detailed statistics are unavailable, the committee developed a working estimate that it deemed sufficiently accurate for its purposes.

To develop the working estimate, the committee began with the R&D funding categories for which it had at least rough estimates of current annual expenditures. These were: construction contractors (both general and specialty), $54 million; manufacturers of construction products and equipment, $838 million; and federal agencies (both consumers and nonconsumers), $220 million. The committee then assumed that R&D expenditures by all other members of the construction community would not exceed 10 percent of the sum of these expenditures, that is, 10 percent of $1.112 billion or $111 million. The committee decided that the sum of these ($1.223 billion) could be used for comparative purposes as an approximate working estimate of total annual construction-related R&D in the United States.

## Construction R&D vs R&D in Other Industries

Using $312 billion (the value of construction put in place in 1984) as the total annual sales of the construction industry, the industry's R&D investments, expressed as a percentage of sales, equal 0.39 percent. This compares to the following percentages reported in Business Week (1985) for other mature industries: appliances, 1.4 percent; automotive, 1.7 percent; containers, 0.9 percent; food and beverage, 0.9 percent; fuel, 0.7 percent; oil service and supply, 2.9 percent; paper, 1.0 percent; steel, 0.5 percent; textiles and apparel, 0.8 percent; tobacco, 0.4 percent.

Assuming that the construction industry, including manufacturers that supply construction products and equipment, employs about 8.6 million workers, the dollar value of R&D expenditures per employee equals about $142. The comparable figures from Business Week for the previously listed industries are as follows: appliances, $1,231; automotive, $1,498; containers, $877; food and beverages, $1,015; fuel, $3,110; oil service and supply, $2,348; paper, $1,261; steel, $740; textiles and apparel, $571; tobacco, $267.

Both of these comparisons show that the construction industry invests less for R&D than other mature industries.

## Federal R&D in Construction vs Federal R&D in Other Fields

Although the current level of federal investments in construction R&D--approximately $220 million/year--is substantial, it is not large in comparison to the amount spent by the federal government on construction ($44 billion/year), nor is it large compared to federal spending for R&D in other fields. For example Schwartz (1985) reports that in 1984 the federal government spent $29.29 billion on defense R&D; $4.78 billion on health-related R&D; $2.30 billion on space R&D; $2.58 billion on energy R&D; $1.68 billion on general science R&D; $1.04 billion on transportation R&D; $0.96 billion on R&D regarding natural resources and the environment; $0.76 billion on agricultural R&D; and $0.20 billion on R&D regarding education, training, employment, and social services.

## Construction R&D in Foreign Countries

The committee also hoped to compare the amount of construction R&D conducted in the United States with the amount conducted in other industrialized countries. Unfortunately, the committee could find few statistics on construction R&D in various foreign countries. The United Nations has published some data on the number of individuals in construction research in various countries (UNESCO, 1980); however, the number of countries reported is limited (the United States, for example, is not included) and the data appear suspect (e.g., researchers are numbered only in the hundreds in most industrialized countries).

Although statistics were unavailable on construction R&D in foreign countries, the committee learned that similar concerns about inadequate construction R&D have been expressed in other countries. A report by Revay and Associates (1983), for example, concluded that "the amount of construction R&D performed in Canada...is exceptionally small, amounting to only 0.1 percent to 0.2 percent of the value of the annual construction program." The report also suggested that the Canadian federal government needed to take action. Similarly, a report by the Swedish Council for Building Research (1983) expressed great concern about the low priority given to construction R&D in Sweden. It suggested that both government and industry should increase their construction R&D efforts to ensure that the Swedish construction industry remains internationally competitive. It should be noted that the Swedish government already invests more heavily in construction R&D (relative to the GNP of the country) than does the U.S. government. In 1980, for example, construction expenditures in Sweden totaled about $15 billion (in U.S. dollars), and the Swedish Council for Building Research (a government organization) spent about $60 million (U.S.), or about 0.4 percent of construction expenditures.

There is evidence that contractors in at least one foreign country, Japan, are investing considerably more in construction-related R&D than their U.S. counterparts. For example, Suzuki (1984) reported that the Taisei Corporation (one of the largest construction firms in Japan) invests approximately $30 million/year (roughly 0.7 percent of sales) in R&D. It is doubtful that any large U.S. construction firm invests even a fraction of that amount in R&D.

Albus (1985) verified that Japanese construction firms invest heavily in R&D. He reported that Taisei Corporation had a Technical Research Institute with a staff of 130 researchers; Takemaka Corporation has a Technical Research Laboratory employing 256 people; Hazama Gumi, Limited, has a large research laboratory (size not specified) doing advanced research on tunneling and other subjects; Shimuzu Construction, Limited, supports a Research Institute employing 213 people; and Kumagai Gami Company, Limited, has an Institute of Construction Technology of undisclosed size doing research on various subjects.

The fact that several large Japanese construction firms invest large sums of money in R&D, whereas their U.S. counterparts spend almost nothing, does not by itself prove anything. It is possible, for example, that the Japanese firms are merely wasting money (as some U.S. construction company officials have suggested), or that the nature of the construction business in Japan is so different from the United States that comparisons are meaningless. On the other hand, the potential significance of the heavy investment in R&D by Japanese firms in comparison to their U.S. counterparts cannot be ignored.

## CONSTRUCTION R&D CAPACITY IN THE UNITED STATES

One related issue that the committee explored was whether the United States has the human and physical resources (i.e., researchers and laboratory facilities) needed to effectively carry out a significantly expanded construction R&D effort. The answer, the committee concluded, was a qualified yes.

The committee members believe, based on personal knowledge of the situation, that the construction R&D laboratories of most manufacturers, government agencies, academic institutions, and other research organizations are not currently operating at capacity, and that they could expand their operations somewhat almost immediately. The ability of these institutions to expand their activities further would depend most on how quickly academic institutions could produce additional, well qualified researchers.

The evidence suggests that the supply of new researchers could be increased significantly within a few years. The Construction Education Committee of the Associated General Contractors (1985) reported that at the end of 1984 over 150 universities and 4-year colleges in the United States offered construction programs. Approximately 16 of these are accredited by the American Council for Construction Education. Most of the remainder are accredited by the Accreditation Board for Engineering and Technology--21 as construction programs and the rest as options or areas of specialization in civil engineering, architecture, or some other discipline. The AGC Construction Education Committee also reported that 57 colleges and universities offered advanced degrees in some construction-related field. Since most researchers are produced through graduate programs, this is probably a better indicator of the current capacity of academic institutions to supply researchers than the total number of schools with construction programs. Although the number is low, past experience indicates that academic institutions can develop new graduate programs very quickly when there is a demand for them. Furthermore, formal education in construction is not needed for all construction-related R&D. Indeed, a considerable portion of such R&D can be and already is performed by engineers and scientists whose formal education has not included any courses in construction per se, and if the need arises, there are thousands of mechanical, electrical, industrial, and chemical engineers, and physicists, chemists, and mathematicians who could be quickly recruited and trained to do construction-related R&D.

## CONCLUSIONS

It has been clearly demonstrated that, as a general rule, investments in R&D result in productivity gains that more than offset the investment. There is no reason to believe that the construction industry does not follow this rule. Therefore, it can be assumed that the productivity of the construction industry has benefited from R&D in the past and that it would benefit from increased R&D in the future.

The committee's analysis of construction-related R&D in the United States indicates that the total annual investment in R&D by all elements of the construction community probably totals about 0.39 percent of the annual value of construction put in place. Manufacturers of construction products and equipment probably account for almost 69 percent of all construction-related R&D in the United States, government agencies for about 18 percent, contractors for about 4 percent, and all other elements of the building community for about 9 percent.

The U.S. construction community, (including users, manufacturers, contractors, government agencies, and others), probably invests proportionally less in R&D than any other United States industry. It also probably invests less in R&D than the construction industries in some foreign countries, notably Japan. In addition the federal government invests less in construction R&D than in other R&D.

Based on the lack of increase in the U.S. construction productivity over the past 20 years and the low rate of investment in construction R&D, the committee concludes that construction R&D has been inadequate in the United States and needs to be increased. Because of the complexity and diversity of the construction industry, it is impossible to determine precisely how much of an increase in R&D is needed. It is apparent, however, that the current level of investments in R&D is sufficiently low that the amount of R&D could easily be increased several fold before the point of diminishing returns is reached.

The committee also concludes that there is little reason to hope that the increase will come from the private sector. Although the existence of a construction-productivity problem has been recognized and discussed for many years, the amount spent on R&D by private members of the construction community (except manufacturers) has remained low. It seems unlikely that the factors that have caused this situation (e.g., the attitudes of those involved, the cyclical nature of construction activity, and the structure of the industry) would change now. While it is possible that some type of special tax incentive might be devised to encourage more private investment in construction-related R&D, this also seems unlikely. Tax incentives for R&D investments applicable to all segments of industry have existed for many years, and they have not resulted in any massive investment in construction R&D yet. Furthermore, it seems unlikely that additional incentives would be enacted especially for the construction industry. Therefore, if there is to be an increase in construction R&D, some direct action by the federal government will be required.

Finally, although relatively few academic institutions currently offer undergraduate and graduate degrees in construction per se (i.e., the management of construction projects and the technology of construction work), the number would probably increase rapidly if the demand for construction researchers increased. Furthermore, there are thousands of engineers and scientists who could be recruited and trained to do construction-related research even though they have not taken any construction courses. Thus, while an increase in spending for construction R&D might produce a temporary shortage of construction researchers, the shortage would not persist. Therefore, the fact that the number of construction researchers currently is limited would not limit for very long the size of the U.S. construction R&D effort.

# 6

# LESSONS FROM PREVIOUS GOVERNMENT EFFORTS TO PROMOTE TECHNOLOGICAL DEVELOPMENT

Over the years, the federal government has initiated countless programs to promote industrial innovation or scientific or technological development of some type, and while many have been successful, many others have failed. As part of its investigation, the committee reviewed the results of previous or ongoing federal efforts to promote technological development in an effort to determine whether a new R&D program would be likely to succeed, and if so, what kind of program would have the best chance.

A review of the literature revealed that in the past federal R&D activities have frequently been evaluated by politicians, economists, accountants, scientists, engineers, and others. In general, the evaluations have been of three kinds: analyses of the broad economic impacts of federal R&D in general or of specific large-scale, multifaceted programs, like the defense R&D program; detailed analyses of the results achieved from specific programs (both large-scale and narrow in scope), usually in terms of the stated program objectives; and discussion of the politics of federal R&D programs. The committee's findings are summarized below.

## BROAD ECONOMIC IMPACTS OF FEDERAL R&D PROGRAMS

To evaluate the impact or benefits of federal R&D programs in macroeconomic terms, most economists have used one or more of the following indicators: rate of return on R&D investments (measured by growth in output of goods and services), number of patents filed or number of patents commercialized or both, and the impact of federal R&D on private R&D spending. Because of the macro nature of the available data, most economists are primarily concerned with the impact of the R&D programs of the federal government as a whole or of specific large-scale R&D programs like the defense program. In general, economists have not evaluated small, narrow-scope R&D programs.

The most striking theme that runs through most papers on the broad impacts of federal R&D efforts is that the available data or analytical tools to evaluate the data or both are inadequate to the task. Hertzfeld (1985), for example, after reviewing the efforts of various several conclusions regarding federal R&D. One is that federal R&D organizations and individuals to measure the economic impact of federal R&D activities relating to civilian space programs concluded that "measuring the magnitude of the long-term economic impacts is nearly impossible. About all that can accurately be said is that the impacts will occur and that they will be sizable." He further concluded that "no economic study should attempt to put a bottom line ratio or return on space R&D investments. There is no such number in existence--it only lives in the uncharted world of general equilibrium theory. All such numbers that have been used as representative of a total return to space R&D have actually measured partial returns." Similarly, Weaver (1985) expressed skepticism about the validity of various analyses of the benefits of agricultural R&D programs, even though all but one of the eleven analyses he reviewed showed sizable rates of return. Mowery, (1985), Reiss (1985), and Terleckyj (1985) have also noted the limitation of current economic models for evaluating the impact of federal R&D.

Although most economists freely admit the inadequacies of the available data and tools, they seem to have reached consensus on programs as a group produce significantly lower rates of return than private R&D investments. However, many economists (e.g., Lichtenberg, 1985, Reiss, 1985, and Terleckyj, 1985) also caution against assuming from these lower rates that federal R&D programs are not beneficial. They note that the benefits of federal R&D usually cannot be observed statistically by traditional techniques. Reiss (1985), for example, suggested that "we will never be able to measure some of the consequences of federal R&D. For example, the political benefits of a strong national defense or a sophisticated space program are difficult to reduce to numbers as is the desirability of income redistribution caused by technical change. There are also some benefits that are potentially quantifiable, but for which we presently lack adequate data. Our limited progress in quantifying health care improvements is a ready example...."

Similarly, Terleckyj (1985) observed that in spite of the difficulties associated with proving it, "there is no reason to think that government financed R&D programs aimed directly at raising productivity either of particular industries or of the economy in general do not succeed in this objective."

Another generally-accepted conclusion among economists about federal R&D is that it complements rather than substitutes for private R&D (Reiss, 1985). This means that federal R&D programs generally do not cause private firms to cut their R&D expenditures. The conclusion is based on the work of several economists, including Mansfield (1984), who surveyed 25 major industrial firms to determine how their energy R&D efforts were affected by federal R&D support for energy research. Mansfield found that in many cases federal R&D funding actually stimulated additional private R&D investments.

Finally, economists now generally believe that government R&D programs tend to increase the cost of private R&D. Lichtenberg (1985), for example, reported that "there is reasonably strong econometric evidence that supports the hypothesis that increases in federal R&D result in significantly higher starting salaries for scientists, engineers, and technical personnel, at least in the short run," and that this increases private R&D costs. He also noted, however, that the effect is probably much less (perhaps even zero) in the long run. When federal R&D programs are first initiated the supply of researchers is relatively inelastic, causing salaries of researchers to rise. After colleges and universities have responded to this need, salaries stabilize. It is sometimes suggested that the tendency of federal R&D programs to increase private R&D costs is offset by the contributions of federal R&D to general knowledge, which would tend to reduce private R&D costs. However, Lichtenberg (1985) concluded that "evidence regarding the incidence of cost-reducing (from the perspective of private R&D sponsors) spillovers from federal R&D is extremely limited."

## GENERAL CRITIQUES OF MISCELLANEOUS FEDERAL R&D PROGRAMS

In the past, various researchers, committees, and government officials have analyzed the results of individual programs or groups of programs the federal government has undertaken to promote industrial innovation or scientific or technological development of some kind. Some of these programs have lasted for many years; others were terminated shortly after they began. These analyses were designed to determine if the programs succeeded, either in terms of the original objectives or possibly in ways not originally anticipated. Such critiques often have been somewhat subjective, either because the original program objectives were unclear or because detailed results were unavailable and prohibitively expensive to obtain.

As part of its investigation, the committee reviewed several programs that had been carefully critiqued by individuals and organizations as described above; the results are summarized in Appendix C. The programs represent a cross section of those undertaken by the federal government, and include: Operation Breakthrough, the Civilian Industrial Technology Program, the Industrial Energy Conservation Program, the National Shipbuilding Research Program, the Experimental Technology Incentives Program, the Research Applied to National Needs Program, the U.S. Department of Agriculture's science and education programs, the federal highway research programs, and the Modular Integrated Utility Systems project.

On the basis of its reviews, the committee found that the government has been involved in a wide variety of efforts, some of which have been very successful and others, failures. A single explanation for the failures is not readily apparent. Some programs seem to have failed (or in some cases have never really gotten started) because of political opposition based on budgeting concerns, opposition by the academic research community or the targeted industry, or congressional concerns about the appropriateness of the proposed effort. Other programs seem to have suffered from faulty planning, poor management, or technical difficulties. Similarly, there appears to be no single explanation for the success of some R&D programs.

Four previous government efforts to promote technological development are particularly relevant to this study: Operation Breakthrough, The Civilian Industrial Technology Program (CITP), the various federal highway research programs and the federal agricultural research programs (see Appendix C). Although Operation Breakthrough and CITP are generally regarded as unsuccessful, they are relevant here because they were directed specifically at the construction industry. In the case of Operation Breakthrough, the problems appear to have been due to a combination of technical difficulties and excessive haste; CITP's failure was probably related to political considerations.

The federal highway research programs and agricultural research programs are relevant because they involve industries similar to the construction industry. They are among the most successful long-term R&D efforts of the federal government and their success has probably been due to two factors: (1) they satisfy real technical needs; and (2) they have been adroitly planned and managed to ensure continuing political support.

## THE POLITICS OF FEDERAL R&D PROGRAMS

Observers of government affairs have recognized for many years that political and other nontechnical considerations often determine the success or failure of federal R&D efforts. The views of several observers are summarized below.

Fundingsland (1984) reviewed General Accounting Office studies of "mission-targeted" R&D projects, including the Liquid Metal Fast Breeder Reactor program, R&D to support regulation at the Environmental Protection Agency, water-related research, the Small Business Innovation Research Program, the Urban Tracked Air Cushion Vehicle program, Federal Short Take-off and Landing Air Transport programs, The Experimental Schools program, and The Operation Breakthrough housing program. Based on his reviews, Fundingsland made the following recommendations regarding government sponsored R&D:

- Discontinue the somewhat arbitrary practice of distinguishing basic from applied research, but separate all generic research from mission-targeted R&D in the federal budget.
- Use different criteria and a longer-range perspective for resource allocation among fields of science in generic research than for mission R&D.
- Continue the policy that the government will not support research that is adequately funded by the private sector.
- Explicitly acknowledge that the stability and continuity of federal research funding is more important than the actual level of support.

- Establish a long-term investment strategy for federal support of generic research that assures a minimum threshold and moderate growth, and is insulated but not isolated from fluctuations in the economy and changing priorities of each administration.
- Provide multiyear funding for R&D, especially for generic research.
- Let mission-targeted R&D absorb most of the adjustments that reflect changing priorities constrained by a short-term economic outlook and budget limitations.

Teich (1985) critiqued the Civilian Industrial Technology Opportunities Program, Industrial Innovations Incentives, the NSF Interdisciplinary Research Relevant to Problems of Our Society program and the Research Applied to National Needs program, federal funding for alternative energy R&D and demonstrations, the Cooperative Automative Research Program, aeronautics research of National Advisory Committee on Aeronautics and National Aeronautics and Space Administration, agricultural research, applied research in the biomedical field, general research at the National Bureau of Standards, and some aspects of Department of Defense research.

Teich identified four points that need to be considered in developing federal R&D programs:

1. Modesty in defining and promoting the programs seems useful. Grandiose plans tend to enter the realm of high policy debate, are opposed on principle and, often as not, become political footballs. Less fanfare may produce more results.
2. The character of the industry which is the presumed beneficiary of the program is central to its potential for success. The structure of the industry must lend itself to taking advantage of the program's results and the leaders of the industry must be interested in and not opposed to the program. Government-industry ties need to be based on trust and perception of mutual benefit.
3. Careful attention needs to be given to the balance between user needs and the technical and institutional capabilities of the R&D institutions in designing programs. The programs need to be built on strength while yielding results that can be put to use in commercial applications.
4. Programs of generic applied research seem to be a particularly fruitful avenue of collaboration. The precise nature of such generic research may vary from one field or area of application to another, however, and the conduct of such research in and of itself is not sufficient to assure that it is used productively in the appropriate industry.

Tassey (1985), in discussing lessons learned from the Experimental Technology Incentives Program (ETIP), emphasized the need to take into account the dynamics of the market place and the interactions of the relevant factors when planning government policies and programs intended to influence the rate and direction of industrial innovation. He also stressed the importance of maintaining flexibility to make mid course adjustments to fine tune policies under investigation.

Noll (1985) noted that the government has undertaken three types of R&D programs: (1) those aimed at improving the quality or reducing the costs of the goods and services the government itself uses, (2) those aimed at contributing to the general technological base of the society by supporting basic research in science and technology, (3) those aimed at producing new commercial technology for a specific industry or sector of the economy because that sector is especially weak at innovating on its own.

Two reasons, according to Noll (1985), are usually given for government involvement in R&D programs: First, "R&D is desirable because it promotes economic growth, strengthens national defense, and contributes to national prestige, not to mention that it creates new knowledge that may be a valued end in its own right." Second, "R&D tends to be insufficiently undertaken by the private sector if left to its own devices." He also observed, however, that there are serious political barriers to the efficient implementation of R&D programs that must be taken into account. He suggested that, from a political standpoint, the most attractive R&D programs will have the following characteristics:

- They can be readily connected to one of the very few salient political issues on which elections normally turn: the state of national defense or, in the mid-1970s, the rapid increase in the price of energy.
- They can easily be spread around to all the important components of the contracting industry, either because the industry is concentrated (so that a few contracts and subcontracts do the job), or by fragmenting the program in an unconcentrated industry into numerous small projects (e.g., agricultural extension, and basic research grants to universities).
- They promise relatively short-term payoffs in politically visible benefits and expenditures to politically important constituencies.
- They are unlikely to produce an embarrassing failure that will lead to investigations and scandal; hence to the maximal extent the government itself will have control over the decision to use the new knowledge or to declare it a success.

Finally, Noll (1985) describes the ideal federal R&D program:

> The most attractive R&D, then, is short-term in nature, is directed at the production of government goods (e.g, defense or space exploration) so that it can lead to utilization regardless of the shortfall in performance or overrun in costs, is addressed to a widely accepted, generally uncontroversial national objective, and can be

undertaken without substantially altering the distribution of market advantages in the private economy. Least attractive are programs that address unsensational, long-term goals (e.g., long-term economic growth), that require very large contracts for a relatively small fraction of an industry, that are not only uncertain in terms of results but that can end in obvious failure, and that are unlikely to produce tangible evidence of success for a long period of time.

## CONCLUSIONS

With currently-available statistics and analytical tools, it is impossible to determine in terms of macroeconomics how federal R&D programs affect the overall economy. Most economists seem to believe intuitively that such programs are beneficial, however they cannot prove it. Most also believe that federal R&D expenditures do not cause a decrease in private R&D investments and that while an increase in federal R&D causes salaries of researchers to rise, the salaries tend to stabilize in a few years when the supply of researchers catches up with demand.

The results of previous and ongoing federal R&D programs are varied. Some programs have been highly successful, others have failed. Whether a program succeeds or fails seems to depend more on political and nontechnical considerations than technical ones. Thus, if a federal construction-related R&D program is carefully crafted to account for the political factors, it should have a good chance of succeeding.

The keys to a successful federal R&D program are the following:

- Involve representatives of all segments of the building community in the process of formulating the program, and design the program to address a broad spectrum of needs. For example, the concerns of federal agencies that procure buildings as well as those of agencies that are interested in broader issues should be recognized.
- Concentrate on generic (nonproprietary) problems, opportunities, and issues; avoid involvement in the design, development, manufacturing, or marketing of proprietary products or concepts.
- Try to get a long term commitment to the program from Congress.
- Design the program to generate numerous small payoffs over an indefinite period of time; do not promise big results quickly.

- **Design the program to cover the full spectrum of research projects, from the discovery of new basic knowledge to the development of better methods of disseminating known technology.**
- **Design the program to permit researchers and research organizations from various segments of the industry to participate.**
- **Include a mechanism for promoting continuous two-way communications between users of technology (e.g., owners, contractors, designers) and researchers. R&D is of little value if it does not address real problems and important issues and if the results are not widely disseminated.**
- **Keep the size of the program large enough to ensure that many members of the building community can be involved and that the results of R&D will have widespread impact, but not so large that it becomes a target for budget cutting.**
- **Find a mechanism for funding the program that will help ensure its stability and continuity.**

# 7

## SUMMATION AND RECOMMENDATIONS

The committee's investigation has shown that the U.S. construction industry is a major element of the U.S. economy, that the federal government has a legitimate interest in construction because of the size and importance of the industry and because the government is a major construction consumer, that the industry has a serious productivity problem, that R&D can help improve productivity, and that construction-related R&D investments have been inadequate in the United States.* It has also shown that federal R&D programs aimed at promoting technological development can succeed if they are properly planned and executed.

The committee also found that although federal agencies already perform or fund a considerable amount of construction-related R&D, most of it appears to be concerned with the design of federal facilities, and it probably contributes little to construction productivity. Consequently, the current programs do not effectively compensate for the lack of R&D by other elements of the construction community. Even though the federal government would benefit from lower costs through R&D-generated increases in construction productivity, it is probably unrealistic to expect operational agencies to take the lead in performing or funding R&D of a generic nature. Agencies are under almost constant pressure to reduce budgets and expenditures, and most are unwilling to try to defend requests for funds that are not clearly related to their missions.

Finally, the committee found no reason to believe that the private sector will substantially increase its investment in R&D. Although a construction-productivity problem has been recognized and discussed for many years, the amount spent on R&D by most segments of the construction community has remained low. It seems unlikely that the factors causing this situation (e.g., the attitudes of those involved or the

*It should be emphasized that the term R&D, as used here, includes investigations and studies dealing with management, administration, cost control, and other nontechnical subjects. Indeed, some committee members believe that R&D in nontechnical areas are likely to produce more productivity gains for construction than technically-oriented R&D.

structure of the industry or both) will change. It is possible that some kind of special tax incentive might be devised to encourage private investment in construction-related R&D. However, tax incentives for R&D investments in all segments of industry have existed for many years, and they have not yet resulted in any large investment in construction R&D. Furthermore, the enactment of additional incentives for the construction industry seems unlikely.

Thus, a significant increase in construction-related R&D, especially R&D aimed at improving construction productivity, will probably occur only as a result of some direct, congressionally mandated federal action. Given the seriousness of the construction industry's productivity problems, the committee is convinced that a substantial increase is needed in federal funding for construction-related R&D, especially R&D aimed at improving productivity. Such an increase can be justified on the grounds that both the national economy and the federal government itself would benefit from lower construction cost. The committee is also convinced that a new federal construction R&D program would have a high probability of producing worthwhile results if it is organized in accordance with the guidelines presented in Chapter 6. Therefore, on the basis of its findings and conclusions, the committee makes the following recommendations.

1. The Congress should formally acknowledge the need for federal leadership in conducting, funding, and coordinating general construction-related R&D, just as it has in agriculture, medicine, transportation, and many other fields. This acknowledged leadership should be reflected in federal programs.

2. In order to ensure the stability of the program, the Congress should consider methods of funding a strong federal R&D program that would provide stability and continuity. Numerous options are available. Congress might consider, for example, providing multi-year authorization and appropriation for the program, establishing a program trust fund of some type, or funding the program through an automatic surcharge on all federal construction appropriations--like the approach that has been used for many years to fund highway research and planning.*

3. In order to ensure that a broad spectrum of construction R&D needs are met, the Congress should provide for the distribution of program funds to the various federal agencies that have construction-related responsibilities; for example, some funds could be allocated to

*In FY 1984 the federal government spent a total of almost $44 billion on construction (see Chapter 3). If, for example, a 1.0 percent surcharge had been added to each construction appropriation that year, approximately $440 million would have been generated for construction related research. Inasmuch as federal agencies actually spent about $220 million in FY 1984 on construction R&D, the 1.0 percent surcharge would have increased the FY 1984 budget by only $220 million.

the agencies that are responsible for procuring federal facilities for R&D on the design and construction of such facilities; some funds could be allocated to agencies like the National Bureau of Standards and the National Science Foundation for generic R&D for the entire construction community; and some funds could be allocated to information-generating agencies like the Bureau of the Census and the Bureau of Labor Statistics for the development and publication of more accurate construction statistics.

4. In formulating the program, the Congress should provide a mechanism to ensure that the construction R&D activities of the various federal agencies are coordinated and that information and technology produced through such activities are widely disseminated. To accomplish this, the Congress might consider giving a particular agency overall responsibility for managing the program and distributing R&D funds to other agencies. Alternatively, Congress might permit the various agencies to manage their own R&D programs, but require them to participate in a cooperative, coordination body (either public or private) that would do for construction R&D what the National Research Council's Transportation Research Board has done for highway research for many years. (See Appendix C for a discussion of federal highway research programs and the Transportation Research Board's role in those programs.)

# APPENDIX A

## PRODUCTIVITY INFERENCES FROM COST ESTIMATING DATA

Some members of the committee objected to relying too heavily on national statistics to form judgments on construction productivity. The true measure of productivity, they believe, is what occurs at the job site. Usually, however, contractors who keep productivity data that would shed light on the question are reluctant, for competitive reasons, to reveal such data. The committee, therefore, sought other sources of data on on-site productivity.

For more than 10 years, the Robert S. Means Company has included estimates of the daily output of crews ordinarily employed to perform various tasks in its widely-used annual construction cost estimating manual. The committee believed that the Means' estimates of the daily output of construction crews would give an accurate indication of the productivity of construction workers at the task level and that productivity trends in construction might be obtained by comparing the output of selected construction crews over a period of years. The use of cost estimating guides to develop productivity statistics previously had been suggested by Dunlop (1972).

The committee took this approach and compared the productivity of construction crew members performing 30 different tasks in 1975 and 1985, using data published in Means (1974, 1984). The tasks were selected randomly but not scientifically. Results are presented in Table A-1. The last column indicates the percentage change in output over the 10-year period.

The results show great variation in productivity during the period for the 30 tasks investigated. Specifically, output per crew member increased for 13 tasks, decreased for 11 tasks, and remained unchanged for 6 tasks. This suggests no clear trend in construction productivity, either up or down, between 1975 and 1985.

TABLE A-1 Output of Construction Workers Performing Various Tasks: 1975 versus 1985

| Task[a] | Unit[a] | Daily Output Per Crew Member 1975 | Daily Output Per Crew Member 1985 | Percentage Change In Output |
|---|---|---|---|---|
| Clear medium trees to 10-in diameter; cut and chip | Acre | 0.095 | 0.133 | +40 |
| Core drilling (4-in diameter), reinforced concrete slab up to 6-in thick | Each | 4.9 | 34 | +594 |
| Bulk excavation, medium earth, self propelled scrapers, 15 Cu yd capacity, 1500-ft haul | Cu yd | 300 | 457 | +52 |
| Hand excavation, pits to 6-ft deep, ordinary soil | Cu yd | 8 | 8 | 0 |
| Dozer backfilling, bulk, up to 300-ft haul, compacted, 6-in to 12-in lifts, vibrating roller | Cu yd | 367 | 533 | +45 |
| Install, base course, select gravel, 6-in deep | Sq yd | 277 | 750 | +171 |
| Install concrete paving, 6-in thick, with mesh, not including base, joints, or finish | Sq yd | 182 | 182 | 0 |
| Sodding in East, 1-in deep, on level ground | Sq yd | 78 | 166 | +114 |
| Install concrete slabs, 4-in thick, elevated, including finish, but not forms or reinforcing | Sq yd | 214 | 384 | +79 |
| Install brick masonry veneers, single wythe, standard size red face brick, running bond | 1,000 bricks | 0.25 | 0.27 | +9 |
| Install concrete block partitions, 6-in thick, sand aggregate, not reinforced, regular 8-in x 16-in block | Sq ft | 61 | 58 | -5 |
| Install structural steel space frame, 5-ft modular, 4.5#/sq ft | Sq ft | 150 | 84 | -44 |
| Install structural steel for offices, hospital, etc., 3 to 6 stories, bolted | ton | 00.875 | 0.9 | +3 |
| Rough carpentry, light framing, 8-ft high wall, 2-in x 4-in studs | 1,000 board ft | 0.35 | 0.46 | +31 |
| Rough carpentry, heavy framing, 6-in x 10-in beams | 1,000 board ft | 0.55 | 0.55 | 0 |
| Install built-up roofing, asphalt and gravel, 4-ply roofing on flat roof | 100 Sq ft | 4.67 | 2.86 | -39 |
| Install factory and industrial rolling steel service doors, manual, 10-ft x 10-ft high | Each | 0.9 | 0.7 | -22 |
| Install glass plate, 1/2-in thick, clear, plain | Sq ft | 30 | 27.5 | -8 |
| Install dry wall, standard gypsum plaster board, 1/2-in thick, nail to studs | Sq ft | 900 | 900 | 0 |

Table A-1 cont.

| | | | | |
|---|---|---|---|---|
| Install partition walls, 5/8-in gypsum dry wall, taped both sides, on 2-in x 4-in wood studs | Sq ft | 127.5 | 150 | +8 |
| Install ceramic tile floors, natural clay, random or uniform | Sq ft | 100 | 091.5 | -9 |
| Install suspended ceiling, metal pan with acoustic pad, including standard suspension system but not 1-1/2-in carrier channels | Sq ft | 205 | 205 | 0 |
| Interior painting on plaster or drywall, walls and ceilings, roller work, primer + 1 coat | Sq ft | 1330 | 1125 | -15 |
| Install 4-in diameter cast iron soil pipe, lead and oakum joints, fittings 10-ft on center on hangers | lin ft[a] | 22 | 22 | 0 |
| Install 3-in diameter plastic drain, waste and vent pipe, including fittings and 3 hangers/10-ft. | lin ft | 25.5 | 26.5 | +4 |
| Install 5-ft cast iron bathtub, recessed, shower and curtain, | Each | 2.2 | 2.0 | -9 |
| Install boiler insulation, 1-1/2-in calcium silicate, with 1/2-in cement finish | Sq ft | 34 | 25 | -26 |
| Install 4-light recessed flourescent troffers 48-in x 24-in | Each | 3.5 | 4.7 | +34 |
| Install steel duct work, 1000 to 2000 lb, including fittings and joints, but not insulation | lb | 90 | 88 | -2 |
| Install electric cable, non metallic, with two #12 copper wires and ground | lin ft | 383 | 250 | -35 |

[a]Abbreviations: cu yd. cubic yards; ft, feet; lin ft, linear feet; lb, pounds; sq ft, square feet; sq yd, square yards.

SOURCE: Means (1974, 1984).

# APPENDIX B

## CONSTRUCTION R&D ACTIVITIES OF FIVE FEDERAL AGENCIES

During the study, five federal agencies briefed the committee on their R&D activities: the Army Corps of Engineers, the Naval Facilities Engineering Command, the Air Force Directorate of Engineering and Services, the Office of Construction of the Veterans Administration, and the National Science Foundation. The highlights of those briefings are summarized below. The information is neither official nor exhaustive.

The Corps of Engineers operates eight laboratories concerned with construction. Five laboratories concerned with water resources are located at the Waterways Experiment Station at Vicksburg, Mississippi. The other laboratories are the Construction Engineering Research Laboratory, Champaign, Illinois; the Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire; and the Engineering Topographical Laboratory, Fort Belvoir, Virginia. In FY (fiscal year) 1985 the Corps expects to spend approximately $42.7 million for research, development, testing, and evaluation (RDT&E). Of this total, approximately $27.6 million is for logistics- and combat-related research, $2.2 million is for work for the Department of Defense and other agencies (mostly related to mapping), and $12.9 is for "base support", which includes work related to environmental quality, facilities engineering, installation support, and facilities development in such areas as pavements and foundations, construction technology, construction management, and planning and design.

The Air Force conducts research, development, testing, and evaluation (RDT&E) related to the maintenance and repair of Air Force facilities at Tyndall Air Force Base in Florida. The Air Force expects to spend approximately $33 million on such RDT&E in FY 1985. The Air Force program is divided into two parts: civil engineering ($18.8 million) and environmental quality ($14.2 million). Civil engineering is subdivided as follows: $6.1 million for research, $6.3 million for development, and $6.4 million for testing and evaluation. In the civil engineering portion of the program, work is carried out in such areas as fire protection, contingency lighting, pavement construction, and bomb crater repair. The environmental quality portion of the program includes work on hazardous wastes disposal and combustion.

The Navy conducts facilities-related RDT&E at Port Hueneme, California. The Navy FY 1985 budget for such work is approximately $4 million, of which $1 million is for research and development and $3 million is for testing and evaluation. Among the topics being investigated are concrete durability, roofing, and quality control. Unlike the Air Force, the Navy does not include projects related to environmental quality and energy consumption in the RDT&E budget for facilities.

The Veterans Administration (VA) spends approximately $1 million/year on facilities-related research and development. All such research is performed under contract; the VA has no facilities laboratory. Topics investigated in 1985 included reducing VA construction costs, smoke control, hot water demand, fire tests of floor and ceiling components, and operations and maintenance manuals for VA facilities.

The National Science Foundation (NSF) has no laboratories. Its primary mission is to support R&D in academic institutions. In FY 1985 the NSF expected to distribute approximately $4.4 million in the form of grants to academic institutions for research on structural systems, building systems, and the construction process.

# APPENDIX C

## SOME PREVIOUS GOVERNMENT EFFORTS TO PROMOTE TECHNOLOGICAL DEVELOPMENT

In connection with its investigation of the feasibility of federal agencies taking action to promote, fund, or conduct R&D to improve productivity in the construction industry, the committee reviewed the results of previous and in some cases ongoing government efforts to promote technological development in various industries, including the construction industry. Among the programs reviewed were: Operation Breakthrough, the Civilian Industrial Technology Program, the Industrial Energy Conservation Program, the National Shipbuilding Research Program, the Experimental Technology Incentives Program, the Research Applied to National Needs Program, the U.S. Department of Agriculture's science and education programs, the federal highway research programs, and the Modular Integrated Utility System project. These particular programs were selected for review because they represented a cross-section of federal technology-development programs and because critiques of them had been published.

### OPERATION BREAKTHROUGH

In accordance with Section 108 of the Housing and Urban Development Act of 1968, the Department of Housing and Urban Development (HUD) embarked in mid-1969 on a major project called Operation Breakthrough. This effort had as its primary objective the establishment of mechanisms to mass-produce and mass-market housing for families at all income levels, but particularly for those of low and medium incomes.

In addition to its primary objective, HUD established a number of secondary objectives for the Breakthrough program, including stimulating the modernization and broadening of the housing industry, increasing participation by state and local governments in planning and site aggregation, waiving or removing constraints to the introduction and use of tested and proven innovations, introducing new organizational concepts and management techniques, encouraging identification and development of performance standards for evaluation of innovations, developing an ongoing testing and evaluation mechanism, and developing techniques for increased participation by consumers and community groups.

At HUD's request, the National Research Council (NRC) established the Advisory Committee to the Department of Housing and Urban Development (ACHUD) in June 1969. ACHUD's primary mission was to provide guidance to HUD on the technical aspect of Operation Breakthrough. In 1974, when its work was completed, ACHUD prepared a critique of Operation Breakthrough (Advisory Committee to the Department of Housing and Urban Development, 1974).

ACHUD noted that while the objectives of the program were not fully achieved, Operation Breakthrough was of some value in that it helped advance the industrialization of housing construction (particularly with regard to components), helped broaden the housing industry, increased the participation and awareness of state and local governments in housing, encouraged removal of some constraints on the use of innovations, and promoted the application of performance criteria. ACHUD also noted, however, that the program was very costly ($72 million) and that numerous difficulties were encountered, many because the managers of the program set unrealistic goals and schedules that could not be met. In its report, ACHUD made an obvious effort to be fair to the planners and managers of Operation Breakthrough, but there was a clear implication that ACHUD considered the program largely a failure.*

## CIVILIAN INDUSTRIAL TECHNOLOGY PROGRAM**

In 1962 the Department of Commerce requested congressional appropriations for a proposed Civilian Industrial Technology Program (CITP), which had three purposes:

1. to foster innovation in such lagging industries as building and textiles,
2. to study the information needs and state of technology in other industries, and
3. to create an industry-university service to diffuse information and provide technical aid.

The CITP was proposed as a method of providing the benefits of R&D to areas of the economy that were perceived as technically backward and unable or unwilling to fund the necessary R&D themselves. The presumption was that a federal program was needed to fill the gap. Although funds were provided for a short time for the textile technology portion of CITP, the building technology portion of the program was never funded due to the vehement opposition of some leaders of the building industry. This opposition eventually caused the demise of the entire program.

---

*One benefit of Operation Breakthrough was that it destroyed some myths about the advantages of industrialized housing.

**Information on this program is primarily from Nelkin (1971).

Nelkins (1971) noted that the building industry was included in the CITP because--in spite of the availability of new materials and new means of mass production--it was believed that the rate of change in construction methods would not be sufficient to meet the increasing need for adequate shelter at reasonable cost. The proponents of the program believed that construction costs could be reduced through more R&D and that the proposed federal program would provide the needed R&D. Opponents of the program argued, however, that there was no evidence that R&D would produce worthwhile results that would lower the cost or improve the quality of housing. Nelkins suggests that CITP opponents were motivated by political conservatism and concern that federally sponsored technological innovation would disrupt the building industry.

Eventually, the CITP evolved into a much more modest effort known as the State Technical Services Program (STS), which was approved by Congress in 1965. Instead of supporting R&D, STS sought merely to deliver technical information, using state and local agents and other means to be developed jointly by industry, universities, and the federal government. Teich (1985) noted that without the kind of strong ties to specific research programs that supported the Agricultural Extension Service, the STS program never really took hold. It was terminated by Congress in 1969.

## INDUSTRIAL ENERGY CONSERVATION PROGRAM

The Industrial Energy Conservation Program of the Department of Energy was initiated in the mid-1970s on the premise that investments in energy conservation by industry were being constrained by uncertainty regarding both economic factors (e.g., fuel prices, fuel availability, taxes, and tax credits) and technical considerations (i.e., uncertainty about whether various proposed conservation measures actually would work). The program was intended to help eliminate such uncertainty. In particular, the following areas were singled out for study under the program:

- Existing but underutilized technologies whose implementation could be stimulated by an identifiable federal action.
- New technologies from R&D that provide advanced concepts with proven economic and technical feasibility in industrial operating environments.
- Economic incentives, such as tax credits, which provide economic rewards for industrial actions in the national interest.
- Other actions that have been legislated to establish requirements and motivation for industry.
- A market-oriented commercialization effort to ensure accelerated transfer of technology for specific industrial end-users and the maximum implementation of these technologies.

In 1980 the Department of Energy asked the National Research Council (NRC) to form a committee to evaluate the Industrial Energy Conservation Program. The NRC Committee on Assessment of the Industrial Energy Conservation Program (1981) found that, with some exceptions, the program included a "well balanced mix of projects," eight of which had been successfully completed and were producing savings of more than $60 million/year. By 1984, the detailed objectives of the program had been changed, though the overall goal remained the same. Therefore, the Department of Energy asked the NRC to form another committee to again critique the program. The findings of the new Committee on Industrial Energy Conservation (1985) were similar to those of the first committee.

## NATIONAL SHIPBUILDING RESEARCH PROGRAM

Authorized by the Merchant Marine Act of 1970, the National Shipbuilding Research Program is a cooperative venture between the shipbuilding industry and the Maritime Administration (MarAd). It provides financing and management of research projects to improve the productivity of U.S. shipyards and their competitiveness in the world shipbuilding market. The program, initiated in 1971, is financed by both industry and government and provides for industry involvement in technical management and execution through the Ship Production Committee (SPC) of the Society of Naval Architects and Marine Engineers. The SPC collaborates with MarAd in the management of the program, especially to set program priorities, assign responsibilities for projects, provide technical direction, and assist in demonstrating program results.

Individual projects are developed by panels of the SPC. The panel structure is flexible--panels are added or abolished as the SPC determines the need. Lead shipyards provide an administrative and technical base for each panel's activities. Panel activities are overseen by a full-time project manager, an employee of the base shipyard. The salaries and expenses of the project managers are paid jointly by the lead yard, MarAd, and the Navy.

The NRC Committee on Navy Shipbuilding Technology (1982) reviewed the program in connection with its 1981 study of productivity in Navy shipyards. The committee found that by 1982, 76 major projects had been completed under the program, and 18 more were in progress. The committee also found that "the program has stimulated pragmatic, results-oriented projects, fostered technical communication and exchange among shipyards, enhanced the incorporation of productivity improvements into shipyards, and promoted communication of shipbuilding industry requirements to industrial suppliers." The committee concluded that the program "has resulted in productivity-related research and development in the shipyards and a growing awareness on the part of management of the value of such activities."

## EXPERIMENTAL TECHNOLOGY INCENTIVES PROGRAM

The Experimental Technology Incentives Program (ETIP) was created at the National Bureau of Standards in 1972 as a means for the federal government to help increase innovation in civilian technology. Under ETIP, various federal agencies were expected to cooperate in exploring ways in which technological development could be stimulated though terminated in 1982. Tassey (1985) cites several reasons: First, changes in the policies and procedures of the federal government. The emphasis in ETIP was on R&D regarding government policies. In practice, ETIP R&D centered on procurement policy, regulation, and economic assistance policies. Procurement policy projects were carried out with high volume purchasing agencies, particularly the Federal Supply Service (FSS). A number of procurement mechanisms were tried, including life-cycle costing, value incentive clauses, and performance specifications. Regulatory projects dealt with federal regulations concerning a wide range of regulated industries, including the pharmaceutical, railroad, transport, and communications industries. Economic assistance projects dealt with R&D, small business, capital formation, and venture capital market policies.

The ETIP program was reviewed in 1977 by the NRC Evaluation Panel for the National Bureau of Standards (1978), at which time the ETIP staff numbered 17 and had an annual budget of about $3.2 million. The panel found that the program was both effective and important and that the potential for future benefits was extremely good. Subsequently, several projects were successfully completed. Nevertheless, ETIP was internal management problems, which resulted in a shift in emphasis away from pragmatic projects toward more research oriented studies (reflected in program name change to the Center for Field Methods); second, lack of support by the National Bureau of Standards and the Department of Commerce; third, the perception that the program lacked an overall strategy for integrating individual experiments into an effective, broad plan.

## RESEARCH APPLIED TO NATIONAL NEEDS PROGRAMS*

The original 1950 charter of the National Science Foundation (NSF) defined the NSF mission as basic research. Almost from the beginning, however, some engineering research and applied research was undertaken, and in 1968 the NSF charter was modified to officially authorize these areas of research. The change also helped the NSF deflect criticism from some members of Congress and the public that it only sponsored esoteric and useless research.

NSF's first response in 1969 to the change in its charter was to form a program called Interdisciplinary Research Relevant to Problems

*Information on this program is primarily from Science Applications Task Force (1977).

of Our Society (IRRPOS). The Research Applied to National Needs (RANN) program was an outgrowth of IRRPOS, created during the preparation of the FY 1972 NSF budget with encouragement from The Office of Management and Budget. An ad hoc Task Force on Research Applied to National Needs was formed to integrate some existing NSF problem-oriented units into the new program. The proposed FY 1972 budget of $43 million included all of IRRPOS, plus earthquake engineering from the Engineering Division, and weather modification and other interdisciplinary or problem-oriented activities from various parts of the NSF. RANN received formal approval in March 1971 when the Research Applications Directorate was formed. Its mission was to identify "national needs" not being addressed by existing research agencies; to fund both basic and applied research relevant to the national needs; and to obtain utilization of the funded research.

Several advisory groups helped develop the early RANN programs and objectives. Two subcommittees of the Committee on Public Engineering Policy (COPEP) of the National Academy of Engineering were highly influential. The first subcommittee concentrated on criteria for RANN programs, and the second (in 1973) examined a number of possible issues and suggested those that should take priority. New programs particularly stressed energy. As a result, the budget grew to over $130 million by FY 1975, when most of the energy work was transferred to the Energy Research and Development Administration (ERDA). Later, other RANN projects were transferred to other agencies; e.g., the fire safety research program went to the Department of Commerce in FY 1976, and the Chesapeake Bay Project went to the Environmental Protection Agency in FY 1977.

The fiscal year 1978 budget request, $78 million, focused on the following major areas: resources ($11.5 million); environmental issues ($34.5 million); productivity ($23.0 million); exploratory research and technology assessment (i.e., research to provide better understanding of the long-range social, environmental, and economic impact of new technology) ($2.0 million); and intergovernmental science and public technology (i.e., integration of science and technology into the policy planning activities of state and local governments) ($7.0 million).

The following criteria were used in selecting problems for RANN support:

- The problems should have national importance.
- The payoff of research is expected to exceed significantly the costs of research on the problem.
- The leverage of science and technology on the problems is substantial.
- The research efforts will be timely and scientifically up-to-date.
- Academia, industry, and the federal government are able to mount a successful research program.
- There is a need for federal action, in that normal market forces are not likely to generate the required research on the problems.

- The problems to be addressed by RANN either overlap the boundaries of several mission agencies, fall between the boundaries of the charters of mission agencies, or meet the longer range needs of one or more agencies.

The RANN program was reviewed several times during its life; e.g., by the General Accounting Office (GAO); the Committee on Social and Behavioral Sciences of the NRC, the Research Triangle Institute, and the NSF Science Applications Task Force. The program got mixed reviews. The GAO report recommended a number of administrative changes, which were made. The NAS report called the RANN program "a useful component of the federal government's support of applied behavioral and social science research" but rated the program as "highly variable in quality." The members of the NSF Task Force were split. Several members felt that RANN constituted the most successful and cost-effective broad applications program ever mounted by the government. Other members felt that RANN's overall effectiveness had not been demonstrated. Most of the members agreed, however, that many useful programs had been conducted under RANN; e.g., energy research, fire safety research, earthquake engineering, truck-drag research, automatic optical pattern recognition research (for production work), work on environmental law and uniform state statutes, and research on technological aids for the handicapped.

The RANN program ended on September 15, 1977. In an unpublished paper, McNinch (1984) noted that during the 6-1/2 years the program lasted, $468.3 million were distributed as follows: 48 percent to universities and colleges, 34 percent to industry, 16 percent to nonprofit organizations, and 2 percent to state and local governments. The average RANN award was $72,000. McNinch attributed the demise of the program to the fact that "RANN never enjoyed the support of NSF's basic research clientele in universities"; some personality conflicts, and the fact that the interdisciplinary, problem-oriented organizational approach used with RANN was "totally foreign to the basic research community." The opposition of the basic research community to RANN, McNinch says, was prompted by fear that NSF support for pure research would be jeopardized by RANN. Ironically, the program's considerable support in Congress may have contributed to RANN's death by increasing the concern of basic researchers about continued funding for their own work. Finally, McNinch observed that even though the RANN program was terminated, many of the RANN projects have been continued, some as part of other NSF programs and some in other agencies.

## U.S. DEPARTMENT OF AGRICULTURE'S SCIENCE AND EDUCATION PROGRAMS*

Although the act that established the U.S. Department of Agriculture (USDA) in 1862 said little about research, the House Committee on

*Most information on this program is from the United States Government Manual 1984/85 (General Services Administration, 1984).

Agriculture clearly had research in mind. Consequently, one of the first acts of the new Department was to establish a 40-acre experimental farm on the Mall in Washington, D.C., and USDA has been heavily involved in R&D and education ever since. Currently, five elements carry out the science and education activities of the USDA: The Agricultural Research Services, the Cooperative State Research Service, the Extension Service, the National Agricultural Library, and the Office of Grants and Program Systems.

The Agricultural Research Service (ARS) administers a basic, applied, and developmental research program in animal and plant protection and production; the use and improvement of soil, water, and air; the processing, storage, and distribution of farm products; and human nutrition. Research activities are carried out at 136 locations nationwide, in Puerto Rico, in the Virgin Islands, and in 8 foreign countries. Much of this research is conducted in cooperation with state universities and experiment stations, other federal agencies, and private organizations.

The Cooperative State Research Service (CSRS) distributes federal funds for agricultural research performed by the state agricultural experiment stations and by various schools around the country. Grants are awarded on the basis of research proposals submitted by state agricultural experiment stations and other institutions.

The Extension Service is the educational agency of the USDA. It is one of three partners in the Cooperative Extension System; state governments, through their land-grant universities, and county governments are the other partners. All three share in financing, planning, and conducting the Extension's educational programs. Created by the Smith-Lever Act of 1914, the Extension Service helps the public learn about and apply the latest technology developed through USDA research and other sources. Major areas of assistance are agricultural production, marketing, natural resources, home economics and human nutrition, 4-H Club youth development, rural development, and related subjects. State specialists, located in nearly every county nationwide, provide technical assistance to county and area organizations. Area and county agents work directly with individuals, families, and groups to help them apply the most recent proven technology.

The USDA also operates the National Agricultural Library, which is the largest agricultural library in the United States, and administers a program of competitive extramural grants to promote research in food, agriculture, and related areas. These grants are awarded to state agricultural experiment stations, colleges and universities, other research institutions and organizations, federal agencies, private organizations or corporations, and individuals.

The R&D activities of the USDA have been reviewed on numerous occasions in past years by Congressional committees, the GAO, and committees of the NRC; many changes have resulted from these reviews. In 1981 a comprehensive critique of USDA R&D and education programs was conducted by the Office of Technology Assessment (OTA) (1981). OTA found some problems, such as friction between state and federal re search units that has resulted in the loss of an enormous amount of time and effort, and extra layers of administration resulting from various USDA reorganizations. The OTA also expressed concern whether USDA could meet the future agricultural research needs of the country due to the lack of well-defined long-range goals and a decline in funding for R&D. In general, however, the OTA gave the USDA R&D program high marks and credited it with making the United States the preeminent agricultural nation in the world.

Weaver (1985) reviewed and analyzed the efforts of several economists who calculated the return on federal investments in agricultural R&D. Nearly all of the economists reviewed had reported a positive return. Weaver noted, however, that such calculations are subject to dispute and he cautioned against accepting them uncritically.

## FEDERAL HIGHWAY RESEARCH PROGRAMS*

Federally sponsored highway research antedates the automobile age. In 1883 the USDA established the Office of Road Inquiry to investigate the best methods of road-making and to help disseminate this information. In 1900 a federal laboratory was created to evaluate highway materials. The desperate need for better roads and better road-building techniques was obvious. Europeans visiting North America at the time were struck by the excellence of the railroads and the inferiority of the roads.

Over the years, the federal government has maintained a strong interest in highway research. The Highway Act of 1921 authorized sustained support for highway research, and the Hayden Cartwright Act of 1934 provided that 1.5 percent of annual road appropriations to any state could be used for surveys, plans, or engineering investigations. The Federal-Aid Highway Act of 1944 broadened the uses of this 1.5 percent to include planning and research. The Surface Transportation Assistance Act of 1982 broadened the funding base for each state's federal-aid highway apportionment, and the planning and research authorization increased proportionately. As a result, research projects roughly doubled from 1982 to 1983 (from approximately 300 to 600 projects).

The $70 to $75 million that the United States spends annually on highway research is disbursed through a variety of programs. The Highway Planning and Research (HP&R) Program is by far the major source of support for highway research. Each state receives HP&R funding in the amount of 1.5 percent of its federal-aid highway apportionment. In addition, some states elect to receive 0.5 percent available for urban highway planning and research activities. State highway and transportation departments can divide HP&R money between planning and research as they see fit. Usually, about 15 to 20 percent of HP&R funds is

*Most information is from the Transportation Research Board, (1984).

spent for research, but some states spend as much as 55 percent for this purpose. State-sponsored research in the HP&R program may or may not be included in the Federally Coordinated Program of Highway Research and Development (described below under Federal Highway Administration). Approximately $20 million of the $30 million that states spend each year on research (excluding the $4.4 million allocated for the National Cooperative Highway Research Program, discussed below), comes through the HP&R program. The remainder is state matching funds. States also spend about $5 million/year of their own funds on research, independent of any federal program or matching funds.

The National Cooperative Highway Research Program (NCHRP) emerged not long after construction began on the Interstate Highway System, when many states began to experience similar new problems related to the design of that system. Instead of attempting to deal with the problems individually in each state, the states arranged through the American Association of State Highway and Transportation Officials (AASHTO), the Federal Highway Administration (FHWA), and the Transportation Research Board of the NRC to combine resources in a new research program created to address common problems. Since NCHRP was organized in 1962, 358 projects have been completed and 100 syntheses published. The program operated at a level of about $4.5 million/year for many years; however, funding increased to about $6.8 million/year as a result of the Surface Transportation Assistance Act of 1982.

The FHWA funds a broad array of research conducted by private contractors, consultants, universities, or FHWA staff. Many staff studies are continuing efforts in major research areas, but a significant portion of the research effort is in quick response to particular operational problems and preliminary investigations of new problems. Although FHWA's research expenditures have been roughly consistent over the past 5 years, inflation has substantially reduced the size of this program. A principal part of the FHWA research effort is the Federally Coordinated Program of Highway Research and Development (FCP) established in 1971 to coordinate federal and state activities. Recognizing that the states control the larger research efforts and also possess much of the talent needed to perform effective research, the FCP works with the states to coordinate four programs that are largely derived from federal funding--NCHRP and HP&R, discussed above, and the FHWA administrative contract and staff research programs. Virtually all work in the FHWA contract and staff research programs and approximately 70 percent of work in the HP&R and NCHRP programs are included in the FCP.

The National Highway Traffic Safety Administration (NHTSA) funds and conducts highway-related research on specific safety problems, in addition to a substantial program of upgrading accident data records systems. Some $2 million of research funded and performed by NHTSA is directly applicable to the design and operation of roads and streets.

The Office of University Research of the U.S. Department of Transportation funds highway transportation research projects through a special grant program. The Urban Mass Transportation Administration

(UMTA) has also funded highway research, particularly for urban street operations and transportation systems management techniques that directly relate to street design and operation. Policy research related to highways is performed from time to time by the Office of the Secretary of Transportation. Pavement-related research conducted by the Federal Aviation Administration (FAA) also can be applicable to highways. Recently, the Environmental Protection Agency and the Department of Energy funded staff and contract research in the general area of highway transportation, with particular emphasis on environmental impacts and energy conservation techniques.

Both the U.S. Army Corps of Engineers and the U.S. Forest Service undertake research applicable to highway transportation. Their research is usually directed to specific problems encountered in road construction and maintenance programs within their agencies. The Forest Service builds and maintains a 320,000-mile road system nationwide, adding approximately 10,000 miles each year. It is the fourth largest road system in the world, and annual road-related expenditures are approximately $750 million.

The Transportation Research Board (TRB) of the NRC was organized in 1920 (as the Highway Research Board) to help stimulate, correlate, disseminate, and perform highway research. (The name of the board was changed during the 1960s when the scope of its activities were broadened to encompass research in nonhighway modes and interactions between transportation and social, environmental, and economic issues.) TRB programs are carried out by some 270 committees, task forces, and panels comprised of more than 3,300 members from a wide range of scientific and technological disciplines. TRB is supported by state transportation departments, various administrations of the U.S. Department of Transportation, the Association of American Railroads, and many private companies and individuals.

## MODULAR INTEGRATED UTILILTY SYSTEM PROJECT*

The Modular Integrated Utility System (MIUS) project was initiated in 1972 by the Department of Housing and Urban Development (HUD) in an effort to help reduce housing and energy costs. By definition, MIUS is a combined energy, utility, and waste disposal plant that is small-scale and highly integrated, and that can supply up to five services to a community: electricity, space and water heating, air-conditioning, solid waste processing, and waste water treatment.

In the MIUIS project, HUD joined with several other federal agencies and private organizations to assess the technical and economic feasibility of the MIUS concept, to carry out at least one full-scale real-life test of the concept, to assist the private sector in implementing MIUS, to identify relevant institutional constraints (e.g.,

---

*Most information is from Shostak (1979).

laws or public attitudes that would impede commercialization of MIUS), and finally, to monitor impacts after the concept had been implemented by the private sector.

The MIUS project was terminated in 1979. Two attempts had been made to build full-scale MIUS installations (one in New Jersey and one in Maryland) but neither was completed. However, a considerable amount of technical data was accumulated, and this was disseminated through a series of HUD-sponsored seminars and a MIUS handbook. Overall, the MIUS project must be considered unsuccessful. Nevertheless, the project probably helped lay the groundwork for the subsequent surge in cogeneration facilities and for the Intergrated Community Energy System Project of the Department of Energy.

Shostak (1979) attributes the difficulties of the MIUS project to: the failure of the project leaders to develop a constituency, the involvement of too many individuals and organizations in the planning process, the attachment of too much importance to the proposed demonstration installations (which could not be completed), and the insistence on private-sector involvement in financing the demonstration project.

# REFERENCES

Advisory Committee to the Department of Housing and Urban Development. 1974. A report on Operation Breakthrough. Washington, D.C.: National Academy of Sciences.

Associated General Contractors Construction Education Committee. 1985. AGC Collegiate Construction Education Directory, Fourth Edition. Washington, D.C.: Associated General Contractors.

Albus, J. 1985. Summary trip report on a study mission on Japanese progress in robotics in construction. Construction Robotics Laboratory, Carnegie Mellon University, Pittsburgh, Pa. July 7. Photocopy.

Allen, S. G. 1985. Why Construction Industry Productivity is Declining. Working Paper Series, Working Paper No. 1555. Cambridge, Mass.: National Bureau of Economic Research.

American Business Lists. 1985. Need Sales Leads? September. Omaha, Nebr.: American Business Lists Inc.

Ashley, D. B., and R. L. Tucker. 1984. Enhancing construction through state-of-the-art research. Report on a 1984 Workshop Sponsored by the National Science Foundation. Austin: University of Texas at Austin.

ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers). 1985. 1985-86 research report. 27(10):49.

Baily, M.N. 1981. Productivity and the Services of Capital and Labor from Brookings Papers on Economic Activity, 1. Washington, D.C.: Brookings Institution.

Ball, R. 1981. Employment created by construction expenditures. Monthly Labor Review, December.

Blum, A. November 1980. Comparison of the 1977 census of construction industries and the value of New Construction Put in Place Series. Economic and Demographic Statistics: Selected Papers at 1980 Annual Meeting of the American Statistical Association. Washington, D.C.: American Statistics Association.

Bourdon, C. C. 1980. Is Construction Productivity Declining? Cambridge, Mass.: Joint Center for Urban Studies, Harvard University.

Building Research Advisory Board. 1962. A Program for Building Research in the United States. Washington, D.C.: National Academy of Sciences.

Building Research Advisory Board. 1980. A national strategy for improving productivity in building and construction. Proceedings of a 1979 Building Futures Forum. Washington, D.C.: National Academy of Sciences.

Bureau of the Census. 1985. Value of New Construction Put in Place, May 1985. Washington, D.C.: U.S. Government Printing Office.

Bureau of Labor Statistics. 1985. The Employment Situation: July 1985. News Release. Washington, D.C.: U.S. Department of Labor.

Business Roundtable. 1982a. Measuring Productivity in Construction. CICE Report A-1. New York City: Business Roundtable.

Business Roundtable. 1982b. Technological Progress in The Construction Industry. CICE Report B-2. New York City: Business Roundtable.

Business Roundtable. 1982c. Construction Technology Needs and Priorities. CICE Report No. B-3. New York City: Business Roundtable.

Business Roundtable. 1982d. Size of construction industry. A supplement to CICE Report A-1, of Measuring Productivity in Construction. New York City: Photocopy.

Business Roundtable. 1983. More Construction for the Money. Summary report of the CICE, New York City: Business Roundtable.

Business Week. July 8, 1985. R&D Scoreboard. Pp. 88-106.

Center for Building Technology. 1981. Research for Building Construction Productivity--Report on the June 2, 1981 Conference. Washington, D.C.: National Bureau of Standards.

Clark, K. and Z. Griliches. 1984. Productivity Growth and R&D at the Business Level: Results from the PIMS Data Base. In R&D, Patents, and Productivity. Chicago: University of Chicago Press.

Columbia Books. 1984. National Trade and Professional Association of the United States. Washington, D.C.: Columbia Books.

Committee on Assessment of the Industrial Energy Conservation Program. 1981. An Assessment of the Industrial Energy Conservation Program. Washington, D.C.: National Academy Press.

Committee on Industrial Energy Conservation. 1985. Assessment of the Industrial Energy Conservation Program: FY 1985 and Planned FY 1986. Washington, D.C.: National Academy Press.

Committee on Navy Shipbuilding Technology. 1982. Productivity Improvements in U.S. Naval Shipbuilding, Washington, D.C.: National Academy Press.

Construction Review. March-April, 1985. Construction put in place. P. 19. Federal construction related expenditures, 1980 to 1986. P. 3.

Dunlop, J. T. 1972. Future research directions. Closing Remarks at a Conference on Measuring Productivity in Construction, National Commission on Productivity and the Construction Industry Collective Bargaining Commission, September 14, 1972, Washington, D.C.

Employment Standards Administration. 1979. Seasonal and Cyclical Fluctuations in Construction Activity, Employment, and Unemployment, Washington, D.C.: U.S. Department of Labor.

Engineering News Record. August 25, 1983. Executives map productivity push. P. 138.

Engineering News Record. April 18, 1985. The top 400 contractors. P. 47.

Engineering News Record. May 16, 1985. The top 500 design firms. P. 36.

Evaluation Panels for the National Bureau of Standards. 1978. An evaluation report on the Experimental Technology Incentives Program. Washington, D.C.: National Academy of Sciences.

Fundingsland, O. T. 1984. Evaluation of federal sponsored mission-targeted research and development in the United States. Paper Prepared for a Seminar on the Evaluation of Research and Development, French Ministry of Industry and Research, Paris, May 3-4, 1984.

General Services Administration. 1984. The United States Government Manual 1984/85. Washington, D.C.: U.S. Government Printing Office.

Griliches, Z. 1984. R&D Patents and Productivity. Chicago: University of Chicago Press.

Griliches, Z. and F. Lichtenberg. 1984. R&D and Productivity Growth at the Firm Level in R&D, Patents, and Productivity. Z. Griliches, ed. Chicago: University of Chicago Press.

Hertzfeld, H. R. 1985. Measuring the Economic Impact of Federal Research and Development Investments in Civilian Space Activities. Paper prepared for a Workshop on The Federal Role in Research and Development, National Academy of Sciences, Washington, D.C., November 21-22, 1985.

Inside R&D. June 5, 1985. Volume 14, Number 23.

Lange, J. E. and D. Q. Mills. 1979. The Construction Industry. Lexington, Mass.: D. C. Heath.

Lichtenberg, Frank R. 1985. Assessing the Impact of Federal Industrial R&D Expenditures on Private R&D activity. Paper Prepared for a Workshop on The Federal Role in Research and Development, National Academy of Sciences, Washington, D.C., November 21-22, 1985.

MacAuley, P. H. 1985. Federal Construction-Related Expenditures, 1980 to 1986. Construction Review. March-April, 1985.

Mansfield, E. 1984. R&D and innovation: Some emperical findings. R&D Patents and Productivity, Z. Griliches, ed. Chicago: University of Chicago Press.

McNinch, S., Jr. 1984. The rise and fall of RANN. National Science Foundation. Washington, D.C. Photocopy.

Means, R. S., Jr. 1974. Building Construction Cost Data 1975. Duxbury, Mass.: Robert S. Means.

Means, R. S. 1984. Building Construction Cost Data 1985. Kingston, Mass.: Robert S. Means.

Mowery, David C. 1985. Federal Funding of R&D in Transportation: The Case of Aviation. Paper prepared for a Workshop on the Federal Role in Research and Development, National Academy of Sciences, Washington, D.C., November 21-22, 1985.

National Commission on Productivity. 1972. Measuring productivity in construction. Conference Proceedings. Washington, D.C.: National Commission on Productivity.

NSF. (National Science Foundation). 1983. Research and Development in Industry, 1982. Washington, D.C.: National Science Foundation.

NSF. 1984a. Federal Funds for Research and Development Fiscal Years 1983, 1984, and 1985. Washington, D.C.: National Science Foundation.

NSF. 1984b. Early Release of Summary Statistics on Academic Science/ Engineering Resources. Washington, D.C.: National Science Foundation.

Nelkin, D. 1971. The Politics of Housing Innovation. Ithaca, N.Y.: Cornell University Press.

Noll, R. G. 1985. Economics, politics, and government R&D. Paper Prepared for a Workshop on the Federal Role in Research and Development, National Academy of Sciences, Washington, D.C., November 21-22, 1985.

Office of Technology Assessment. 1981. United States Food and Agricultural System. Washington, D.C.: Congress of the United States.

Paulson, B. C., Jr. 1975. Goals for Basic Research in Construction. Report on a 1975 Workshop Sponsored by the Stanford Construction Institute. Stanford, Calif.: Stanford University.

Project 2000 Committee. 1985. Project 2000 Committee Report and Recommendations. Washington, D.C.: International Union of Bricklayers and Allied Craftsmen.

Reiss, P. C. 1985. Economic measures of the returns to federal R&D. Paper Prepared for a Workshop on the Federal Role in Research and Development, National Academy of Sciences, Washington, D.C., November 21-22, 1985.

Revay and Associates. 1983. Construction R&D in Canada. Montreal, Canada: Revay and Associates.

Scherer, F. M. 1982. Inter-industry technology flows in the United States. Research Policy 11: 232-241.

Scherer, F. M. 1984. Using linked patent and R&D data to measure inter-industry technology flows. In R&D, Patents, and Productivity, Z. Griliches, ed. Chicago: University of Chicago Press.

Schriver, W. R., and R. L. Bowlby. 1985. Changes in productivity and composition of output in building construction, 1972-1982. Review of Economics and Statistics 68 (2): 318-322.

Schwartz, J. 1985. Federal R&D Funding by Budget Function; The Washington Post, December 10, 1985. P. A-19.

Science Applications Task Force. 1977. Report to the Director of the National Science Foundation. Washington, D.C.: National Science Foundation.

Shostak, A. B. 1979. America's modular integrated utility system project: A case study in the problems of pioneering new energy systems. Supporting Paper for the Study of Nuclear and Alternative Energy Systems. Washington, D.C.: National Academy of Sciences.

Steering Committee on Civil Engineering Productivity. 1983. Report on the Workshop on Civil Engineering Productivity. New York: American Society of Civil Engineers.

Stokes, H. K., Jr., 1981. An examination of the productivity decline in the construction industry. The Review of Economics and Statistics, Vol 63 No. 4:495-502.

Suzuki, E. 1984. The view from Japan of future building programs. In Four Papers: Technological Trends and the Building Industry. Washington, D.C.: Advisory Board on the Built Environment.

Swedish Council for Building Research. 1983. The Swedish Building Sector in 1990. Stockholm: Swedish Council for Building Research.

Tassey, G. 1985. The technology policy experiment as a policy research tool. Research Policy 14:39-52.

Teich, A. H. 1985. Federal support of applied research: A review of the United States experience. Paper Prepared for a Workshop on the Federal Role in Research and Development, National Academy of Sciences, Washington, D.C., November 21-22, 1985.

Terleckyj, N. E. 1985. Measuring economic effects of federal R&D expenditures: Recent history with special emphasis on federal R&D performed in industry. Paper Prepared for a Workshop on the Federal Role in Research and Development, National Academy of Sciences, Washington, D.C., November 21-22, 1985.

Transportation Research Board. 1984. America's Highways, Accelerating the Search for Innovation. Washington, D.C.: National Research Council.

UNESCO, 1980. Statistical Yearbook. Paris, France: United Nations Educational, Scientific, and Cultural Organization. P. 801.

Weaver, Robert D. 1985. Federal R&D and U.S. agriculture: An assessment of role and productivity effects. Paper Prepared for a Workshop on the Federal Role in Research and Development, National Academy of Sciences, Washington, D.C., November 21-22, 1985.