CHAPTER 6

Research and Development for Public Works

Photo credit: American Consulting Engineers Council

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CHAPTER 6
Research and Development for Public Works

Most Federal agencies with major roles in public works provide important management and financial support for research and development (R&D) in their areas of interest. They are the primary bodies (and in some cases the only ones) with enough resources to do this, although, like their State and local counterparts, they must allocate resources carefully. Furthermore, Federal R&D support often ranks behind agency responsibilities for funding construction, operations, or grant programs. The absence of any comprehensive Federal attention to infrastructure, the gaps and overlaps in R&D programs, and the competition for scarce funds for Federal R&D mean that attention to future infrastructure needs is inadequate. Only a few non-Federal researchers in State, university, and industry programs are addressing the resulting voids in infrastructure R&D.

Among the many infrastructure R&D efforts supported by executive branch agencies are a number of in-house programs in direct support of each agency's mission and programs to fund university research and other, more specialized agendas. The U.S. Army Corps of Engineers, the U.S. Environmental Protection Agency (EPA), and each modal administration in the U.S. Department of Transportation (DOT) all sponsor mission-related R&D programs dedicated to infrastructure. Other executive agencies, including the U.S. Department of the Interior, the U.S. Department of Commerce, and the National Science Foundation (NSF), conduct a smaller amount of public works R&D.

In addition to the primary executive agency sponsors of mission-related R&D, several other executive agencies have programs tangential to public works, such as the Department of Commerce's National Oceanic and Atmospheric Administration marine R&D and the U.S. Department of Agriculture's Soil Conservation Service agricultural R&D. However, the level of effort related to infrastructure is small compared with the programs discussed in this chapter. Though the relevant programs of the U.S. Department of Defense (DoD) and the U.S. Department of Energy (DOE) are also limited, these agencies are discussed because some of their R&D could be applied to infrastructure.

Focusing first on the Federal agencies devoted to public works, then on those with related programs, and then on DoD and DOE, this chapter will outline the patchwork of public works R&D programs, paying special attention to in-house and federally funded university research. State efforts and several relevant programs, including technology transfer efforts, will be discussed, and conclusions reached about options for redirecting Federal R&D.

Executive Agency R&D

Infrastructure-related R&D under the direction of executive branch agencies is directly tied to, and limited by, each agency's agenda and responsibilities. Even though many of the technologies and infrastructure needs are cross-cutting (see chapter 5), cooperative R&D and coordination between agencies-even within a single agency—is relatively rare. When a specific R&D need is common to several agencies, the efforts to cooperate are so narrow and uncoordinated that the research results often do not reach the public works organizations that could benefit. (See box 6-A for an example.)

U.S. Army Corps of Engineers

The U.S. Army Corps of Engineers has both civil works and military missions focused largely on infrastructure, for which yearly R&D expenditures total about $350 million. In civil works, the research emphasis is on water resources structures and functions primarily related to navigation, flood control, and environmental quality. Corps military R&D focuses on design, construction, operation, and maintenance of military facilities; some of this is also applicable to public works infrastructure.

Although it is within DoD, the Corps has more extensive contact with State and local governments, the private sector, and other Federal agencies than do other military R&D operations. The Corps' Construction Productivity Advancement Research Program (CPAR) is aimed at stimulating collaboration on technology issues between Corps laboratories and private enterprise, particularly the construction industry. CPAR attracted an investment of $7 million from the private sector in 1989.

Box 6-A—Tunneling: A Buried Research Priority

Tunnel research and development (R&D) in the United States has never been a top priority or even a focused activity for Federal Government agencies, despite its broad applications for public works. Government agencies that fund tunnel and underground construction projects include the Federal Highway Admin"stration, the Urban Mass Transportation Administration, the Office of the Secretary of the Department of Transportation (DOT), the Department of Defense (DoD), the Department of Energy, the Bureau of Mines, and the Bureau of Reclamation. These agencies generally fund specific construction projects, with occasional attention to subtasks, such as tunneling. Most university research is funded by DoD and, to a lesser extent, the National Science Foundation.

In contrast, tunnel research abroad tends to be long term and not tied to a specific project. U.S. projects related to underground structure currently underway include the Superconducting Super Collider in Texas and a feasibility study for a high-level nuclear waste repository in Nevada These efforts could further understanding of waterproofing techniques and tunneling through unstable rock. Gummily, however, non-DOT projects have little applicability to public works tunnels, even though the technologies developed could, with appropriate development, benefit public infrastructure.

Machine manufacturers conti"nually conduct research to improve cutting and excavation methods, and contractors occasionally focus on ways to improve field instrumentation and monitoring methods. See chapter 5 for a discussion of the difficulties of using proprietary equipment and procedures for public works projects. The National Academy of Science's National Cmmittee on Tunneling Technology acts as a technology clearinghouse, provides guidelines on needed research, and represents the United States in the International Tunneling Association.

Most important for tunneling is research to find ways of integrating tunnel boring and excavation with adequate tunnel support. Having the initial support become the permanent lining is desirable, but difficult. In excavating, the next big R&D breakthrough will be machines that can cut through ground with variable geology; water jets and heat are among the technologies for cutting and excavation now under study.

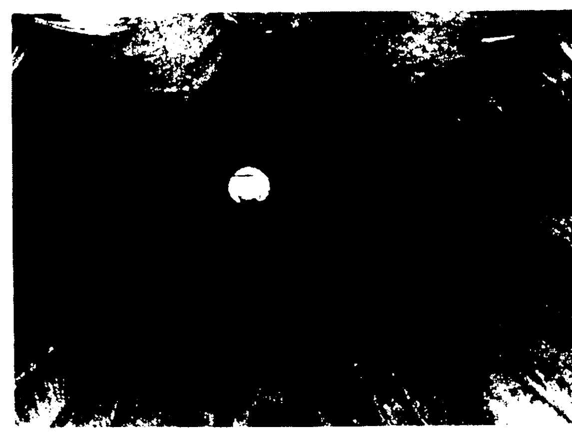


Photo credit: American Consulting Engineers Council

Although tunnels such as this are crucial to surface transportation, technologies to construct have not been a research and development priority in the United States.

Until the early 1980s, Corps civil works R&D was concentrated on technologies and techniques in support of new construction to develop water resources. Since 1983, however, the Corps' appropriations related to operations and maintenance have outpaced those for new construction. While " . . . technology development has lagged in the area of operations and maintenance . . .' the Corps has taken steps to enhance such R&D as the 6-year, $35-miIlion civil works Repair, Evaluation, Maintenance, and Rehabilitation Research program.

The Corps supports 16 laboratories; 6 of these have active research programs, while the others conduct tests related to Corps district construction activities and concerns. (For more on the Corps' administrative structure, see chapter 2.) The combination of experimental facilities, computer modeling, simulation expertise, and experience in the field working with user communities makes the Corps' large laboratories a unique resource. Because Corps laboratories do not receive a direct congressional appropriation, the laboratories work on a reimbursable basis, with sponsors, most frequently other Corps' offices, paying all costs of the work involved.

Three of the Corps' six main laboratories, the Waterways Experiment Station (WES), the Cold Regions Research and Engineering Laboratory (CRREL), and the Construction Engineering Re-

[1]U.S. Army corps of Engineers, "Advanced Technologies for Infrastructure," unpublished manuscript prepared for the Office of Technology Assessment, n.d., p. 20.

search Laboratory (CERL), are involved primarily in infrastructure technology R&D. Each has substantial research and testing facilities and in-house technical staff.

The WES laboratory complex in Vicksburg, Mississippi, is the Corps' principal research, testing, and development facility. WES has six subdivisions, which collectively execute engineering investigations and R&D in areas such as hydraulics, soil and rock mechanics, earthquake engineering, coastal effects, concrete, pavements, water quality, and dredged material. Although Corps' offices are the source of the majority of WES' work, WES also undertakes studies for other Federal agencies, State and local governments, private industry, and foreign governments.

CRREL, located in Hanover, New Hampshire, concentrates on the science and engineering problems of cold regions, such as river ice management for winter navigation, ice jam flooding, and other ice-related, hydrological problems. CRREL also conducts R&D on reducing life-cycle costs of pavements, buildings, and environmental engineering facilities. CRREL has ongoing cooperative programs with the Federal Aviation Administration (FAA), the Federal Highway Administration (FHWA), the Strategic Highway Research Program, EPA, DOE, other DoD organizations, and a number of State DOTS.

CERL, located in Urbana, Illinois, emphasizes improving construction quality and energy efficiency while still safeguarding the environment. CERL works with nondestructive testing technologies, corrosion prevention, materials, and information systems, in support of Army programs in military construction, operations and maintenance, and engineering, with some attention to civil works. Technologies developed by CERL applicable to public works include PAVER, a pavement maintenance and management information system. CERL cooperates with DOT's FHWA and FAA, and with municipalities through the American Public Works Association.

The Corps works hard on technology transfer through seminars, conferences, the publication of technical papers—WES alone issues over 225,000 publications annually-demonstration and transfer programs, input to national standards development, cooperative agreements with universities and the private sector, participation in professional societies, and formal training courses. However, the agency acknowledges difficulties in keeping even its own personnel up-to-date on all the latest technology?

The Corps probably has the most extensive in-house civilian public works R&D capacity in the country, though it is now heavily committed to water resources development. The Corps is trying to diversify its role, targeting environmental engineering and hazardous waste cleanup as potential new areas of expertise. The Corps could be a more widely shared resource for other agencies and the private sector, if prospective client agencies are willing to develop appropriate R&D programs and able to make firm financial commitments.

Environmental Protection Agency

EPA conducts much of the Federal environmental infrastructure R&D, with most of the agency's R&D resources focused on its in-house program in support of its regulatory activities. Some R&D is written into legislation, such as the 1990 requirement for continuing acid rain assessment and research. Some of the R&D, such as toxics research, is mandated in EPA's founding statutes.[3]

EPA spreads its R&D budget across a number of media-specific programs, as well as in a newly structured interdisciplinary program. Air-related problems, such as ozone, global warming, and acid rain, have consumed 23 percent of EPA's R&D budget, with 24 percent going to hazardous materials, 24 percent to interdisciplinary research, 11 percent to water-related issues, and 9 percent to toxics (especially pesticides). Air-related research is largely concerned with health issues, though work includes research on State controls for ozone and other airborne pollutants.[4] Research on hazardous materials is concentrated on engineering issues

[2]Ibid., p. 20.

[3]American Association for the Advancement of Science, Intersociety Working Group, *AAAS Report XIV: Research and Development, FY 1990* (Washington, DC: 1989), p. 100.

[4]American Association for the Advancement of Science, Intersociety Working Group, *AAAS Report XV: Research and Development, FY 1991* (Washington, DC: 1990), p. 131.

related to disposal and cleanup of hazardous wastes and on interdisciplinary work at EPA's university centers. EPA has recently consolidated some diverse R&D and added new programs emphasizing "interdisciplinary research. " These now comprise the single largest program type focused on basic research-especially in the areas of ecological studies and human exposure assessments.[5]

R&D Resource Allocation

In late 1990 EPA had nine assistant administrators, each overseeing several offices that do research, and each separate from, but cooperating with, the regional administrative offices. EPA's assistant administrator for research and development alone oversees five offices (see figure 6-1) that administer R&D laboratories that support EPA's regulatory activities and responses to legislative and executive directives. A sixth office, the Office of Technology Transfer and Regulatory Support, serves as the connection between EPA laboratories and "clients' needing direct contact with EPA, and serves as manager for an information clearinghouse in Cincinnati. The Office of Research Program Management is a policymaking office, and does not conduct research. In 1979, Congress established the Office of Exploratory Research to support basic environmental research, mainly through research grant programs and university-based research centers.

Of the offices that administer laboratories, the Office of Modelling, Monitoring Systems, and Quality Assurance has the largest combined budget and staff (see table 6-l). The largest of the office's three laboratories, the Atmospheric Research and Exposure Assessment Laboratory in Research Triangle Park, North Carolina, conducts research focusing on quantifying, measuring, and modeling airborne pollutants and potential controls. The Las Vegas Environmental Monitoring Systems Laboratory, the next largest, does applications-oriented research on systems and strategies for monitoring environmental and human exposure to pollutants and conducts field tests and demonstrations of monitoring systems. The Cincinnati Environmental Monitoring Systems Laboratory has a similar charge, but focuses on biological and chemical assessment methods and operates EPA's Quality

Table 6-l—Environmental Protection Agency Laboratories

Office	Number of laboratories	Number of staff	1989 budget (in millions of dollars)
Office of Modelling, Monitoring Systems, and Quality Assurance	3	441	$84.0
Office of Environmental Engineering and Technology Demonstration	2	282	78.5
Office of Environmental Processes and Effects Research	6	407	59.3
Office of Health Research	1	286	46.2
Total	12	1,416	$268.0

SOURCE: Office of Technology Assessment, 1991.

Assurance Program, which is charged with maintaining the credibility of many of EPA's databases.[6] The laboratories all have some technical assistance and technology transfer programs for EPA clients, including public works agencies.

The Office of Environmental Engineering and Technology Demonstration manages EPA's most amply funded laboratory, the Risk Reduction Engineering Laboratory, which performs engineering research and provides technical assistance to the agency for drinking water, hazardous wastes, underground storage tanks, pesticides, Superfund, toxics, and wastewater. The Air and Energy Engineering Research Laboratory in Research Triangle Park, North Carolina, is staffed primarily by engineers who conduct research on air pollution from stationary sources, focusing on the industrial sources of air pollution, mitigation and prevention of pollution, and developing equipment for all of these.

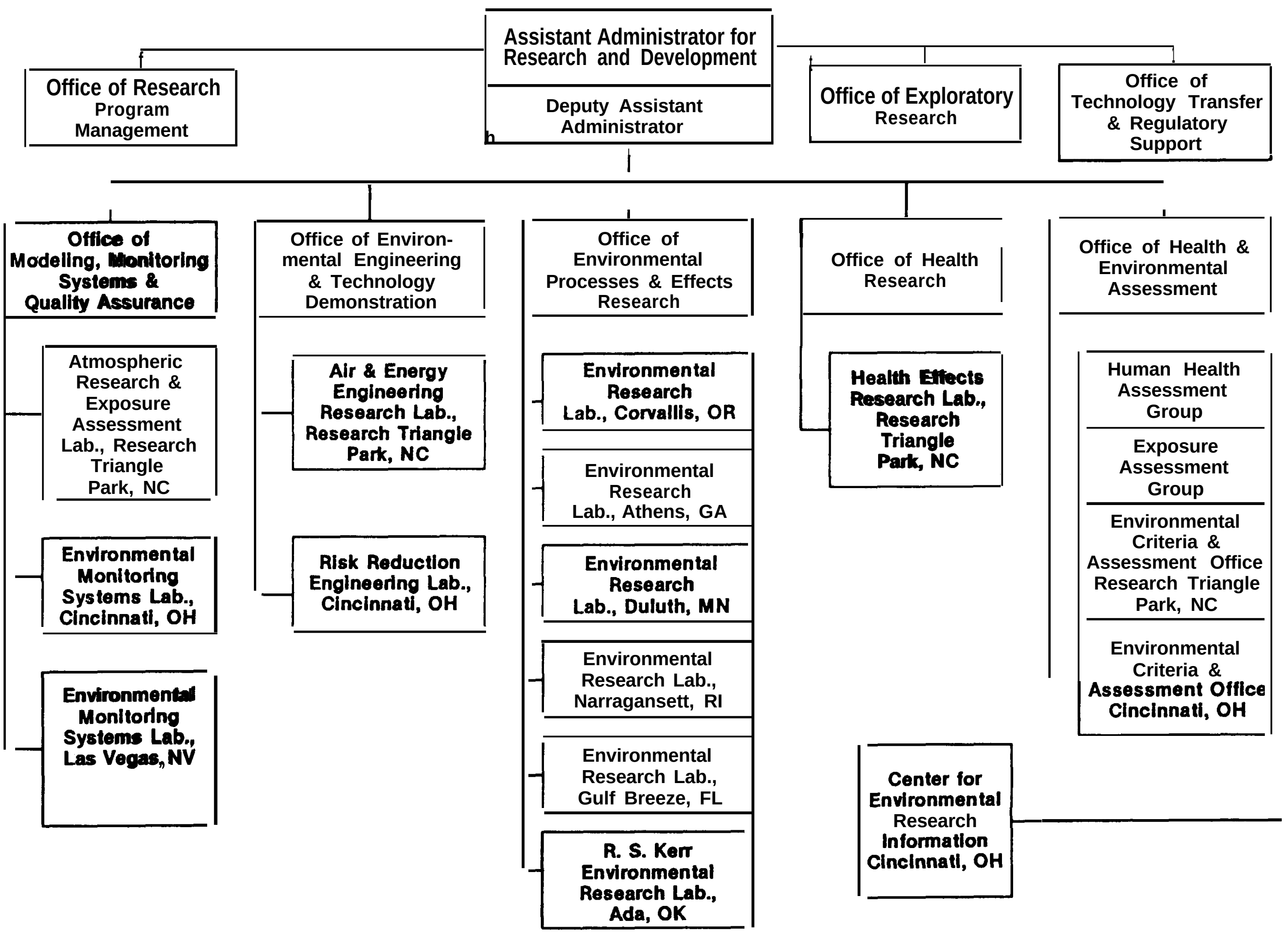
The Office of Environmental Processes and Effects Research administers six Environmental Research Laboratories that focus on marine and inland aquatic ecosystems. The laboratories are located in Oregon, Minnesota, Florida, Oklahoma, Georgia, and Rhode Island.

Both the Office of Health Research and the Office of Health and Environmental Assessment support EPA's regulatory activities through preparing criteria and risk assessment methodology and guidelines. The Office of Health Research administers the Health Effects Research Laboratory in Research

[5] Ibid., p. 93.

[6] U.S. Environmental protection Agency, *Technical Assistance Directory* (Washington DC: March 1989).

Figure 6-1—Environmental Protection Agency's Office of Research and Development Organization Chart



SOURCE: Environmental Protection Agency, Technical Assesstance Directory(Washington, DC: March 1989).

Triangle Park, North Carolina, which provides a basis for EPA's health-related regulations, focusing on a broad range of pollutants and media. The Office of Health and Environmental Assessment administers two Environmental Criteria and Assessment Offices, one in Cincinnati and one in Research Triangle Park, which focus on data collection in support of EPA regulations.

The research agendas for all of EPA's laboratories are set by steering committees composed of staff from the Office of Research and Development and the Agency programs. The committees designate and coordinate research for the laboratories, giving the laboratories little reason for direct communication with each other. In some cases, a program office needing R&D will contact a laboratory directly,[7] and the Office of Technology Transfer and Regulatory Support provides some coordination among the offices. However, the laboratories maintain a good deal of independence, each producing its own publications and making its own cooperative agreements for extramural research with universities, other Federal agencies, and the private sector. Although the steering committees are more heavily emphasized than in the past, media-specific programs still dominate discussions about what research will be done at which laboratory.

While the laboratories are allowed flexibility in their research approaches, R&D is not truly interdisciplinary, since the Agency remains dominated by programs and directives aimed at individual environmental media. In addition, EPA research must provide a scientific basis for the Agency's regulations. Outside pressures, such as congressional action and lawsuits (see chapter 2), and limited Agency resources ensure a continued focus on regulations-related research. As a result, EPA conducts little R&D on condition assessment and repair and rehabilitation technologies, despite the acute interest of infrastructure managers in these areas (see chapter 4).

University Agreements

EPA funds universities through solicitations and through cooperative agreements made between program offices, laboratories, and universities. Total annual university awards have been in the $50- to $60-million range over the last 5 years.

The bulk of EPA's university funding flows through "cooperative agreements" with EPA laboratories. A key difference between these flexible arrangements and other grants is that the cooperative agreements include substantial involvement of an EPA staff liaison, who chooses to work with university staff because the university is well equipped in the field or is doing work pertinent to ongoing EPA research. More money reaches universities through this direct EPA-laboratory collaboration than through EPA centers and competitive solicitations combined.[8] Although EPA seems to be unique in its systematic use of cooperative agreements, Executive Order 12591 (April 1987) and Public Law 96-480 called for this type of collaboration at all Federal laboratories. Such collaboration can bean effective and flexible means of contracting and transferring information between sectors and laboratories. However, EPA's agreements tend to be limited in both scope and the potential for innovation, because the research is targeted at supporting regulations.

interdisciplinary Research Centers—The Office for Exploratory Research (OER) at EPA supports a competitive grants program and is also responsible for two programs supporting university-based research centers. Based on an NSF model, the centers in these two programs carry out interdisciplinary and collaborative research on diverse environmental themes.

The first of these programs, the Exploratory Research Center Program, is based on competitively awarded cooperative agreements. The eight current centers each receive approximately $540,000 from OER each year, and may receive additional support from EPA laboratories. According to Federal requirements, a minimum of 5 percent matching funding must come from the university, the private sector, or other non-Federal sources.[9] Centers are encouraged to use EPA funds to leverage additional support for their programs, and efforts to attract aid have ranged from completely unsuccessful to hugely successful. The director of each center works in

[7] Jerry Garman, Office of Technology Transfer and Regulatory Support, U.S. Environmental Protection Agency, personal communication Apr. 10, 1990.

[8] Karen Morehouse, Office of Exploratory Research, U.S. Environmental Protection Agency, personal communication Mar. 5, 1990.

[9] Required in part by the Stevenson-Wydler Act.

tandem with an EPA project officer and receives technical guidance from an independent Science Advisory Committee. The original eight centers currently are being phased out, and a new competition is under way to select four new centers, each to be funded at approximately $1 million annually over 9 years. Each Exploratory Research Center is responsible for distributing its findings, and most do so through technical project reports, books, articles, and participation in seminars or technical conferences.

The projects at the Exploratory Research Centers tend to be problem-specific, pollutant research. Though none of the centers focuses on infrastructure, the research has potential, through new or changed regulations, to affect methods of and systems for waste and drinking water treatment and waste disposal and facility siting. An example is the Ecosystems Center's work on establishing a methodology for ecological risk assessment, which all developers using Federal funds could use in performing the required environmental impact assessments.

The "Superfund" legislation directed EPA to establish centers of excellence programs to study all aspects of the manufacture, use, transportation, disposal, and management of hazardous substances, and publish and disseminate the results of such research. The resulting five Hazardous Substances Research Centers, also under the direction of OER, were established in 1989 after a competition. EPA provides each center with $1 million annually, to which the centers must add a 20-percent match. Using EPA funds as leverage, the centers have been successful in obtaining additional support from such sources as DOE, DoD, State appropriations, industrial affiliates and organizations, and others.

In addition to the legislated requirements, EPA developed a special structure for the Hazardous Substances Research Centers. The research is problem-oriented, and the centers are supported and advised twice yearly by a Science Advisory Committee, consisting of scientists and engineers from academia, government, and industry. EPA established a Training and Technology Transfer Advisory Committee and required the centers to direct between 10 and 20 percent of their budgets to training and technology transfer. The centers have satisfied these requirements mostly through short courses, publications, demonstration projects, conferences, and consultation and cooperation with industry and regional and State governments to determine needs. All of the programs take a multidisciplinary approach and share advisory panel members and directors.

EPA encourages innovative basic research at both the Superfund Centers and the Exploratory Research Centers, although the Superfund Centers also perform applied research. Many of the projects target remediation and other applicable R&D that can readily benefit the region, but since the centers focus on basic research, technology application and development remain the business of EPA laboratories. EPA also now operates three "line item" centers that are similar to and cooperate with the Hazardous Substances and Exploratory Research Centers. However, funding for each of these centers was earmarked in legislation and did not include a competition; furthermore, none of the centers is managed through OER.

Department of Transportation

DOT supports applied R&D of transportation technologies (see table 6-2). Most current research is conducted or supported separately by each modal administration, although in the late 1960s and early 1970s, the agency had centralized R&D coordination in the Office of the Secretary. The Department began to cut back its research agenda in the 1970s, targeting funds at R&D to support technology development for the National Airspace System (NAS) Plan (see figure 6-2). Basic and broad-based research declined two-thirds from 1975 to 1985, although at the same time, applied research funding doubled, with much of the increase going to FAA.[10]

Though some limited coordination of R&D continues through the DOT R&D Coordinating Council, DOT no longer has a departmentwide R&D coordinator within the Office of the Secretary of Transportation. Such a position was briefly re-created in 1985, but dropped again after proving ineffective.[11] As a result of budget cutbacks and the lack of coordination for R&D over the past decade, each

[10] U.S. General Accounting office, *Department of Transportation: Enhancing Policy and Program Effectiveness Through Improved Management* (Washington, DC: U.S. Government Printing Office, July 1987), p. 212.

[11] Ibid.

Table 6-2—Department of Transportation Public Works Research and Development

Agency	FY 1991 funding (millions of dollars)	Funding source	Comments
Federal Highway Administration			
Highway Planning and Research Program	$51'	A portion of 1.5 percent set-aside of Federal-aid construction funds from the Highway Trust Fund	Supports State and local planning, traffic measurement, and other research
National Cooperative Highway Research Program	8	5.5 percent set-aside of HP&R funds	Contract research managed by Transportation Research Board (National Research Council)
Staff research	18	Highway Trust Fund	30 percent in-house research; balance in contracts
Strategic Highway Research Program	30	0.25 percent set-aside from Highway Trust Fund	Contract R&D focused on highway construction; 5-year program
Federal Railroad Administration	15	From appropriated budget	In-house and contract R&D (does not include $6.15 million for magnetic levitation rail initiative)
Urban Mass Transportation Administration	2	From appropriated budget	Development projects
Research and Special Programs Administration			
Volpe National Transportation Systems Center	115b	Fee-for-service reimbursements	Two-thirds of research is for DOT coming out of other administrations' budgets; one-third is for extramural clients
Federal Aviation Administration	205	From appropriated budget	63 percent of budget for in-house R&D
Total	$44&		

a Total funds for the Highway planning and Research (HP&R) Program are about $153 million, meet of which is used for planning. The portion used forresearh is $53 million.
b Estimate for Department of Transportation (DOT) research.
c Total does not include the one-third of Volpe National Transportation System Center's total budget that comes from other sources.

SOURCE: Office of Technology Assessment, 1991, based on information from the Federal Highway Administration, Volpe National Transportation Systems Center, and the U.S. Department of Transportation.

administration's R&D has become increasingly modally oriented and focused on supporting short-term program objectives. The lack of long-range and systems-oriented R&D has left DOT unprepared to address current national needs, such as transportation-related air quality issues and intermodal and urban capacity problems. While the agency is attempting to makeup for these shortcomings now, developing and implementing appropriate new programs and ensuring adequate funding are major challenges.

With the exception of FAA, DOT agencies are increasingly turning to universities and outside contractors to execute R&D. The recent National Transportation Policy stressed the need to seek out additional alternative R&D funding and performance sources, directing that programs ". . . foster increased public-private partnerships and strengthen the tools and incentives for innovative research funding by the private sector, state and local governments, and non-profit organizations.' '[12]

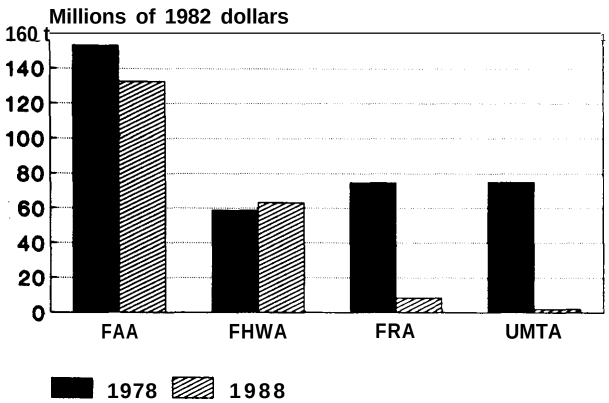
For a number of years DOT has used universities as outside R&D resources. About 71 percent of all Federal research funds for universities take the form of grants to individuals for specific research projects.[13] DOT invested $31.3 million in such contracts in fiscal year 1988,[14] with FAA allocating over one-half of the total.

[12] U.S. Department of Transportation, *Moving America: New Directions, New Opportunities* (Washington, DC: February 1990), p. 104.

[13] U.S. General Accounting Office, "University Funding: Assessing Federal Funding Mechanisms for University Research,'' unpublished report, 1986, p. 2.

[14] National Science Foundation, *Federal Funds for Research and Development: Fiscal Years 1987,1988, and 1989*, vol. 37, NSF 89-304 (Washington, DC: 1989), p. 28.

Figure 6-2—Annual Department of Transportation R&D Obligations, 1978 and 1988



KEY: FAA-Federal Aviation Administration; FHWA—Federal Highway Administration; FRA-Federal Railroad Administration; UMTA-Urban Mass Transportation Administration.

SOURCE: Office of Technology Assessment, 1991, based on data supplied by the U.S. Department of Transportation.

Research and Special Programs Administration (RSPA)

Most RSPA research is carried out at the Volpe National Transportation Systems Center (TSC) in Cambridge, Massachusetts. TSC conducts and manages some R&D for most DOT agencies as well as for outside agencies, and has recently tried to focus on a systems approach to cross-cutting and intermodal issues.

The center does research on a reimbursable basis for RSPA, FAA, FHWA, the Federal Railroad Administration (FRA), the Coast Guard, the National Highway Traffic Safety Administration, the Office of the Secretary, and the Urban Mass Transportation Administration (UMTA), and is also responsible for administering DOT's Small Business Innovation Research Program. Over the last few years, FAA has consistently been TSC's largest single source of funds. One-third of TSC's current work is done for other executive agencies needing transportation-related R&D, including DOE, DoD, and EPA. Although the Corps of Engineers and TSC conduct overlapping research, the agencies have just begun collaborative work on magnetic levitation rail, under an agreement with FRA. TSC's total current budget is about $147 million.[15]

TSC seeks to integrate public and private resources in projects such as the Track Safety Research Program, sponsored by FRA. In this effort, TSC researchers coordinate and promote track safety practices with individual railroads, the Association of American Railroads (AAR), the American Railway Engineering Association, track producers, universities, consultants, DoD rail-related programs, and a few foreign researchers.

The center is remunerated on a project-by-project basis by its client agencies and departments, and research is conducted and managed in partnership with the sponsoring agency. About two-thirds of the R&D is conducted onsite by teams formed from government, industry, and university personnel. TSC has substantial contact with both industry and university researchers and currently has over 300 different sources for technical support, with approximately 75 percent of the center's budget going to such outside entities. By drawing from its database of contractors, the center can award competitive contracts for technical support within 10 weeks of making an interagency agreement. TSC's ability to bring multidisciplinary teams of sophisticated industry and university resources together quickly makes it an attractive R&D broker for DOT and other Federal agencies with transportation research needs. operating as an enterprise on a cost reimbursable basis has helped TSC become more dynamic, cost-effective, and accountable.[16]

Federal Aviation Administration

Accounting for over one-half of DOT's R&D budget, FAA is the only modal agency that has consistently invested in applied R&D over the past decade. The majority of this R&D is conducted in-house,[17] primarily at FAA'S Technica1 Center in New Jersey and the Civil Aeromedical Institute in Oklahoma. FAA'S R&D program also conducts some cooperative research with DoD and the National Aeronautics and Space Administration (NASA). Over two-thirds of FAA's R&D budget supports its mission to operate and manage the Nation's airways through the NAS Plan and other

[15] Gary Ritter, Volpe National Transportation Systems Center, Research and Special Programs Administration, U.S. Department of Transportation, unpublished memorandum, May 10, 1990.

[16] Ibid.

[17] National Science Foundation, op. cit., footnote 14, p. 28.

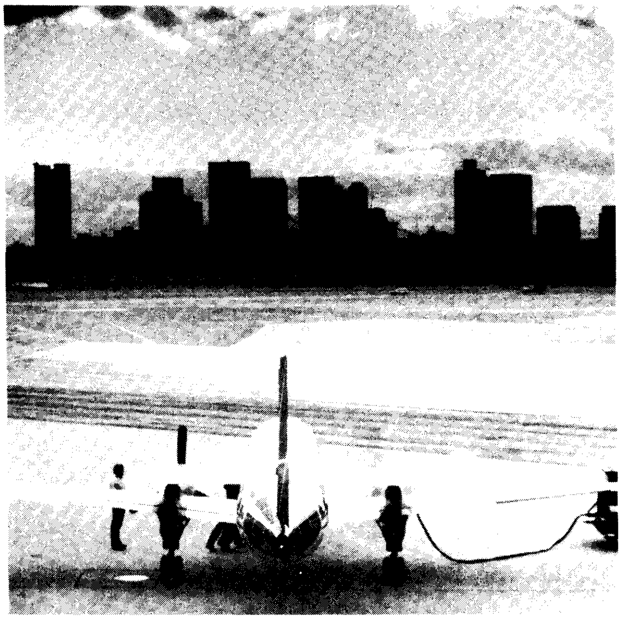


Photo credit: Federal Aviation Administration

The Federal Aviation Administration's research and development budget accounts for over one-half of the Department of Transportation's total spending on R&D.

surveillance, communications, navigation, and system management technology development programs. Aircraft safety programs-crash worthiness, fire protection, aging aircraft issues, and explosives detection—represent about 15 percent of FAA's R&D effort. Weather, medical, and effects of aviation on the environment comprise the remaining areas of research.

While human behavior, capabilities, and interaction with technologies underpin the safety and efficiency of transportation systems, until recently, FAA (and other agencies within DOT) paid scant attention to human performance research. As required by the Aviation Safety Research Act of 1988, FAA has begun to focus more on ''human factors" areas. To ensure continued and effective R&D, however, consistent long-term support will be needed, and human factors research must be fully integrated into technology development projects.

Much of FAA's R&D plan for air traffic control and management directly or indirectly aims to improve the air transportation system's capacity. However, FAA's R&D plan does not address critical groundside access issues. Without dramatic improvements in surface links to airports, including serious attention to mass transportation alternatives, the growing numbers of passengers will, at best hinder system efficiency and, at worst, will constrain capacity. More research within FAA, and across DOT, on intermodal operations is essential.

Federal Highway Research

Most highway research (more than 80 percent)[18] is directly supported by the Federal Highway Trust Fund monies that flow through FHWA. The major research efforts include the Highway Planning and Research Program (HP&R), the National Cooperative Highway Research Program (NCHRP), the FHWA Administrative Contract and Staff Research Program, and the Strategic Highway Research Program (SHRP) (see figure 6-3).

States are required to set aside 1.5 percent of their Federal-aid construction funds for highway research and planning through the HP&R Program and to provide up to a 40-percent match to the Federal-aid monies. HP&R funds typically total $150 million to $200 million annually, with two-thirds of the total going to planning and the remaining one-third (about $53 million in FY 1990) going to research. Although States have identified HP&R as a high-priority program, funds have declined 45 percent over the last 20 years.[19]

NCHRP is a contract, applied research program focused on national-level, operational problems and funded by the States through the American Association of State Highway and Transportation Officials (AASHTO), from a 5.5 percent set-aside of HP&R monies. NCHRP is managed by the Transportation Research Board (TRB) of the National Research Council with FHWA support. Total NCHRP spending is around $8 million per year, and the States must approve funding annually.[20]

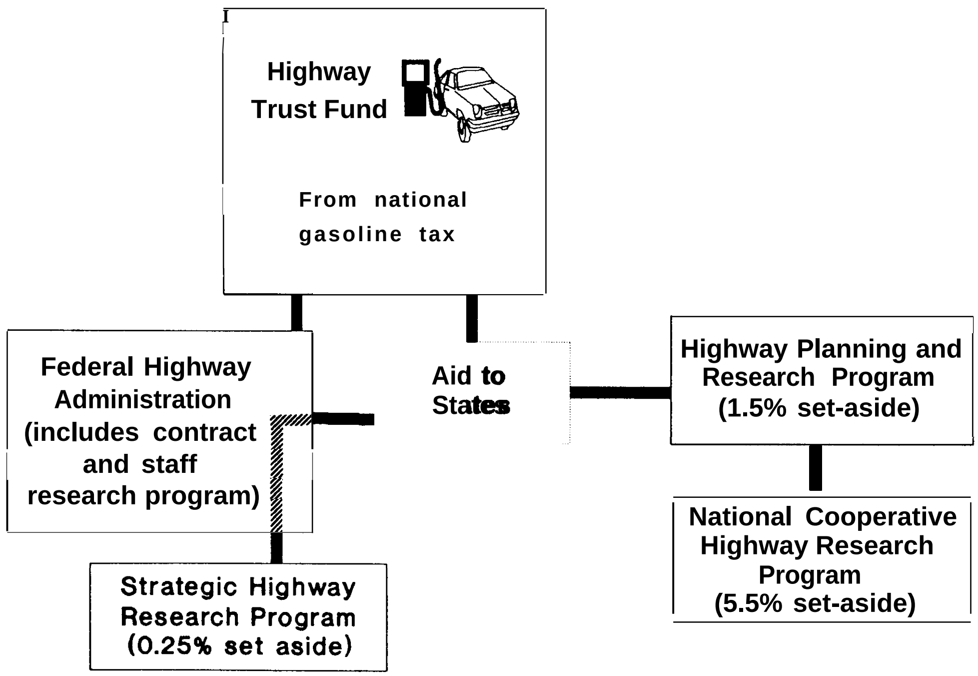
SHRP was established to examine gaps in current knowledge and the lack of coordinated R&D, and to target short-term, high-payoff technologies and issues. Congress included in Public Law 100-17 the release of $150 million from the Highway Trust

[18] American Association of State Highway and Transportation Officials, *Innovation: A Strategy for Research, Development, and Technology Transfer* (Washington DC: October 1989), p. ES-11.

[19] Ibid., p. 1-8.

[20] Ibid., p. 3-3.

Figure 6-3-Federal R&D Funding for Highways



SOURCE: Office of Technology Assessment, 1991.

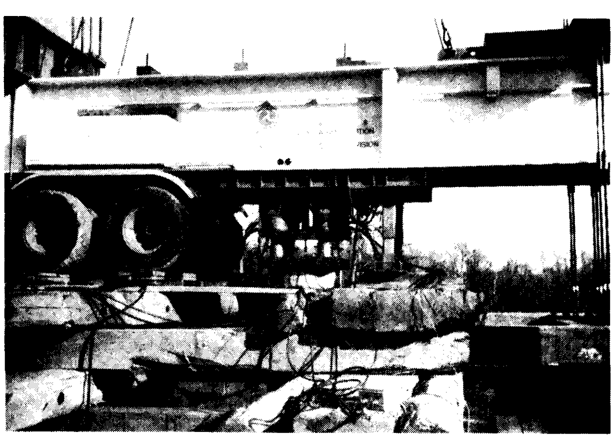


Photo credit: American Consulting Engineers Council

The Federal Highway Administration's research emphasizes projects aimed at immediate highway needs, such as this pile tester being used at a highway interchange construction site.

Fund, as a 0.25 percent set-aside from Federal-aid to States, for a 5-year program. SHRP was intended to supplement existing highway research and compensate for the lack of funding of untried technologies.

Limiting its efforts to highways and bridges, SHRP manages research with applications in six neglected areas-asphalt, long-term pavement performance, maintenance cost-effectiveness, protection of concrete bridge components, cement and concrete, and chemical control of snow and ice on highways. Research is contracted to various laboratories—mostly university and private laboratories—and subcontracted to the National Institute of Standards and Technology (NIST) and the Corps of Engineers' Construction Engineering Research Laboratory. Representatives of FHWA, DoD, FAA, and TRB participate on SHRP's advisory committee. Because little alternative funding is available for risky R&D, many technologies not receiving SHRP contracts or falling outside of SHRP's narrow areas of research remain untried.

The Contract and Staff Research Program is primarily conducted at FHWA's Turner-Fairbank Highway Research Center. The FHWA budget for R&D in fiscal year 1990 is approximately $21 million ($20 million for contracts, $1.5 million for staff research). FHWA manages contract research with the private sector, universities, and other agencies.[21] The one-tenth of FHWA's research funding going to in-housework accounts for approximately 30 percent of FHWA staff time.

FHWA's research has generally favored short-term R&D aimed at immediate needs in highway safety, traffic operations, structures, pavements, and motor carrier safety. The agency plans a greatly expanded research focus on intelligent vehicle/highway systems in 1991, giving overdue attention to R&D aimed at a specific, long-term problem area.

FHWA disseminates information and results of its investigations to the highway user communities through technical reports, conferences, seminars, and other typical technology transfer paths. FHWA's National Highway Institute also offers in-the-field technical training and education for Federal, State, and local highway employees. The Rural Technical Assistance Program, administered by the National Highway Institute, conducts training workshops, onsite demonstrations, and other transfer activities, mostly through rural Technology Transfer Centers.

To further stimulate communication, FHWA developed the Nationally Coordinated Program (NCP), a management link between HP&R, NCHRP, and FHWA staff research programs to track research activities in the Federal-aid programs and prevent gaps or overlap. If used effectively, NCP could help FHWA transfer technology, set priorities for future Federal research, and allocate R&D resources accordingly. These issues currently are not adequately addressed in FHWA's R&D framework.

NCHRP and SHRP are good examples of successful cooperation in both applied R&D and technology transfer among Federal, State, and local highway authorities. Although additional technology transfer programs are badly needed, the most significant limitation for highway R&D is insufficient funding. According to a recent AASHTO report, ". . . funding for research has not kept pace with the growing needs and opportunities for technological innovation in the transportation industry. Highway research spending as a share of total highway program expenditures is currently about 0.2 percent. . . .' '[22] Issues detailed in chapter 3 highlight the inadequacy of presently used technologies; the current under-investment in highway R&D could lead to wider gaps between problems and solutions in the future.

Federal Railroad Administration

Most of FRA's modest research efforts are conducted with cooperation and cost-sharing from other research organizations, government agencies, and private organizations, including AAR, TSC, DOE, and individual railroads and universities. In 1985, FRA's 14-member Office of Research and Development was placed under the direction of the associate administrator for safety, giving priority to safety R&D. Most testing and simulations of track structures and rail vehicles are carried out at the Transportation Test Center in Pueblo, Colorado, a federally constructed facility, leased to and operated by the Research and Test Department of AAR, under a contract with FRA. Train handling experiments, locomotive environmental assessments, and engineer training experiments are performed at FRA's Research and Locomotive Evaluator/Simulator in Chicago, Illinois, which is operated by the Illinois Institute of Technology Research.

In-house research at the Office of Research and Development is divided into a number of programs. The Equipment, Operations, and Hazardous Materials Program focuses on rail vehicle design and operations and those aspects of hazardous materials transportation peculiar to rail. The Track Safety Program focuses on all aspects of track structure, railroad bridges, signal and train control systems, and interaction between the track and vehicle.[23] In addition, FRA has recently contracted with TSC to conduct major R&D work on magnetic levitation technology (see chapter 3), marking anew foray into high-risk, high-technology R&D.

Urban Mass Transportation Administration

Transit operations are not profitmaking, and in any case mass transit represents such a small market that manufacturers have no incentive to undertake related R&D. This makes the Federal Government the only entity with any ability to fund mass transit R&D and take the risks associated with bringing new products into use. However, UMTA's R&D budget has declined dramatically over the last 15

[21]Robert Kreklau, Federal Highway Administration, U.S. Department of Transportation, unpublished memorandum, June 11, 1990.

[22]American Association of State Highway aud Transportation Officials, op. cit., footnote 18, p. ES-11.

'Federal Railroad Administration, Office of Research and Development *1988 Research andDevelopmentProgram (Washington DC:* August 1988).

years. Estimated R&D outlays for fiscal year 1990 were $2 million, down from $52.1 million in 1980.[x] The entire 1990 budget expenditures were earmarked for development of existing mass transit technologies, including projects on alternative fuels.

Most of UMTA's budget goes to capital and operating assistance for State and locally run systems;[25] of the $3.5 billion in assistance awarded in fiscal year 1989, just under $6 million went to 40 projects under the authority of section 6 for Research, Development, and Demonstration Projects.[26] The average grant was for about $150,000, and most of the grants supported some type of systems planning or management study. Additionally, almost one-third of the money allocated went to two congressionally mandated studies. Because UMTA supports very little technical R&D, either in-house or in the form of grants to States, very little R&D is done in this country on mass transit.

University Centers

DOT has a cross-cutting Transportation Research Centers Program under the authority of the Office of the Secretary of Transportation. The program supports 10 university-based centers, 1 in each of the 10 standard Federal regions, and each center has a consortium-with a total of 68 universities involved. In addition to providing applied R&D for transportation, the centers aim to build an 'esprit de corps' among the center students and encourage a commitment to careers in transportation.

The centers were authorized by the Surface Transportation and Uniform Relocation Assistance Act of 1987 (Public Law 100-17) for ". . . multimodal research and training concerning the transportation of people and goods. " The authorizing legislation provides Federal funds from the Highway and Mass Transit Trust Funds and requires centers to provide dollar-for-dollar matching from non-Federal sources. Ultimately, these centers are intended to become self-sustaining through regional government and industry support. Although $10 million was authorized for each of the fiscal years 1988 through 1991, authority to obligate $5 million from the Highway Trust Fund was not provided until 1990. As a result, the program received only one-half of the authorized funds during its first 2 years.

The majority of the projects approved in fiscal years 1988 and 1989 were systems and policy analysis; a few had specific products, such as training manuals and development of existing materials and construction technologies, and a few were demonstration projects. Projects may reflect regional priorities (for example, the University of Alaska consistently conducts projects on the effects of extreme cold on structures and materials), but the program is as concerned with involving talented students and teachers in transportation research as it is with getting applicable results. In fact, the third-year projects will explicitly focus on education over research. At least two regional centers have formed an advanced institute to serve as the focus for the educational projects, and many will focus on

. . . a melding of expertise in traffic operations, demand management, trip generation estimation, and public-private negotiations . . . .' '[27]

Federal funding for these centers is limited, and the hope is that regional and local governments and industries will provide and even increase funding as they find the centers valuable. It is not yet clear whether non-Federal monies will continue to be forthcoming, though DOT may be able to assist with some funding beyond the original 1991 deadline.[28] Another type of center, FHWA's Technology Transfer Centers, is managed under the Rural Technical Assistance Program. These centers, mostly run by universities, focus on transferring technology developed at the Federal and State levels to county and local managers.

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[24] U.S. Department of Transportation, Office of the Budget, unpublished documents, February 1990. Figures are not adjusted for inflation.

[25] U.S. Department of Transportation, Urban Mass Transportation Administration, 1989 *Statistical Summaries: Grants Assistance Programs* (Washington, *DC:* Apr. 15, 1990), p. 4.

[26] U.S. Department of Transportation, Urban Mass Transportation Administration, *Technical Assistance and Safety Programs: Fiscal Year 1989 Project Directory* (Washington DC: January 1990).

[27] Thomas Larson, "Metropolitan Congestion: Towards a Tolerable Accommodation," *Transportation Quarterly*, October 1988. The Department of Transportation officials involved in the center's program cited this article as the quintessence of their program.

[28] Gracie Carter, Office of the Secretary, U.S. Department of Transportation, personal communication, Mar. 2, 1990.

National Institute of Standards and Technology

From its inception in 1901, NIST, housed in the Department of Commerce and formerly known as the National Bureau of Standards, has been a national laboratory cooperating extensively with other Federal agencies, universities, and the private sector. The Institute's primary mission has been to conduct research leading to setting uniform standards for American industries; the standards are typically adopted voluntarily by industry.

Over the years, NIST's work on measurement and measurement methods has served a wide variety of clients; for example, the agency is currently working to develop international standards for the Open Systems Interconnection Network to overcome computer interface inconsistencies. Its standards for construction and materials have had an appreciable effect on infrastructure technologies, though NIST tends to be oriented toward manufacturing and computer networks. The Institute's spending on infrastructure research accounts for only 1.6 percent of NIST's total budget.[29]

In the process of setting standards, NIST has developed impressive in-house research capabilities-the Center for the Utilization of Federal technology lists 57 laboratories within NIST. One of the three main NIST laboratories, the National Engineering Laboratory, includes the Center for Building Technology (CBT), which develops technologies for predicting, testing, and measuring the performance of building materials, components, systems, and practices, many of which are applicable to infrastructure. The center has a congressionally mandated Earthquake Hazard Reduction program, and performs key research on materials and corrosion-protective coatings for steel. CBT has taken a leadership role in R&D for high-performance concrete for both public and private sector components of the concrete industry, including SHRP, the Corps of Engineers, and the American Concrete Institute. In fact, the chief of the Building Material Division of CBT is on the SHRP Concrete and Structures Advisory Committee, and the center has developed the impact-echo method for flaw detection in reinforced concrete and techniques for increasing concrete strength and durability.

Photo credit: Massport

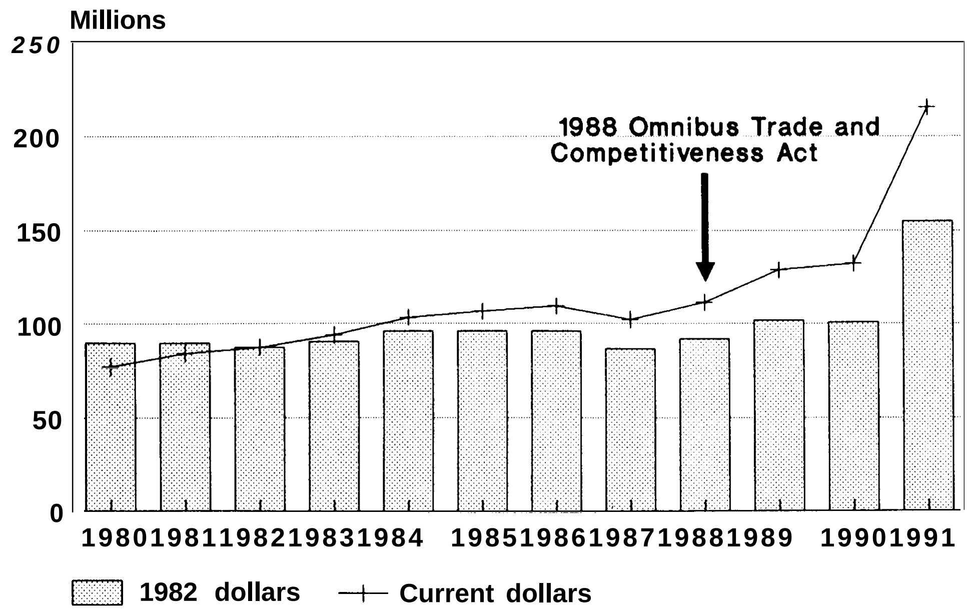
The Center for Building Technology of the National Institute of Standards and Technology has developed advanced methods for detecting flaws in concrete structures such as those in this runway.

Despite CBT's contributions to public works, the Administration proposed budgets for fiscal years 1984 to 1987 that eliminated CBT, and substantially cutback funding in fiscal years 1988 to 1990. Although Congress has restored most of the funding each year, the center's uncertain existence has tippled its ability to attract qualified staff to execute the basic research for which it has been an important source. CBT has supported itself by doing contract research, usually applied, for Federal agencies. Currently, about 60 percent of CBT's $10-million annual budget comes from these agencies on a project-by-project basis, with a small amount from the private sector.

Other NIST research transferable to public works is conducted in its Materials Science and Engineering Laboratory, which focuses on nondestructive evaluation, corrosion, and plastics. The agency also awards some R&D contracts to individuals at universities.

[29] U.S. Congress, Office of Technology Assessment "Construction and Materials Research and Development for the Nation's Public Works," staff paper of the Science, Education, and Transportation and Energy and Materials Programs, June 1987, pp. 2-15.

Figure 6-4-National Institute of Standards and Technology Total Federal Appropriations, 1980-90



SOURCE: Office of Technology Assessment, 1991, based on Office of Management and Budget data.

Cooperation With Industry

The 1988 Omnibus Trade and Competitiveness Act directed NIST to develop ". . . fundamental scientific and engineering research. . . to improve manufacturing and to assist industry to transfer important laboratory discoveries into commercial products.' '[30] The act called for increased direct collaboration with industry, through cooperative research and sharing of NIST's specialized facilities, and provided authority for Institute laboratories to enter into contracts and cooperative research at their discretion. The legislation also established NIST as a touchstone for other Federal agencies and the industry and State representatives with whom the Institute interacts. However, because NIST did not receive funding at the outset to carry out these responsibilities, the promise of a new role in Federal technology management has been largely unfilled.[31] The fiscal year 1991 budget brought a 33-percent increase for NIST (see figure 6-4), more than the agency requested, which should permit it to move toward filling its new role. If NIST's new technology transfer and Federal touchstone functions were broadened to include public works explicitly, State and local public works officials would benefit.

National Science Foundation

NSF provides substantial funding for R&D in a number of engineering and science fields, though the agency itself has no research functions. NSF estimates that it will provide $1.7 billion to support proposals, awards, and individuals in universities and colleges to stimulate academic research in 1991. Its commitment to industry research will be much smaller-$1 17 million.[32] In contrast to the general decline in Federal R&D budgets, NSF's R&D expenditures increased steadily throughout the 1980s.[33]

Although none of NSF's programs is specifically devoted to infrastructure research, support work sponsored by the Directorate for Engineering, which has fared well in recent years, is relevant. The

[30] Public Law 100-418.

[31] Jeffrey Mervis, "Science Hopes Bush's Proposals Survive Upcoming Budget Battle," *The Scientist*, vol. 4, No. 5, Mar. 5, 1990, p. 12.

[32] American Association for the Advancement of Science, Op. Cit., footnote 4, p. 79.

[33] 1bid., p. 47.

Mechanical and Structural Systems Division of the Directorate seeks to improve and expand basic engineering knowledge in structures and materials engineering. Research is directed toward creating new technologies in areas that have possible infrastructure uses, such as the processing of new engineering materials and the more efficient construction of large-scale structures. Special care is being focused on examining and understanding the science and technology of the deterioration of constructed facilities and actions that can be taken to diagnose, repair, retrofit, and enhance the performance of existing structures. These efforts can be directly beneficial for public works infrastructure.

In addition to grants to universities, NSF has several programs aimed at education, including the Science and Engineering Education program, and supports individual fellowships, such as the Presidential Young Investigator awards. The award serves to help universities and colleges attract young engineering faculty to academic careers where they can do research on subjects of importance to the Nation.

NSF Centers Programs

In addition to granting fellowships and awarding individual research contracts, NSF has pioneered research ''centers of excellence," which do not necessarily target advanced, complex technologies. Instead the centers tend to encourage innovative and interdisciplinary research on developing and adapting existing technologies, and public works may be best served by this emphasis. They have the additional charge to educate a new generation of scientists and engineers. Center grants may be used to acquire equipment and reference materials, both of which have become extremely costly for universities.

The 1980 Stevenson-Wydler Act authorized NSF to form cooperative research centers based on an earlier experimental program, with the aim of promoting innovative and interdisciplinary research. The Industry/University Cooperative Research (I/UCR) Centers Program, begun in 1981, is the prototype centers of excellence program for Federal agencies. At the end of fiscal year 1988, there were 40 centers, of which 10 were self-supporting. NSF hopes that all the centers will become self-supporting after 5 years of operation. Although the 40 centers all do research that can have infrastructure applications, none is specifically or solely geared toward infrastructure.

Earlier collaborative experiments taught NSF that multidisciplinary, university-based research done in tandem with an R&D-based industry was a successful coupling for innovative applied research. The industry and university efforts can temper each other; the industry ensures that projects do not get too esoteric and can provide funding, especially for the important developmental phases. The academic framework ensures an array of multidisciplinary approaches and skilled personnel, some of whom industry may recruit, and each can offer the other specialized equipment.

In fiscal year 1988, NSF support for I/UCR centers leveled at $3 million, while industry and State support totaled approximately $40 million. The substantial industry support gives these centers a regional focus.[34] NSF cites the industry commitment as evidence of the success of the program, contending that the private sector would not consistently commit substantial resources without demonstrable benefits.

The Engineering Research Centers Program is specifically aimed at education and training rather than at regional industry-university cooperation. However, the centers will emphasize applied systems research and are expected to make their research available and attractive to industry, as a substantial portion of their operating budget (from 9 to 61 percent)[35] must be supplied by the private sector. Although each of the 19 centers is scheduled to receive $2 million annually from NSF, they are actually receiving from $300,000 to $1 million less than expected, limiting the stability and scope of the projects.[36]

Established in fiscal year 1989, the Science and Technology Centers (STC) program has 11 centers, with total funding of $47.5 million in fiscal year 1990, and plans for as many as 14 new centers. Made up of consortia that usually include a Federal

[34] American Association for the Advancement of Science, op. cit., footnote 3, p. 52.

[35] U.S. Congress, Office of Technology Assessment, *Making Things Better: Competing in Manufacturing*, OTA-ITE-443 (Washington, DC: U.S. Government Printing Office, February 1990), p. 195.

[36] Ibid., p. 197.

laboratory, the STCs are expected to undertake significant basic research on particular topics more effectively and efficiently than the participants could achieve as individual investigators. For example, the Center for Advanced Cement-Based Materials at Northwestern University, the STC most relevant to infrastructure technologies, includes NIST's Center for Building Technology as a member of its consortium. Like the Engineering Research Centers, STCs are expected to focus on technology transfer between universities and industries and the multidisciplinary education of engineering students.

Department of the Interior

Each bureau of the Department of the Interior funds and manages its own R&D in support of its objectives; several bureaus contribute research relevant to infrastructure technologies. The Bureau of Mines, the Bureau of Reclamation, and the U.S. Geological Survey each conduct infrastructure research and award single-investigator contracts to universities. The bureaus meet (usually in pairs), as frequently as bimonthly, to coordinate among themselves and sometimes with related agencies on research of mutual interest.[37]

The Bureau of Reclamation has historically funded research related to water supply, treatment, conservation, and affilliated materials and sensors. Projects cover water quality, dam safety and maintenance, and all aspects of water supply systems; and much of the research, especially that in materials, is relevant to other sectors of infrastructure. The Bureau's R&D budget, $6.3 million in 1986, declined to $3.4 million by 1989,[38] partly due to the agency's shift away from new construction (see chapter 2). The R&D budget is expected to grow again as the agency changes emphasis to water conservation and management. Research directly related to infrastructure is currently funded at $2 million.[39]

Since 1910, the Bureau of Mines has been researching materials, work which now includes plastics for piping. Much of the Bureau's materials research is relevant to public works and is done in cooperation with other Federal agencies; joint tests with FHWA of polymerized, sulfur concrete roads are one example. In addition, the Bureau conducts some research for EPA regulations related to mining, and works with universities and private industries. The agency's overaIl R&D budget in 1987 was about $88 million.[40]

The U.S. Geological Survey has three R&D divisions, the Geologic Division, the Mapping Division, and the Water Resources Division, all data-collecting offices for evaluating national natural resources. Research in minerals, energy and marine uses, geological mapping, climate, and hazards such as earthquakes and volcanoes is undertaken by the Geologic Division. Geological mapping research leads to maps of subsurface areas, which are useful in siting landfills, toxic waste dumps, and other underground infrastructure. The Mapping Division concentrates on topographic maps and researches aspects of the Global Positioning System and the Geographic Information System, which have wide applications for public works (see chapter 5). A lead Federal water resources research agency, the Water Resources Division, collaborates extensively with EPA, the Corps of Engineers, DOT, the Department of Agriculture, and the Bureau of Reclamation. The central division laboratories focus on basic research and data collection, and district offices conduct applied research in collaboration with States and local governments on a cost-shared basis. The Water Resources Division also manages a congressionally mandated program supporting a water resources research institute located at universities in each State.

DoD and DOE Laboratories

R&D that is potentially applicable to public works is conducted at a number of national-level Federal laboratories that have no infrastructure-related mission. The Department of Commerce's Center for the Utilization of Federal Technology lists over 900 laboratories fitting the general description of a Federal laboratory.[41] Within this category, 36 laboratories are "national laboratories," or government

[37] Roger Wolff, Water Resources Division, U.S. Geological Survey, personal communication, May 18, 1990.

[38] D. King, Bureau of Reclamation, U.S. Department of the Interior, unpublished memorandum, May 21, 1990.

[39] Ibid.

[40] National Science Foundation, op. cit., footnote 14.

[41] Center for Utilization of Federal Technology, *Federal Laboratory and Technology Resources (Washington* DC: U.S. Department of Commerce, 1986).

owned contractor operated (GOC0s) laboratories.[42] Of the $60 billion that the Federal Government contributes annually to R&D, $20 billion goes to these facilities.[43] Although most of the national laboratories are sponsored by DOE, which supports 20 laboratories, and DoD, which funds 10, 5 other government agencies sponsor GOCOs, including the Department of Agriculture and NASA.

The predominant missions of DOE and DoD national laboratories are defense, energy, and related environmental research. Basic research at DOE and DoD has been concentrated in the national weapons-producing laboratories, which have traditionally received the majority of Federal research dollars. Although much of the weapons research at these laboratories is not relevant to or is too sophisticated for public works, some work can be transferred to infrastructure. However, DOE and DoD are newcomers to formal technology transfer, since commercialization is not vital to and may compromise their primary missions.[44] The transfer that does occur is usually tailored to fit commercial, for-profit development and is managed by an Office of Research and Technology Assessment located at each laboratory and by DoD's Defense Advanced Research Projects Agency.

Formal Technology Transfer

Of the 20 DOE national laboratories, 11 historically have been defined as specialized, "single program" facilities, such as the Fermi laboratory accelerator; these are unlikely to explore public works applications.[45] However, five of DOE's multiple agenda or multiprogram laboratories—Argonne, Brookhaven, Lawrence Berkeley, Oak Ridge, and Pacific Northwest-focus on energy research. Each has produced technologies that can be applied to infrastructure, and in some cases, have helped technology make the leap to civilian use. The Pacific Northwest Laboratory has identified 14 technologies developed at these laboratories that are currently ready for commercial public works application. Argonne National Laboratory has developed an acoustic leak sensor that could be commercially available to water utilities sometime this year.[46]

The development of the acoustic leak detector' typifies the potential for technology transfer from a national laboratory to public works. The researcher working on the acoustic sensor at Argonne was told of a utility company interested in developing the technology and contacted the utility to discuss the technical aspects of the project. After Argonne submitted a formal technical proposal to which the utility agreed, lawyers for both parties began to debate the terms. After the lawyers developed a contract, the utility sent Argonne a check. Now that the technology is ready, implementing the sensor and contracting with a manufacturing firm to produce it are entirely up to the utility, because of the proprietary rights guaranteed it as the sponsor.

Despite some success stories, the process of negotiating an agreement to develop a technology takes 1 to 2 years, mostly because of legal complexities,[47] and a 2-year delay in technological innovation can be significant. National laboratories working to transfer technology must resolve difficult problems, such as who owns the technology. Questions about proprietary rights, patents, and copyrights have the potential to block successful transfer to the civilian sector; at a minimum **these are** significant disincentives for public-private cooperation.

University Collaboration

DOE and DoD collaborate extensively with university researchers, mostly through mission-specific contracts, but also through centers of excellence and sharing of facilities. In addition to individual contracts, DOE supports the Oak Ridge Associated Universities, a consortium of 49 academic institutions, which serves as a link between the agency and U.S. universities. The Ames laboratory for physical, materials, and chemical science has a cooperative program with Iowa State Univer-

[42] U.S. General Accounting Office, Competition: *Information on Federally Funded Research and Development Centers* (Washington, DC: U.S. Government Printing Office, May 1988), p. 1.

[43] Robert Weissler, senior analyst, Mice of Technology Assessment, from an unpublished document, Mm. 21, 1990.

[44] Office of Technology Assessment, op. cit., footnote 35, P. 185.

[45] Rick Cheston, U.S. General Accounting Office, personal communication Mar. 21.1990.

[46] J.W. Currie et al., Battelle Pacific Northwest Laboratory, "A Prototype Catalogue: DOE National Laboratory Technologies for Infrastructure Modernization,'' OTA contractor report, January 1990, record 27.01.

[47] David Kupperman, Argonne National Laboratory, personal communication, Mar. 23, 1990.

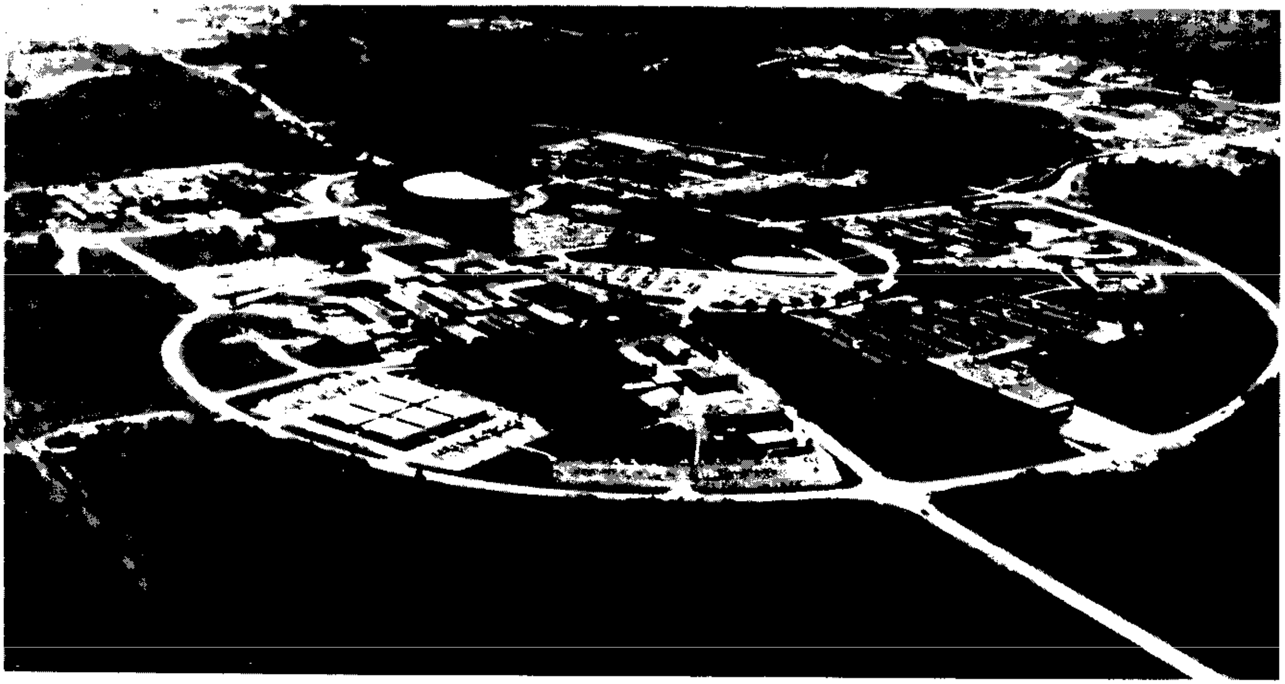


Photo credit: Argonne National Laboratory

While national laboratories, such as the Department of Energy's Argonne National Laboratory, usually focus on advanced technologies, Argonne developed an acoustic leak detector that could be used by water utilities.

sity, which includes sharing of facilities and personnel.

DoD funds about $500 million in basic research and $250 million in applied research for single investigators at universities and colleges. The investigator awards are proposed in response to general solicitations, and the agency currently maintains between 7,000 and 8,000 of these contracts. Although many of the projects could be relevant to infrastructure,[48] dissemination of R&D is the university's responsibility, and sharing information is likely to be difficult because of the institutional barriers between the military and civilian sectors.[49]

DoD's University Research Initiatives Program (URI) has provided approximately $100 million to date for grants to ''block research' teams. These are not considered ''research centers, ' primarily because the term implies continuous support over a period of time, which DoD is unable to guarantee. Block grants are intended to encourage an interdisciplinary approach and may be used for acquisition of large and expensive instrumentation-too expensive for a single investigator-and to support several hundred graduate fellowships every year.

There are between 80 and 100 block research grants under the URI program. These awards are modeled after a discontinued "Army Centers of Excellence" program. The Massachusetts Institute of Technology (MIT) and the University of Illinois, Urbana, have been able to use their URI grants, awarded and administered by the Army Research Office, as hubs for centers of construction technology, and both centers have strong infrastructure-related programs. The University of Illinois also cooperates with the Army Corps of Engineers Construction Engineering Research Laboratory, which is located nearby. Over the 5 years of its URI grant, MIT has allotted $2 million to research, and the remaining $13 million to equipment and fellowships for graduate students.[50] Because the construction industry is fragmented and has few resources for

[48]Mark Herbst, staff specialist, Department of Defense, personal communication, Mar. 16, 1990.

[49]U.S. Congress, Office of Technology Assessment, *Holding the Edge: Maintaining the Defense Technology Base*, OTA-ISC-420 (Washington, DC: U.S. Government Printing Office, April 1989), ch. 9.

[50]Fred Moavanzadeh, professor of civil engineering, Massachusetts Institute of Technology, unpublished memorandum, Mar. 2, 1990.

R&D,[51] the Army Construction Centers are potentially an important resource for technology development.

Technology Transfer

Though most Federal agencies have regular channels of communication with researchers in other fields and other laboratories, technology transfer between Federal agencies and from Federal agencies to industry and public sector entities has generally been slow and halting. Over the last 10 years, Congress has attempted to maximize the Federal R&D investment by centralizing planning and by giving research at Federal laboratories a cohesive focus and a relationship to the market. Key legislation includes the 1980 Stevenson-Wydler Act, the 1986 Federal Technology Transfer Act, the 1988 Omnibus Trade and Competitiveness Act, and the National Competitiveness Technology Transfer Act of 1989. Although previous acts in 1970 and 1976 included technology transfer provisions, the Stevenson-Wydler Act was the first to focus on stimulating technology transfer and to require collaboration between Federal laboratories and non-Federal contacts.

The Stevenson-Wydler Act also recognized the need for a body to coordinate Federal technology transfer, empowering the Center for Utilization of Federal Technology (CUFT), in the Department of Commerce's National Technical Information Service, to fulfill this role as technology broker. Although CUFT retains some of its functions as a technology information clearinghouse, the Federal Technology Transfer Act (Public Law 99-502) moved many of CUFT's functions to the Federal Laboratory Consortium (FLC) in the late 1980s.

Patterned on an earlier DoD Technology Transfer Laboratory Consortium, FLC has maintained a database of Federal technologies since 1974.[52] A researcher can contact FLC with a need or an interest, and a database search will identify the appropriate Federal laboratory contact. At present, with an annual budget of about $1 million, the consortium is operated by a small permanent staff and consists of volunteers from over 300 Federal laboratories. Though FLC processes a number of public works inquiries from industries and the public sector, additional resources would allow it to enlarge its permanent staff, its database, and its customer bank, and shorten the response time for an inquiry.[53] Most importantly, FLC could actively seek contacts; one reason the database is underutilized for infrastructure is that many potential public works customers are simply unaware of its existence and its inexpensive resources.

The Technology Transfer Act amended several other provisions of the Stevenson-Wydler Act. One of the new provisions granted permission for GOCO facilities to enter into cooperative agreements, giving the non-Federal partner title to a patent. Furthermore, the act permits some agencies to offer royalties or other cash awards as incentives for Federal researchers or laboratories participating in collaboration. The Omnibus Trade and Competitiveness Act was intended to build institutional coordination for technology transfer by increasing each Federal laboratory's contribution to FLC's budget and adding programs at NIST. The 1988 act also established a Clearinghouse for State and I.meal Initiatives on Productivity, Technology, and Innovation, which will be similar to FLC with a focus on technology and economic development at the State and local levels. The Clearinghouse currently has an annual budget of $250,000; the agency's effectiveness is likely to be impaired if this support is not expanded.

The National Competitiveness Technology Transfer Act of 1989 (Public Law 101-189) addressed three fundamental problems in federally funded research; bureaucratic rigidity, lack of cooperation among institutions, and ambiguous missions and roles of Federal R&D laboratories. One provision allows GOCOs to make cooperative agreements with a waiver of the Freedom of Information Act for a 5-year period, allowing non-Federal sponsors certain proprietary rights. Other R&D legislation during the 1980s concerned tax credits for private sector firms that increase their R&D funding. While the effectiveness of the tax credit has been subject to much debate since its creation in the 1981 Economic Recovery Tax Act (Public Law 97-34), the credit has been extended three times beyond its original lifetime. The most recent extension under the 1989

[51] Office of Technology Assessment, op. cit., footnote 29, p. 3-1.

[52] George F. Lindsteadt, "Getting Federal Research to the Grass Roots," *Dimensions*, vol. 63, January/February 1979.

[53] Office of Technology Assessment, op. cit., footnote 35, p. 63.

Omnibus Budget Reconciliation (Public Law 101-239) provided several key changes in eligibility that should enhance the incentive effect of the credit. Whether or not the credit is effective and should be permanent is not yet clear.[54]

R&D legislation over the last decade was aimed especially at pushing the national laboratories toward market-driven agendas and technology transfer.[55] However, most of the language directs the national laboratories toward joint research only; little mention is made of development.[56] The Federal Government has concluded that development is more appropriately accomplished by the private sector, but has devised few mechanisms to ensure that development actually occurs. Development for technologies with public works applications is crucial and is especially vulnerable as public projects often do not promise enough profit to make large investments attractive to the private sector.[57] In addition, legislation has not effectively counteracted the fragmentation that characterizes activities in Federal public works agencies and the similar disaggregation in the related industries.[58]

While several laws address the need to stimulate inter-sector collaboration, the combined effects of the legislation need examination, especially for their potential impact on public works R&D. Significant uncertainty persists over patents, proprietary rights, copyrights, the threat of antitrust prosecution, and the effectiveness of the R&D tax credit. Legal change does not appear to have significantly altered behavior patterns for either the Federal laboratories or the private sector. In part, this is a result of targeting the researchers themselves as agents of change, while still holding them responsible for producing mission-related research. To effect major change, technology transfer policies ". . . should be aimed at the Federal laboratory management level in order to have a defined level-of-effort set aside for this purpose."[59]

Successful models of transfer include the programmatic mechanisms in EPA's Hazardous Substances Centers, water supply circuit riders (see box 4-E in chapter 4), information clearinghouses and brokers, and in-kind informal collaboration. DOE's relationship with Iowa State University is based on such widely used in-kind exchange; in 1987, about 185 scientific facilities in the national laboratories were used by 1,623 industry and university participants.[60]

Extra funding for the Federal laboratories' reorientation toward commercial industry and public services has not been forthcoming. In addition, throughout the 1980s, the tension between Congress and the President and their differing concepts of the role of federally supported R&D has retarded change in the Federal laboratories and slowed or eliminated research not directly related to economic development, space, or weapons development. Over the course of the decade, funding for military R&D increased 131 percent; civilian funding only 39 percent.

Non-Federal R&D

State Research Programs

Despite many efforts, the current technology management structure is not very successful in disseminating the benefits of Federal research to university, industry, and State interests. Some of these are instituting programs and policies of their own to stimulate technological innovation, particularly for public works. NIST has identified 41 State-supported organizations, sustaining 137 tech-

[54] David L. Brumbaugh, Economics Division, Congressional Research Service, "The Research and Experimentation Tax Credit," issue brief, Feb. 7, 1990.

[55] Barry Bozeman and Michael Crow, "The Environments of U.S. R&D Laboratories: Political and Market Influences," *Policy Sciences,* 1990, p. 29.

[56] Wendy H. Schacht, Science Policy Research Division, Congressional Research Service, "Cooperative R&D: Federal Efforts To Promote Industrial Competitiveness," issue brief IB89056, Jan. 22, 1990, p. 7.

[57] See conclusions to ch. 5.

[58] Office of Technology Assessment, op. cit., footnote 29.

[59] Louis Mosgavero et al., "Federal Technology Transfer: Critical Perspectives," *State and Local Initiatives on Productivity, Technology, and Innovation: Enhancing a National Resource for International Competitiveness* (Washington, DC: Advisory Commission on Intergovernmental Relations, May 1990).

[60] U.S. Congress, Office of Technology Assessment, Industry, Technology, and Employment Program, "Federal Labs," unpublished paper, November 1989, p. 7-37.

nology research centers of excellence with 2,000 private sector firms participating.[61]

State Programs

Some State universities with engineering schools have developed multidisciplinary R&D programs, and several have focused on public works. The Universities of Cincinnati, Virginia, New Mexico, Nebraska, and Oklahoma all have infrastructure research programs within their engineering schools. Like the NSF centers, these infrastructure centers try to capture a broad funding base and emphasize university-industry collaboration and cooperation. The University of Nebraska Infrastructure Center has, for example, a 5 to 1 ratio of external to center funding. Several universities have developed innovative internal structures to maximize the opportunities for Federal and industry support (see box 6-B).

Although State support for R&D has grown over 63 percent in the last decade, State dollars still represent less than 1 percent of the total spent on R&D in the United States.[62] Instead of heavy direct funding, States have established networks of support for regional R&D, often comprised of a cross section of efforts, involving Federal, State, local, industry, and university resources. The Ben Franklin Partnership Fund (see box 6-C) in Pennsylvania is a successful State university-industry R&D program, which has been described as:

> . . . comprehensive. . . decentralized; it catalyzes significant private investment . . . the commercialization of research, the transfer of technology from academia to industry, the generation of risk capital, the birth of new firms, and the integration of advanced technologies into mature industries.[63]

The Ben Franklin program probably helped to attract NSF Engineering Centers to Lehigh and Carnegie-Mellon Universities (Pennsylvania is the only State with three NSF engineering centers), as well as other individual Federal grants and projects at all of the centers. While the Ben Franklin Partnership is a successful model for collaborative R&D, it does not focus at all on public works. Three State goals the program meets, however, are encouraging the private sector to use available academic resources, altering the university approach to R&D, and activating cooperation among local businesses, academia, and the government. All of these needs have potential to pay off for public works, and the model could be used for a similar program with an explicit charge to consider public needs.

Industry and Association R&D

A variety of industry and professional associations have research programs for their areas of special interest or for market development. The American Trucking Association sponsors the Trucking Research Institute, and other modal associations, such as the Air Transport Association and the Association of American Railroads (AAR), sponsor similar R&D closely related to member interests. These associations, especially AAR (see chapter 3), work with the modal administrations at DOT. Most of the association-sponsored transportation research studies are related to policy and safety development, and are only tangentially connected to infrastructure or public services.

A few associations are initiating R&D programs to address areas of research that they consider to be complementary to or inadequately covered by Federal programs. Among the new efforts is that of the American Society of Civil Engineers (ASCE), which has recently formed a Civil Engineering Research Foundation focusing on R&D relating to repair, rehabilitation, and maintenance of public works. Initially funded by the Foundation at $500,000, ASCE plans to expand the scope of the program. The American Water Works Association also has a small, new research foundation with a limited budget and plans for future growth.

The Water Pollution Control Federation Research Foundation, another recently formed organization, expected a $4 million budget in its second year. The Foundation is a consortium of 37 subscribing municipal and industrial wastewater treatment facilities, with 50 municipalities planning to join. Member facilities range in size from plants processing only 9 million gallons daily to those responsible for more than 1 billion gallons per day. Though the Foundation works closely with EPA's Office of

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61 U.S. Department of Commerce, National Institute of Standards and Technology, *Promoting Technological Excellence: The Role of State and Federal Activities* (Washington, DC: U.S. Government Printing Office, 1989), p. 21.

62 National Science Foundation, *Research and Development Expenditures of State Government Agencies: Fiscal Years 19&' and 1988* (Washington, DC: January 1990), p. 3. Numbers are from 1988 and are adjusted for inflation.

@David Osborne, Laboratories *of Democracy* (Boston, MA: Harvard University Press, 1988), P. 60.

Box 6-B—University infrastructure Research

Established and successful university centers of excellence programs attract substantial Federal, State, and private sector support enabling them to build strong, coordinated well-funded R&D programs. With an overall research budget of $700 million,[1] the Massachusetts Institute of Technology (MIT) has Environmental Protection Agency, National Science Foundation (NSF), Department of Transportation (DOT), and Department of Defense (DoD) centers of excellence contracts. MIT's Department of Civil Engineering houses several federally funded programs related to infrastructure, including the DOT University Transportation Center, the NSF Industry/ University Cooperative Research Centers Program for Composites and Polymer Recessing, and the DoD University Research Initiatives Center for Construction Research and Education. Other major programs, including a New England Regional State Center, a Center for Transportation Studies, an industrial liaison program, and an academic program, also share faculty and students and sometimes announce solicitations throughout the department. The Center for Transportation Studies alone had 126 ongoing projects in 1989. The programs cooperate with one another and with other regional schools, and interdisciplinary research is pursued as a departmental rule.

Another type of university center, at the University of Cincinnati, is planned to provide leadership in determinin g cost-effective and reliable solutions to public works maintenance and rehabilitation problems. The Ohio Infrastructure Institute was established to foster the development of new technology and lead the way in technology transfer to ensure that innovations are put into practice to maximize the impact of tax dollars spent on the repair and maintenance of' infrastructure. The Institute hopes to formulate and develop new technologies that can extend the useful life of public works.

As a third example, the New Mexico Engineering Research Institute, part of the University of New Mexico, operates the Infrastructure Development Assistance Program (IDAP) for the State of New Mexico. IDAP serves **to** strengthen local infrastructure management capabilities through a statewide program of technical assistance, training, and technology development. Similarly, the Virginia University Transportation Center, a coordinated research and training program associated with the Virginia Department of Transportation, focuses on intermediate to long-range transportation problems and issues. Areas of concentration are new technique and technologies for transportation service, planning and management, and research in new structures and materials. The University of Nebraska-Lincoln has established a Center for Infrastructure Research with the goal of using research to improve the economic potential and quality of life for the people of Nebraska, the Nation, and the global community. The center's research agenda is ''market driven,' which means that the priorities and scope of the projects flow from users-those who design, build, operate, maintain, and regulate infrastructure--to researchers. This results in the development of technologies and systems that can be transferred rapidly into use.

[1] Robert Weissler, senior analyst Industry, Technology, and Employment Program, Office of Technology Assessment, personal communication May *21,* 1990.

Municipal Pollution Control, it is addressing R&D issues that EPA often does not address, such as municipal and wastewater treatment, residuals management, and water quality effects. Through workshops and forums, the subscribers themselves set the research agenda, and the Foundation's level of support indicates the high level of interest, especially in municipalities, for such operations-oriented R&D.

The American Public Works Association has a small, longstanding research foundation that executes a variety of studies in cooperation with local governments, and sometimes with States or Federal agencies. These studies are generally intended to transfer technology and information to local governmental clients.

Conclusions and Options

Public works providers need ongoing R&D programs to identify new technologies that can help meet changing public service needs. Despite this, relevant R&D programs are generally underfunded, scattered, and directed at diverse, specific program objectives. Thus Federal and other public works agencies are ill prepared to address future needs and systems problems, such as those that cross transportation modes or environmental media categories. Given the likelihood of continued governmental budget austerity, the outlook for public works-related R&D is bleak, unless a way can be found to capitalize on the extensive individual efforts to benefit public infrastructure.

Box 6-C--Ben Franklin Partnerships

In the early 1980s, as the steel and coal industries dwindled and the economy became increasely depressed, Pennsylvania was searching for industrial revival. The Pennsylvania General Assembly created the Ben Franklin Partnership Fund in 1982 and continues to support the effort, appropriating $28 million for fiscal year 1990-91.[1] The State's aim is to promote innovative development, application, and marketing of techndogies, a comprehensive cradle-to-maturity strategy not found at the Federal level.

The Ben Franklin Partnership operates out of regional centers where university laboratories and private sector sponsors collaborate in censor@a, with general management provided by the State. To date, the State has contributed $110 minim; non-State support has reached $400 million. From 1983 to 1988, Ben Franklin funds were matched by a total of $39 million m Federal funds. Though the program is well coordinated and the State ultimately has control over funds, administration is decentralized, allowing for close ties to local needs and available resources.

The links between universities and businesses ensure that R&D is focused on issues critical to the private sector sponsors, which the participants generally see as a positive union. However, responding to industry criticism, State managers removed the locus of control from the universities and incorporated each of the centers. Now each center is governed by a board consisting of representative of the private sector, the schools, and the regional or local government.[2] The program emphasize quantitative results, because the General Assembly must be convinced of the wisdom in providing about $30 million annually. The biggest selling points have been job creation--although this is not inherent in technology development--and profitability of new products.

Although most of the projects focus on commercial technologies, some deal with construction, materials, robotics, and sensor technologies relevant to public works. The Penn State Technology Center is, for example, currently conducting a demonstration project on roller-compacted concrete in cooperation with the Pennsylvania Department of Transportation. A market demand for such technologies must exist for the Ben Franklin Partnership to pursue a project,[3] so there is no guarantee that the Partnership, which is designed to encourage economic development will benefit public services.

[1] Pennsylvania Department of Commerce, Office of Technology Development, personal communication, Jan. 3, 1991.

[2] Kathleen Marcucci, Northeast Tier Technology Center, personal communication, Mar. 23, 1990.

[3] Ibid.

Federal Agency Public Works R&D

Federal public works R&D efforts tend to be low profile and are often overshadowed by the obvious problems of infrastructure upkeep and construction; R&D programs often fail to weather the first and deepest cuts when departmentwide budgets shrink (see figure 6-5). **In the short term, Congress could consider authorizing and appropriating agency R&D budgets on a separate line-item basis to guarantee executive agency commitment and greater financial stability for R&D programs.**

EPA

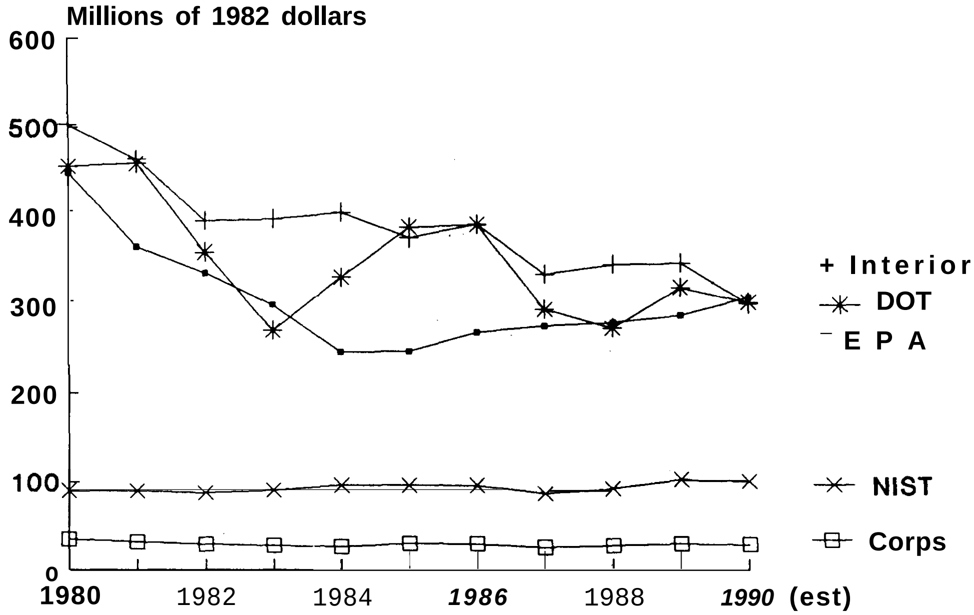
EPA's R&D is task-oriented due to the Agency's congressional mandate, its administrative structure, the immediate need for support of regulations, and limited funds.[64] The research now under way on broad environmental issues is focused on how to meet regulations, with little attention to identifying more effective or efficient alternatives for treating environmental pollutants. Federal **R&D and technology sharing programs for environmental public works are inadequate. Increased R&D directed at alternative, lower cost technologies for meeting standards and at improving operations, especially for small systems, is a top priority. Congress could require EPA to develop a comprehensive program of research, development, and demonstrations to meet these needs. If this occurs, adequate funding should be ensured.**

DOT

While DOT provides direct support for regional transportation, it commits its resources on a modal basis, with R&D support heavily skewed toward FAA and FHWA. Data collection on travel and shipping patterns has been neglected. As a result, alternatives to current and future transportation

[64] ***National Science Foundation, Division*** of ***Science Resources*** Studies, Federal Funds *for Research and Development:* ***Detailed Historical Tables for Fiscal Years 1955-1990 (Washington, DC:*** 1990).

Figure 6-5—Federal Outlays[a] for Public Works R&D, 1980-90



KEY: DOT Department of Transportation; EPA_ Environmental Protection Agency; NIST National Institute of Standards and Technology

[a]Does not include reimbursements.

SOURCE: National Science Foundation, Division of Science Resources Studies, *Fe&a/ Funds for Research and Development: Detailed Historical Tables for Fiscal Years 19S5-1990* (Washington, DC: 1990).

patterns are not pursued, and one outgrowth is the dearth of R&D on intermodal connections. Both public and private transportation officials have identified the lack of information about intermodal linkages, such as airport-ground and port-to-railhead access, as a stumbling block to developing policies that support growth and increased capacity. Revision of current modally defined R&D is long overdue, and DOT needs to develop R&D programs to address intermodal needs and capacity enhancing transportation alternatives. Congress could require DOT to collect and analyze freight commodity and passenger flow data and to constitute and institutionalize a mechanism to ensure that all its R&D takes into account interdisciplinary and intermodal issues. Options include establishing a transportation data office or center, strengthening the R&D Coordinating Council, and creating an effective Secretary-level R&D coordinator.

The Corps of Engineers

The Corps has considerable public works research capacity, and has been successful at networking with its clients, especially the administrative Corps personnel. But the Corps' traditional specialty, water resources development, is declining as a national priority. Federal agencies have been unwilling (or financially unable) to make firm commitments to contracts with the Corps of Engineers, and in response, the Corps has remained committed to its own missions, limiting its value as a resource for other Federal agencies, which could benefit from its expertise and facilities. Restructuring the Corps and moving parts of it to other agencies is an option discussed in chapter 2. A less drastic option for Congress to consider is directing the Corps to reorient some of its R&D toward basic environmental missions, such as water treatment and supply systems, to make the agency a more valuable shared resource. For example, the Corps could help EPA fill the research gap for environmental public works operations and small systems.

Coordinating Existing Research

If substantially greater funding is not available, the three main public works agencies, the Corps of Engineers, EPA, and DOT, must renew efforts to ensure that a substantial portion of their R&D resources address end-users' needs and to maximize the use of existing resources. These resources include TSC, NIST, the interdisciplinary university centers, and existing Federal technology transfer programs. Special programs, such as SHRP, which target neglected areas of R&D, should be integrated into more comprehensive programs and receive adequate support. Many of these existing programs are underfunded, underutilized, or otherwise lack agency commitment. However, with adept intra-agency resource allocation, they could be strengthened and used to leverage the return on public works R&D investment.

Agencies that perform public works R&D are generally underfunded, while DOE and DoD receive substantial Federal R&D commitments. Regardless of funding level, a reallocation of dollars is needed. If Congress does not increase **R&D spending, it may want to consider reallocating some R&D dollars from laboratories doing advanced research to EPA and DOT, where R&D for public works is significantly underfunded.** A systems-oriented management structure for public works R&D could be developed, aiming for comprehensive financial leveraging, management, and review.

Past executive-level public works R&D coordination efforts, such as the now defunct Water Resources Council, have not been successful, because such entities require joint congressional and administration commitment to function effectively. Given such a commitment at their highest levels, the executive agencies alone could coordinate research without compromising their mandated missions. Establishing a framework for coordinating Federal R&D could be a long-term goal, for both the Administration and Congress. Existing institutions, NIST or the Federal Laboratory Consortium, for example, could act as Federal R&D coordinators. Another option is to establish anew agency, such as the proposed Advanced Civilian Technology Agency, and include public works R&D in its scope.

Technology Transfer

Throughout the 1980s, Federal research policy articulated in legislation has been aimed at the "national' Federal laboratories, with the goal of stimulating economic growth and technology transfer to the private sector. Using technology as a tool, Federal and State Governments have encouraged transfer of laboratory research to industry development through law, incentives, and centrally planned programs.

The Federal Government has already provided an important mechanism for technology transfer to the commercial sector by centralizing technology management in NIST, the Federal Laboratory Consortium, and other Federal technology clearinghouses. Most Federal laboratories have been required to consider technology transfer to the commercial sector, and allowances for Federal researchers to share in profits and royalties are provided as incentives. For the most part, however, collaboration is slow in coming due to complex legal problems with patents and proprietary rights and some uncertainty among Federal laboratory personnel about how to go about making deals with the private sector. Moreover, although many technologies have tremendous commercial appeal, those developed for application to public works often do not have an obvious market because of the propensity for public officials to stipulate familiar equipment (see chapter 5).

The Federal Government has sought to bolster public works R&D by stimulating cooperation among academic institutions, Federal laboratories, and industries. The mix of academic, public, and private sectors in technology transfer efforts tends to target technologies according to their potential profitability. However, these groups do not have a long history of cooperation, and overly mission-specific grants and disagreements over intellectual property rights and administrative control inhibit effective collaboration.[65] Transfer of public works technologies from Federal and academic laboratories to private sector production and public sector use is unlikely to occur without specific mechanisms-such as the Technology Transfer Advisory Committees and technology transfer requirements for the EPA Hazardous Substances Research Centers. This limitation must be kept in mind as Federal support for the centers is evaluated. Technology transfer is crucial to infrastructure technologies, but there is no guarantee that the Federal transfer process as it is now most firmly institutionalized will include the needs of public works. Should Congress consider new legislation, an emphasis on technology transfer to public works could provide a much needed stream of innovative R&D and a connection to industries that can adapt advanced technologies for public sector uses. In any case, a periodic review of technology transfer

[65] Osborne, op. cit., footnote 63, p. 58.

laws-how and by whom they are implemented and their effect on the ownership and development of technologies-could provide Congress with information on how well the goals of the laws are being met.

Multidisciplinary programs using academic, private, and public resources can be useful sources of information, expertise, and facilities. Coordinating programs, such as the university centers of excellence and NIST, can be an effective way to allocate scarce R&D dollars. In addition, other Federal public works-related research could be coordinated, and cooperative agreements such as those managed by EPA and authorized by the Federal Technology Transfer Act (Public Law 99-502) could ensure good use of existing resources. NIST, TSC, and the Corps represent valuable resources, which can provide analytical and applied research support to DOT and EPA. Nonetheless, with few exceptions, these resources are not being fully utilized for shared Federal research.

Technical Training and Expertise

Time and again during OTA's research, the need for more well-trained personnel for public works was emphasized. Although the efficacy of Federal university center programs in improving the pool of engineering talent is difficult to evaluate in the short term, it is clear that the center programs do not yet have a large, stable financial backing or substantial student involvement. Only a small percentage of the students attending the 280 universities in the United States that offer engineering education will be involved in the multidisciplinary programs sponsored by Federal agencies. For example, OTA estimates that only 1 percent of engineering undergraduates and 4 to 11 percent of graduate students participate in the NSF engineering centers.[66] **OTA concludes that the focus on education and training is as important as research to improving public works. A generous Federal funding commitment for engineers, scientists, and other university centers is needed to meet the extraordinary need for well-trained public works officials. Federal support is especially crucial if the universities are to cooperate with the private sector without becoming so oriented to private sector goals that they risk their mission to educate.**

[66] Office of Technology Assessment, op. cit., footnote 36, p. 65.