Delivering the Goods: Public Works Technologies, Management, and Financing

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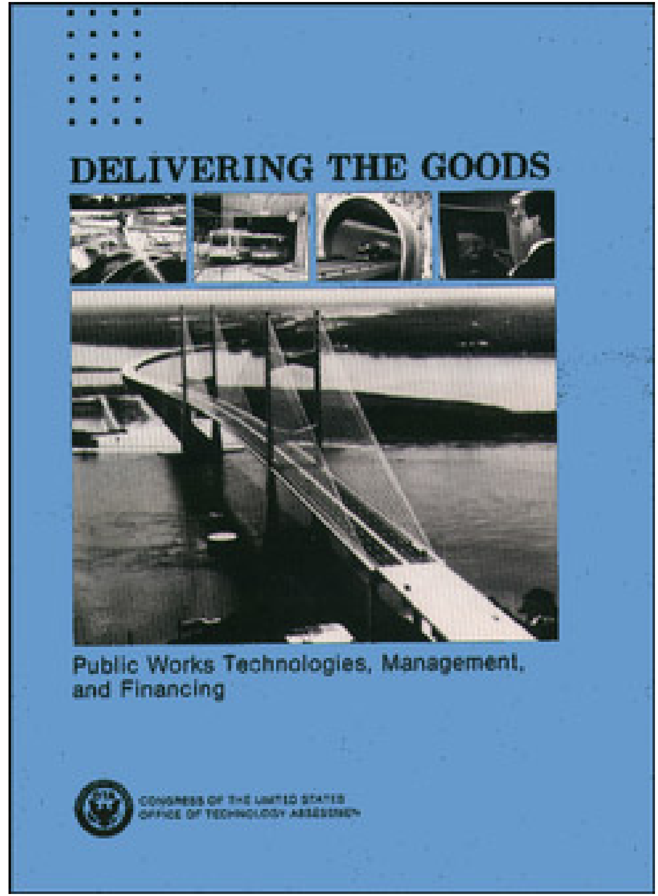

Foreword

Traffic jams and bridge lanes closed for maintenance create headaches for travelers and transportation officials, and public works directors would give their eyeteeth to find a way to solve leaking water pipe and storm water overflow problems. Such vexing difficulties are the legacies of years of neglect and underfunding for the infrastructure that provides vital public works services. In 1988, following a number of national studies calling in vain for more investment in public works infrastructure, the Senate Committee on Environment and Public Works and the House Committee on Public Works and Transportation asked OTA to identify ways to change Federal policies and programs to mobilize management, financing, and technology efforts to make public works more productive and efficient. The Senate Committee on Commerce, Science, and Transportation and the Subcommittee on Transportation of the Senate Committee on Appropriations both expressed their interest and concern by endorsing the study.

OTA identifies several immediate steps the Federal Government could take. First, new environmental standards, population shifts, and industrial changes have transformed the nature of many public works problems, and Federal programs must be refocused to fit the new circumstances. Second, if we expect to maintain our economic health, the Nation must increase its investment in public works, despite budget dilemmas. As it stands now, critical infrastructure, such as bridges, Interstate highways, sewage pipes, and water systems, are breaking down or wearing out faster than we can repair or replace them. The toll on national productivity is already substantial, and, because infrastructure investment has been declining for at least a decade, the situation is likely to get worse before it can get better.

Reauthorization of the Federal highway program is the first piece of major public works legislation to reach the top of the Federal agenda for the 102d Congress. The priorities that OTA has identified should help Congress in its deliberations on this and other transportation and environmental legislation and lead to actions that will ensure the continued vitality of our country's infrastructure.

Members of the advisory panel, workshop participants, and a host of government, industry, and private citizen reviewers for this study provided an invaluable range of perspectives and information. OTA is grateful for the substantial commitment of time and energy given so generously by each. Their participation does not necessarily represent endorsement of the contents of the report, for which OTA bears sole responsibility.

JOHN H. GIBBONS
Director

Delivering the Goods: Public Works Technologies, Management, and Finance Advisory Panel

Carol Bellamy, *Panel Chair*
Principal, Morgan Stanley & Co., Inc.

Jon Lee Craig
Chief, Water Quality Service
Oklahoma State Department of Health

David Davis[1]
Executive Director
New Jersey Highway Authority

Siro DeGasperis
Vice President, Public Affairs
United Parcel Service

Daniel Dudek
Senior Economist
Environmental Defense Fund

Hazel Gluck[2]
President
Public Policy Advisors

Anthony Hall, Jr.[3]
Chairman
Houston Metropolitan Transit Authority

Austin V. Koenen[4]
Managing Director for Public Finance
Morgan Stanley & Co., Inc.

Jerome Kruger
Department of Materials Science and Engineering
The Johns Hopkins University

Fred Moavenzadeh
Director, Center for Construction Research and Education
Massachusetts Institute of Technology

James Poirot
Chairman
CH2M Hill

Harry Reed
Planning Director
Arizona Department of Transportation

Burton Stallwood
Town Administrator
Lincoln, Rhode Island

Michael Uremovich
Vice President of Marketing
American President Companies

Theodore G. Weigle, Jr.[5]
Vice President and Manager,
Surface Transportation-East, Bechtel Corp.

[1]Former Executive Director, Massport
[2]Former Commissioner, New Jersey Department of Transportation
[3]Former Member, Houston City Council
[4]Former Managing Director, Shearson, Lehman, Hutton, Inc.
[5]Former Executive Director, Chicago Regional Transportation Authority

NOTE: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the advisory panel members. The panel does not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents.

Delivering the Goods: Public Works Technologies, Management, and Finance
OTA Project Staff

John Andelin, *Assistant Director, OTA*
Science, Information, and Natural Resources Division

Nancy Carson,
Science, Education, and Transportation Program Manager

Edith B. Page, *Project Director*

Jonathan Atkin, *Analyst*

Julia Connally, *Analyst*

Walter Diewald, *Senior Analyst*

Kevin Dopart, *Analyst*

Sharon Burke, *Research Assistant*

Karen Mathiasen, *Research Assistant*

Daniel Broun, *Research Assistant*

Marsha Fenn, Office *Administrator*

Gay Jackson, *Administrative Secretary*

Tamara Cymanski, *Secretary*

George Branyan, *Research Analyst*

Ian Freed, *Research Analyst*

Ketan Patel, *Summer Intern*

Miriam Roskin, *Summer Intern*

Andrew Scott, *Intern*

Contractors

Analytical Services
Apogee Research, Inc.
Sarah Campbell
Robert Gordon Associates
Government Finance Research Center
L.E. Haefner Enterprises, Inc.

Thomas D. Hopkins
Rochester Institute of Technology
Rizwan *Salim*
Heywood Sanders
Porter Wheeler

Other Contributors

Federation of Materials Societies, National Association of Corrosion Engineers
Pacific Northwest Laboratory/Battelle through the Department of Energy

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CHAPTER 1

Summary and Conclusions

When we try to pick out anything by itself, we find it hitched to everything else in the universe—John Muir

Smart cars and highways, high-speed trains and tiltrotor aircraft, drinking water treatment at the tap, low-flush toilets, and computer-directed sewer inspection robots—how these exotic-sounding technologies contrast with the traffic jams, potholes, sewer system overflows, and air pollution that regularly plague residents in major cities! Most of us take the services provided by public works for granted-until they malfunction at our expense. However, such complacence is foolish, considering the staggering size of our country's investment in public works infrastructure. The value of the capital stock represented in the Nation's roads, bridges, mass transportation, airports, ports, and waterways; and water supply, wastewater treatment, and solid waste disposal facilities is estimated to be about $1.4 trillion, slightly over 20 percent of the country's total public and private capital stock.[1] Federal, State, and local governments currently spend about $140 billion annually on building, operating, and maintaining these facilities.

If the infrastructure is so valuable, and technologies have such promise, why are so many public works systems across the United States outdated, inadequate, or poorly maintained? A combination of three factors is largely responsible. First, most of the basic infrastructure has been in place for at least 20 years (some is a century old) and needs either major rehabilitation or replacement. Second, shifts in population and transportation patterns have overburdened infrastructure in the major urban areas and left small, rural jurisdictions and rural States struggling to provide adequate services from shrinking economic resources. And last, but perhaps most important, Federal, State, and local governments face major budget problems.

The Federal Government has always played a key role, through financing and promoting new capital programs for public works, in spurring economic development. In 1989, Federal contributions totaled just over $24 billion (in 1982 adjusted dollars), 2.5 percent of total Federal outlays, down from about $30 billion, closer to 4 percent, at the start of the 1980s. Environmental public works programs, rail, and mass transit have borne the brunt of the cuts in Federal infrastructure support; aviation and highways have fared better (see table l-l). State and local governments have increased their expenditures for public works, but not enough to makeup for the drop in Federal contributions, and nowhere near enough to cope with their problems.

Economists have expressed concern that slowly ebbing investment in public infrastructure over a period of years has caused a portion of the decline in productivity growth in the United States.[2] OTA's research indicates they are right. Delays due to highway congestion in major urban regions already take a toll of more than an estimated $30 billion annually (see table 1-2), almost one-half of the roughly $65 billion total spent by Federal, State, and

Table l-l—Federal Infrastructure Expenditures, 1980 and 1989 (in millions of 1982 adjusted dollars)

	1980	1989
Total	$29,863	$23,609
Transportation infrastructure:		
Highways	10,584	11,392
Mass transit	3,732	2,838
Rail	3,531	483'
Aviation	4,334	5,378
Ports, harbors, waterways	1,365	1,137
Environmental infrastructure:		
Water supply	1,017	284[b]
Wastewater	5,300	2,097

[a]Drop in expenditure reflects sale of Conrail.

[b]Low spending figures for water supply in 19S9 reflect repayments of Farmer's Home Administration water supply loans.

SOURCE: Office of Technology Assessment, 1991. Based on preliminary Congressional Budget Office estimates, Office of Management and Budget historical data, and U.S. Army Corps of Engineers estimates.

[1]OTA estimates, based On Alicia H. Munnell, "Why Has Productivity Growth Declined? Productivity and Public Investment," *New England Economic Review,* January/February 1990, p. 14.

[2]Ibid.

Table 1-2—Traffic Congestion Increases in 15 Major Cities

Cities	Congestion index[a] (1987)	Percent change (1982-87)	Annual cost of congestion: Total[b] (in billions of dollars)	Annual cost of congestion: Per capita (in dollars)
Los Angeles	1.47	20%	$79	$730
San Francisco-Oakland	1.31	29	2.4	670
Washington, DC	1.25	31	2.2	740
Phoenix	1.23	6	0.9	510
Houston	1.19	1	1.5	550
Atlanta	1.16	30	1.1	650
Seattle	1.14	20	0.9	580
New York	1.11	4	6.8	430
Chicago	1.11	11	2.5	340
Detroit	1.10	-2	1.9	480
San Diego	1.08	38	0.6	280
Philadelphia	1.06	17	2.1	520
Dallas	1.03	22	1.0	530
Minneapolis-St. Paul	0.97	24	0.5	240
Milwaukee	0.94	10	0.2	190

[a]The congestion index is a weighted measure of urban mobility levels, and cities with values greater than 1.0 have congestion problems. Roads carrying more than 13,000 vehicles per freeway lane per day or *5,000* vehicles per arterial lane per day are considered congested.

[b]Congestion cost is the estimated cost of travel delay, excess fuel consumed, and higher insurance premiums paid by residents of large, congested urban areas.

SOURCE: Office of Technology Assessment, based on Texas Transportation Institute, "Roadway Congestion in Major Urban Areas, 1982to 1987," Research Report 1131-2, 1989.

local governments for highways in 1987[6] (the last year of the congestion study), and overcrowding on the roads has increased every year since. However, reversing the downward trend in public works outlays will not be easy. It will require fundamental changes in governmental policies and spending priorities, and these do not happen quickly.

The 1990s thus loom as a pivotal decade for public works. Squeezed by demands for every conceivable type of public service, State and local officials have postponed routine maintenance and rehabilitation of vital infrastructure systems for years. For example, lining the aged water supply pipes of a major city could have prevented a leakage rate of almost 40 percent of treated drinking water over the past several decades, more than enough to make up shortages during dry spells. The city, however, has only recently allocated money for the project, for decades finding expenditures for police, schools, and caring for elderly and homeless more pressing.

But many factors other than fiscal woes keep new management solutions and technologies that could bring greater productivity and efficiency from being integrated quickly into public works. Major popula-

Photo credit: American Society of Civil Engineers

Delays caused by highway congestion cost the public at least $30 billion annually.

tion shifts and industrial and technology changes have occurred over the past 15 years (see box l-A), creating new public works needs far faster than the slow movements in corresponding public attitudes and government policies and institutions. Because public works programs are easy targets for budget cuts and wage scales are low, officials are faced by critical shortages of expert management and technical personnel to plan for, implement, and manage

[6] U.S. Department of Transportation, Federal Highway Administration, "Selected Highway Statistics and Charts 1989," November 1990, P. 19. Federal experts unofficially state that the costs of congestion may now equal or exceed total highway expenditures, which were $72 billion in 1989. Anthony R. Kane, associate administrator, Engineering and Program Development Federal Highway Administration personal communication, Jan. 28, 1991.

new technologies. Liability concerns in both the public and private sectors about the consequences of a new program or equipment that does not perform well are further barriers to new technologies.

Even if such obstacles were to be overcome, reaching consensus on the best approach and choice among new technologies is a Herculean task. While most people agree on the importance of protecting the environment and the quality of life, they do not agree on how to do this in a way that nourishes rather than saps economic vitality. Ironies resulting from attempts to address these divisive concerns can be seen across the country. Although the Nation has been a world leader in developing and implementing environmental protection policies, residents of many of the largest cities confront air quality problems tied to traffic congestion that threaten the quality of life in their communities. Los Angeles, for instance, installed new computer-managed traffiic signal equipment, improving traffic flow by 10 to 20 percent: at significantly lower cost than constructing new highway lanes. But the city still has the worst traffic congestion and air quality in the country, and public debate continues to rage over what to do next. Californians (and residents of other States with large, urbanized areas) must reach agreement on land-use requirements, travel alternatives, and funding for new transportation options, and will probably have to accept major changes in priorities and lifestyles to resolve environmental concerns.

Finding solutions to such complex problems is hard enough, even when known technologies can do the job, but choosing among new technologies (that might do better) is even more difficult, because so little is known about how they will actually perform. Only the Federal Government has the resources to support large-scale, applied research and development (R&D) programs for public works, and these have been cut drastically or neglected in recent years. Now, no significant, comprehensive, Federal technology research and support programs exist for State and local governments seeking advice about solutions to long-range problems. Until appropriate new technology choices are obvious, governments will do well to give priority to upgrading and rehabilitating existing facilities to keep them functioning as efficiently and productively as possible, while the search for abetter answer continues.

Although budget dilemmas make dramatic increases in Federal spending for public works unlikely, if more investment in certain crucial areas is not ensured soon, the negative impacts on transportation efficiency, industrial productivity, and national competitiveness will cost the country dearly. **OTA concludes that changes to Federal program management, investment policies, and R&D are needed now, if the opportunities that technology offers for public works are to be fully utilized. Immediate attention should also be given to developing programs to determine the most promising new technologies for public works and long-term strategies for implementing them. In** brief, the most important steps for Congress to take now to make public works more productive and efficient are to:

- revise Federal investment policies and program management to address today's concerns by making current systems more productive through available technologies, by maintaining existing infrastructure, and by planning and budgeting for future needs, using a comprehensive systems approach to both transportation and environmental problems;
- increase Federal public works funding selectively and use Federal programs to leverage State and local spending, so as to boost the total annual national investment in public works by up to 20 percent initially and to ensure regular, subsequent, annual increases;[5] and
- collect information that will enable the government to refocus support for short-term R&D to target applied technologies that will improve the condition, extend the life, and increase the capacity of existing public infrastructure; then, using the data as abase, develop and implement long-term systems R&D programs to address future needs.

Recognizing that Federal policies for public works urgently need review, Congress asked OTA to assess infrastructure problems across the country and to pay special attention to the problems of small systems and the opportunities for privatization and

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[4]U.S. Congress, Office of Technology Assessment, "Advanced Vehicle/Highway Systems and Urban Traffic Problems," staff paper of the Science, Education, and Transportation Program, September 1989, p. i.

[5]OTA's estimates of the potential impacts of different levels of Federal spending for public works may be found in table 1-6, later in this chapter.

Box 1-A—Trends Affecting Public Works Infrastructure[1]

Demographic Trends

The U.S. population is projected to increase by 32 million people between 1990 and 2010, with middle-age categories showing the most growth. The South and West accounted for 90 percent of population growth in the 1980s. These regions will continue to expand the fastest, and California and Florida will grow the most, Population in the Midwest is projected to decline. Almost all new population growth is expected to occur in the suburbs of major metropolitan areas, where almost two-thirds of the metropolitan population already lives. One-quarter of the population now lives in the seven largest metropolitan areas. Of new metropolitan area jobs, three-quarters will be in the suburbs.

Implications for Public Works

Strong demand for transportation services by the growing numbers of middle-aged baby boomers and growth in vehicles per household will cause travel to outpace both population and economic growth, and ***increase traffic*** congestion, particularly in and between suburbs and in newer cities built without consideration of mass ***transit.*** Demand will rise for mass transit and more efficient intercity travel. Already deep, the divide will widen between service needs and fiscal capabilities of urban and rural jurisdictions. Environmental dilemmas will intensify, particularly air quality and waste disposal problems in metropolitan areas and water supply issues in Florida and the Southwest.

Economic Trends

The shift from goods production to service delivery will continue, with production employment dropping 16 percent by 2000 and service employment increasing **13 percent. The** Nation's labor force growth rate will slow, primarily because the supply of younger workers is shrinking. More flexible manufacturing technologies will encourage decentralized manufacturing and just-in-time delivery. Demand for transportation of industrial raw materials will drop, but overall transportation demand will expand, especially for lightweight, high-value products. This will put a premium on speed and reliability-values likely to favor air and truck transport, although rail can be competitive in certain corridors. Changes in communications and transportation will accelerate economic globalization, encouraging growth around selected deep-water ports and major airports.

Implications for Public Works

Highway travel is expected to double over the next 30 years, putting an enormous burden on existing roadways, To compensate for the adverse economic impact of slower labor force growth, both public and private sectors may invest more heavily in transportation to improve the speed and efficiency of travel and transport. Economic

[1] Trends and analysis in this box are based on material in U.S. Department of Transportation, *National Transportation Strategic Planning Study* (Washington DC: March 1990), chs. 1-5, and OTA research.

public-private partnerships. Building on the conclusions reached in OTA's special report to Congress on State and local public works,[6] this report examines the public works decisionmaking framework and suggests changes in management, financing, and technology that could lead to both robust economic development and environmentally sound transportation and environmental public works systems. This chapter identifies short-term tactical options and long-term strategic goals for Congress to consider, and points to ways to set priorities for more productive and efficient public works services. Additional background and supporting details and findings appear in chapters 2 to 6.

Intergovernmental Framework

Public works provide environmental and health-related services and underpin productive transportation networks, and they must function efficiently or economic vitality and the quality of life will decline. Strong, mutually supportive intergovernmental partnerships and continuous interchange with industry and other concerned groups are essential to shaping appropriate policies and programs. The Federal form of government has long served the country well, because it provides multiple opportunities for debate and discussion before decisions are taken. However, the present intricately complicated intergovernmen-

[6] U.S. Congress, Office of Technology Assessment, *Rebuilding the Foundations. A Special Report on State and Local Public Works Financing and Management,* OTA-SET-447 (Washington, DC: U.S. Government Printing Office, March 1990).

globalization means west coast ports and intermodal connections will become increasingly important as Pacific trade grows. The need to expand capacity and improve intermodal connections will intensify around international and domestic airports.

Environmental Trends

The economic and political importance of environmental preservation and restoration issues will accelerate. While pollution from heavy industry may decrease as a result of economic restructuring, the challange to control nonpoint sources of air and water pollution will grow.

Implications for Public Works

Communities will continue to invest heavily in air and water pollution control and drinking water system improvements and in complying with Federal and State standards. Collection and disposa1 of solid waste and facility siting are becoming dominant issues. Environmental service needs already place a heavy burden on most local budgets, and as more regulations are implemented the fiscal burden is very likely to worsen (see table A-1). As the link between transportation and the environment is better understood, the environmental impacts of all proposed public works projects will be scrutinized carefully by public and private groups. Air quality issues are likely to be major determinants of public policy on transportation and land use. If worst-case projections are correct, global warming and rising of water 1evels will affect infrastructure in coastal areas.

Energy Use Trends

Transportation accounts for approximately two-thirds of all petroleum use, an amount that equals imports, and of that over 70 percent is consumed by highway transport. Substantial increases in world energy and petroleum demand and uncertainty of supply are expected to lead to much higher energy prices. Fuel efficiency of new cars doubled between 1973 and 1988, and many see the potential for further improvement.

Implications for public Works

Despite rising petroleum costs, major modal shifts are unlikely, although the cost-effectiveness of transit and other nonhighway transport will increase. Higher gas prices may limit discretionary trips and Over the long run encourage more Compact development, but unless costs are radically higher, highway travel demand will continue to increase.

Table A-l—Public Works Cited as Having Major Cost Impacts on Cities

Public works requirement	Percent of cities citing Impacts
Solid waste disposal.	75%
Traffic improvements	66
Sewage collection and treatment	58
Drinking water supply and treatment . . .	42

SOURCE: National League of Cities, *City Fiscal Conditions in 1990* (Washington, DC: July 1990).

tal framework (see table 1-3) frequently overtaxes the decisionmaking process and impedes new policy development in public works as effectively as a major accident stalls rush hour traffic.

A word about OTA's approach to analyzing the broad scope of public works infrastructure is appropriate before beginning more detailed discussion. At every governmental level, environmental public works are managed and financed differently from transportation programs and operations. Long-standing and disparate methods of funding and Federal/State/local institutional relationships for each type of service are major roadblocks to integrating environmental with transportation infrastructure management and programs. Moreover, successful improvements seem more likely in the foreseeable future, with continued separation. Consequently OTA addressed environmental and transportation public works separately and developed policy options for each. Over the longer term, incorporating both systems within a comprehensive Federal infrastructure policy could be useful, but attempting such a step now would involve too many changes to existing conditions.

Federal Decisionmakers

The constitutional separation of powers requires that the executive branch, Congress, and the courts share responsibility for developing and implementing Federal policy. For example, to ensure that the U.S. Department of Transportation (DOT) and the U.S. Environmental Protection Agency (EPA) carry out its intent, Congress may write detailed requirements and standards into legislation. This very specificity may ensure that complex standards find their way into the courts. (Further information about these Federal checks and balances of power as they affect public works will be found in chapter 2.)

Table 1-3-Public Works Management

Players	Public works role
• Congress	Congress authorizes programs, appropriates funds, and sets regulations. Multiple committee and subcommittee functions hamper comprehensive policymaking, and may delay change.
• Executive agencies controlling public works construction and regulations:	
EPA, DOT Army Corps of Engineers, and Bureau of Reclamation	Agencies assign, instruct, regulate, and finance public works facilities. Modal and media-based administrative structure hampers integrating programs; implementation of regulations dominates EPA activities.
• Other executive agencies:	
Treasury	Treasury sets revenue policy, including criteria for arbitrage and tax exempt bonds, which affects cost of raising capital for some public works projects.
OMB	OMB reviews agency budgets and regulations and has a strong influence on regulatory and spending policies.
• The courts	Courts interpret and enforce legislation and regulations pertaining to public works programs. Judges set program requirements and standards. Litigation lengthens rulemaking process and implementation, but resolves disputes.
• State government	States fund and construct public works and set and enforce regulations. Activities vary by State according to philosophy and fiscal capability. States play a major role in highways and enforcing environmental regulations, and are enlarging their role in other public works areas.
• Local government	Local governments design, construct, operate and fund public works, set local policy, and deliver service within Federal and State program regulations. They have full responsibility for funding and operating most environmental programs. States limit fiscal options of local governments.
• Private sector	Private firms are major users of public works. Also, they construct (e.g., highways and treatment plants) and operate facilities (e.g., drinking water and solid waste disposal facilities).
Interest groups	Groups influence legislative and executive branch policies through lobbying, and pursue specific objectives through litigation.
• The public	The public creates service demand, but their resistance to taxes and service charges limits public works spending and allows maintenance and improvement to be deferred. Individual lifestyle preferences determine land-use and transportation patterns.

KEY: EPA - U.S. Environmental Protection Agency; DOT - Department of Transportation; OMB. Office of Management and Budget.

SOURCE: Office of Technology Assessment, 1991-.

Executive branch management is critical in shaping the emphases of Federal regulatory programs, which in turn play a major role in affecting State and local approaches.

Executive Branch

Executive branch responsibility for public works is shared by a major department (DOT), an important independent agency (EPA), and parts of three other Cabinet departments. These are the Department of Defense (DoD), through the U.S. Army Corps of Engineers, which is responsible for flood control, harbors, and inland waterways; the Department of the Interior, through the Bureau of Reclamation, which has built a number of dams, mostly for power generation, but some of which supply water; and the Department of Agriculture, which includes the Soil Conservation Service, whose water programs affect both water supply and wastewater treatment.

The Office of Management and Budget (OMB) uses its authority to mod@ the budget and regulatory proposals of executive departments, a power it has used extensively to hold down spending for public works in recent years. Enormous departmental effort must be expended and extraordinary congressional unity must exist to alter the effects of OMB review.

Congress

Congress is a key player in public works decisions, with almost one-half of its 304 committees and subcommittees having jurisdiction over some aspect of public works. This widespread oversight authority provides fertile soil for intercommittee conflicts, discourages good communication between committees on common issues, and enables executive branch agencies and industry interest groups to play committees off against each other. An interest group that has been unsuccessful in making its case for a special cause to one authorizing committee, for example, can lobby another committee with related responsibilities or go directly to a friendly member in the hope of having a special clause inserted into an appropriations bill after the authorization process is over. "It's done all the time."7

The Courts

The courts are the final participants in the Federal policymaking arena. Their impact may be gauged by noting that about 80 percent (see chapter 2) of EPA's standards and requirements go through litigation before becoming effective. Thus the courts' decisions balance private property and individual rights against public health and safety in areas of great scientific uncertainty.

States

Driven by the slump in Federal financing and stagnation in Federal management and by the pressing needs of local communities, many States have developed their own public works strategies. These include regulatory and land-use management controls as well as funding partnerships with local governments. For example, California has moved to control the environmental consequences of explosive growth, enacting State air quality requirements more stringent than Federal standards. New Jersey and Washington State, among others, have created State support programs to help local jurisdictions fund public works improvements (see boxes 2-A and 2-B in chapter 2). Florida has enacted a requirement that local jurisdictions develop long-range land-use plans tied to capital budgets and regional and State plans. Oregon has developed land-use guidelines encouraging high-density housing and development along local mass transit corridors. Other States must follow their lead before long, for most have numerous local jurisdictions with the same critical infrastructure concerns.

Local Governments

Responsibility for managing, operating, and maintaining over 70 percent of all public works facilities and services is borne by the Nation's 83,000 local governments. Each worries about funding schools, jails, and the aging and homeless as well as potholes, collapsing bridges, leaking water mains, stormwater-caused sewer overflows, traffic gridlock, siting a new landfill, or expanding the airport according to the jurisdiction's geographic location, population, economy, natural resources, and a host of other factors. Most of the fiscal and political tools that local officials may use to address these problems are determined by the States.[8] Since the bulk of Federal financial aid goes to States, local officials, who must face angry constituents directly, often feel they are being held responsible for policies, service failures, and other events that are outside their control.

Transportation arteries and pollution do not stop at political boundaries, and despite their power over local jurisdictions, no State, not even large and relatively prosperous California, can solve all its public works problems alone. **OTA concludes that the interlocking nature of Federal, State, and local responsibilities for public works services makes a compelling case for strong Federal leadership. It is time for the Federal Government to acknowledge the broad impacts of its role in public works and to work aggressively to create a policy framework that addresses current problems and shapes the future.**

Federal Public Works Management

At its best, the system of Federal checks and balances ensures thoughtful, comprehensive actions. At its worst, it can result in contradictory policies and stalemate. Federal public works management provides examples of both the best and the worst; however this document focuses on the latter to indicate where change is needed most. Although comprehensive reviews of transportation and environmental issues preceded legislation creating the agencies, few substantive alterations have been made to the management framework of either DOT or EPA since the agencies were formed.

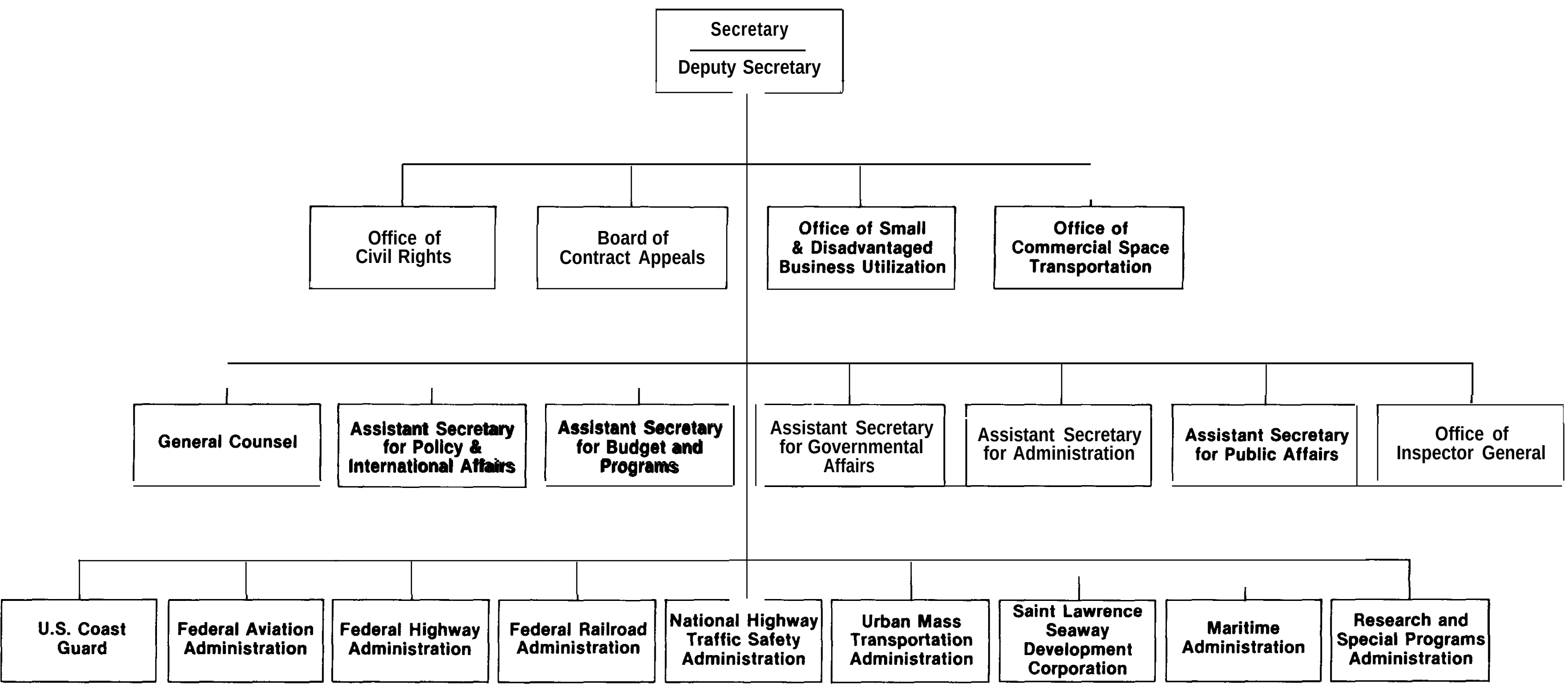
Transportation

Legislation creating DOT in 1966 established independent administrations for each transportation mode, a departmental structure that remains unchanged (see figure l-l). Although virtually all of DOT's offices have some impact on public works, those with direct responsibility include the Federal Aviation Administration (FAA), the Federal Highway Administration (FHWA), the Federal Railroad Administration FRA), the Urban Mass Transportation Administration (UMTA), and the Maritime Administration (MARAD). FHWA, FRA, and

7Michael Uremovich, vice president, Marketing, American President Companies, personal communication, Apr. 18, 1990.

8For more detailed information, see Office of Technology Assessment, op. cit., footnote 6, chs. 3 and 4.

Figure 1-1—U.S. Department of Transportation



SOURCE: U.S. Department of Transportation, 1990.

UMTA collect data, set standards, and administer grant programs for highways, railroads, and mass transit, respectively, but have no operating responsibilities. Unique among the modal agencies, FAA regulates, manages, and operates the air traffic control system, the basic electronic infrastructure for the aviation right-of-way. MARAD is primarily concerned with the commercial aspects of ocean ports and the shipbuilding industry.

The Secretary of Transportation and his office were given responsibility for coordinating and managing the modal administrations to create a multimodal, national transportation system. However, no deputy or assistant secretary position was created to support a systems management approach, and the authority given to the modal administrators has effectively prevented every secretary to date from carrying out this charge.

In any case, DOT management of a folly multimodal system is impossible, because responsibility for the harbor and inland waterway infrastructure system rests with the Corps of Engineers. The Corps built and continues to operate and maintain the Nation's waterways and to maintain the ports. In these respects, management of the infrastructure for waterborne commerce is largely Federal.

Systems Management

Industry shippers moving goods from factory or farm to market need fast, smooth trips, while travelers of all types want safe, easy journeys. Yet traffic jams on urban roadways, often made worse by maintenance projects, cause hours of frustration and costly delay, and have become major contributors to air pollution problems. Important segments of the Nation's transportation system are overcrowded or worn out (sometimes both) and need renewal. Yet no Federal programs collect information relevant to or target intermodal system improvements that would make modal transfers faster and easier for either people or freight.

Finding ways to increase system capacity and handle greater demand without constructing new rights-of-way poses enormous challenges. New technologies can marginally increase the capacity of infrastructure, but they are often expensive and eventually reach structural limits. A systems management approach that makes full use of all modes and encourages carrying the same volume of passengers or cargo on fewer vehicles could address congestion, air quality, and energy use problems.

Intermodal Transport

DOT agencies still manage each mode as a separate, independent system, rather than a contributor to an integrated system that has complex intermodal connections in large, metropolitan areas. The steps taken by Secretary Samuel K. Skinner in early 1990 to develop a national transportation strategy and improve systems management by focusing on intercity movements and the impacts of economic, social, and environmental factors on transport are moves in the right direction.[9] However, the Department has missed out almost entirely on the major industry shift to multimodal transport, which requires intermodal transfers. DOT has no data collection or management mechanisms in place to use in analyzing or resolving the resulting issues-such as that of overweight maritime containers, which cause severe highway damage when transferred to trucks.

While recognizing that reorganizations often do not change longstanding attitudes and behavior, **OTA concludes that unless steps are taken to institutionalize an integrated, multimodal approach within DOT, the existing strongly segmented modal structure will continue to prevail. One way** to effect change would be to create surface transportation programs that support intercity passenger, urban, and freight transportation, and connections to ports and airports. **Over the longer term, DOT could be restructured in divisions by broad mode—aviation, surface, and water transportation-or by function, such as metropolitan passenger and intercity freight transportation. Separating any of the current modal responsibilities from DOT would be counterproductive to long-term national transportation policy goals.** Reforming congressional oversight, by consolidating responsibility for transportation authorization under fewer committees, could support a restructured DOT.

One way to integrate management of water transportation into the national system would be to shift civilian water transportation authority from the Corps of Engineers to DOT, as was originally envisioned when DOT was created. The

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

rationale that the system is necessary for defense purposes is no longer any more applicable to waterways than to aviation. Consolidating the water-related agencies already in DOT would also make good management sense.

The Corps of Engineers: Time for a Change

As its defense-related responsibilities dwindle, the role of the Army Corps of Engineers deserves a fresh look. The Corps has a vast reservoir of technical expertise and research and engineering capabilities that could supplement other Federal resources, for both environmental and transportation public works. One possibility is to create, based on the civil functions of the Corps, a semiautonomous national engineering agency analogous to, but different from, the National Institute of Standards and Technology. Such an agency could undertake public engineering projects, such as the wetlands restoration activities the Corps is now doing under its agreement with EPA, and programmatic activities as well. With its nationwide network of regional and division offices, the Corps is well suited to develop more effective applications and transfer programs for technologies initiated in the national laboratories and technical assistance programs targeted at public works engineers. The new civil Corps could be an independent agency or function under the auspices of either the Department of Commerce or DoD.

The engineering capabilities of the Bureau of Reclamation overlap to a certain extent with those of the Corps, occasionally creating competition over projects. As the roles of these agencies are reexamined, consideration could be given to merging the duplicative aspects of their respective missions and redefining the remaining activities to improve governmental efficiency.

Environmental Public Works

EPA's responsibilities are spelled out through the specific requirements of a number of laws, such as the Clean Air Act, the Clean Water Act, and the numerous laws affecting pesticides, fertilizers, and wastes. Standard setting and enforcement activities for drinking water, wastewater treatment, and solid waste disposal are each overseen indifferent offices, headed by associate administrators. Although its complex standards affect public services provided by every local government and many private entities and used by every citizen, the Agency has never been given a substantial budget for planning, technical assistance, or public information and education.

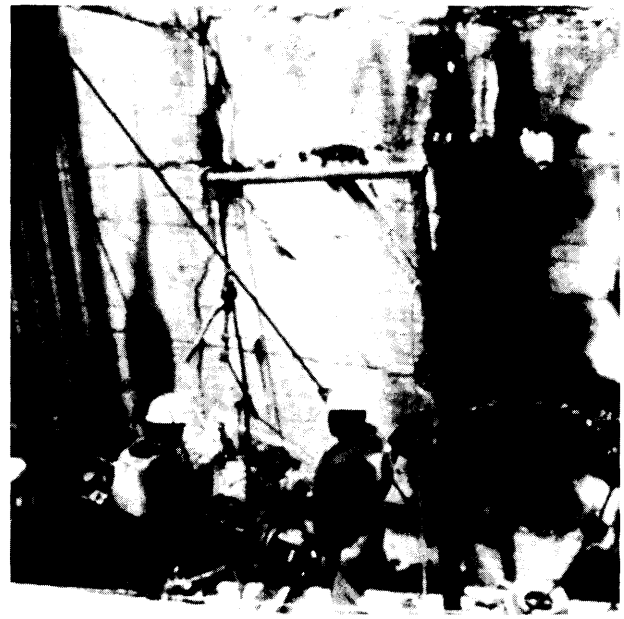


Photo credit: Army Corps of Engineers

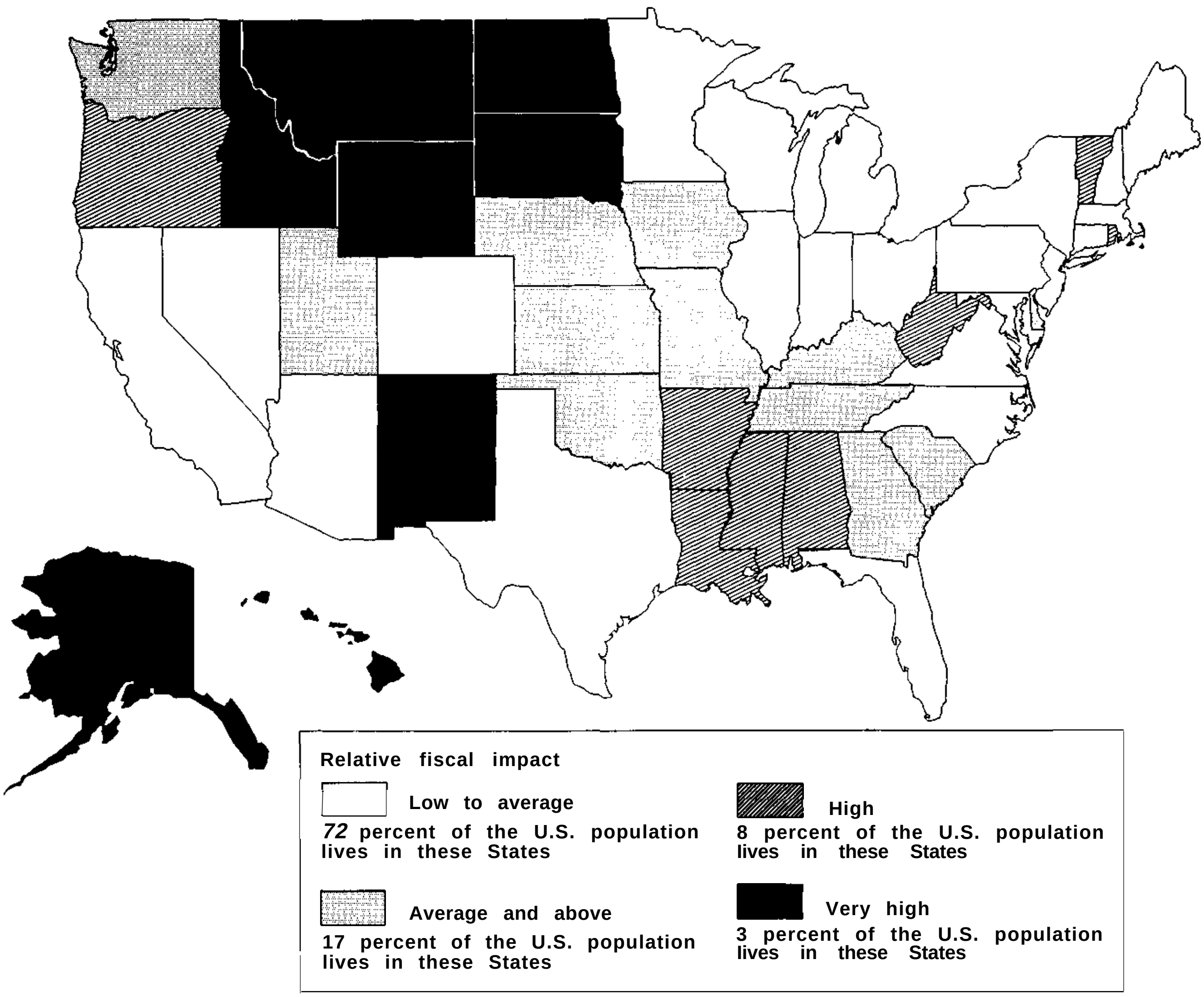
The Army Corps of Engineers has effective technology development programs for its engineers across the country.

The statutes determining EPA's activities have led to creation of an organizational structure under which each section of the agency pursues separate activities (see chapter 4 for further details). These programmatic divisions are reinforced by court decisions related to specific laws and by State laws or programs, making setting priorities for overall environmental protection a daunting challenge.

Standards and Enforcement

EPA has been required by legislation to set and implement standards for drinking water contaminants, wastewater treatment, municipal solid waste, and other environmental protection activities simultaneously with a reduction in Federal contributions for State and local construction grants. The Agency is thus in the position of having to enforce compliance with standards for public works, which may or may not provide a jurisdiction with additional health benefits commensurate with the costs of the facility and technology. The question must be raised of whether it is responsible government to take enforcement action for noncompliance with new standards that impose unreasonable costs relative to the health benefit, if no Federal assistance is available.

Figure 1-2—Projected Impact on States of Reduced Federal Aid for Public Works*



[a]OTA established an arbitrary 50-percent reduction in Federal aid to evaluate the impact on each State.
SOURCE: Office of Technology Assessment, 1991, based on information provided by Apogee Research.

At a minimum, given the widespread gaps in financial abilities, technical information, and management know-how, Congress will want to address the issue of environmental enforcement policy for public systems facing severe fiscal stress imposed by Federal mandates. As figure 1-2 indicates, over one-quarter of the States and 11 percent of the population potentially fit this category. One option is development and implementation of a formal strategy and program for staging compliance requirements. This could be coupled with stepped up Federal development and fielding of lower cost technologies for compliance. **Adequate funding for outreach and information programs, research, and evaluation of enforcement priorities is called for.**

Systems Management

The current EPA administrator is attempting to heighten the awareness of the interactions within the environment and to take steps to incorporate these into the Agency's programs, but it is far too early to tell whether the efforts will have any effect. Clarification of enforcement policy and the need for environmental systems management could be included as part of legislation to make EPA a Cabinet department to bolster his efforts. However, whether or not the Agency becomes a department, legislative direction could help the EPA administrator (or secretary) to improve policy coordination and communications between the sections of the Agency and ensure that environmental public works requirements reflect the ways natural systems interact. **Congress could enact legislation requiring EPA to protect and manage the environment as a complex system and to clarify the role of the Agency in assisting public jurisdictions in complying with environmental standards.** Such a mandate would not guarantee improvement; as discussed elsewhere in this chapter, DOT has such a mandate for transportation, which it has not fulfilled. Nonetheless, such an action would provide additional leverage for broadening the present media-specific programs. Consideration could also be given to establishing formal mechanisms for regular review of cooperative programs for EPA, the Corps of Engineers, and the Bureau of Reclamation to avoid duplication and maximize resources.

OTA concludes that the fragmented congressional and executive branch responsibilities for public works impede setting policy goals that could lead to better investment decisions, more effective management, and better use of technologies. Research for this study showed that better data collection and program management changes are needed now, to address the needs of State and local governments and industry and ensure adequate investment and wise policy and technology decisions.

Difficult as management changes are, it would be unrealistic to assume that efforts made now to update Federal activities would continue to be appropriate for the indefinite future. Rather, the reverse is true; Federal public works programs and policies must be understood as dynamic and subject to rigorous periodic review and revision to keep them relevant and focused appropriately.

Congress

The current, atomized congressional oversight structure for public works is both inefficient and counterproductive. To cite a recent example, during the course of research for this study, OTA searched in vain for staff members on the committees with authority for financing or tax matters who had consulted with staff on public works committees about the impacts on States and municipalities of changes to the tax requirements for municipal bonds. The response from every committee staffer contacted was the same, "No, we didn't look at that." It took more than 2 years of sustained effort on the part of local officials to reverse sections of 1986 tax legislation that severely hampered their revenue raising ability.[10] **Financing, budget, and appropriations committees need to take into account the broad impacts of Federal tax and fiscal policies on the other governmental levels responsible for public works operations, areas in which authorizing committees have expertise.**

More thoughtful consideration of the complexities of public works issues and better policymaking might occur if Congress chose to review and consolidate widely dispersed committee responsibilities and develop better communications between committees of jurisdiction. If a complete overhaul of committee responsibilities is too daunting a task, special or ad hoc committees could be established to develop legislation on system problems-for example, to clarify EPA's mandate and identify important future directions for the agency.

Congressional oversight and responsibility for transportation needs reevaluating, with the goal of diminishing modal rivalries and developing legislation that leads to integrating the modes into an effective, national transportation system. At a minimum, mass transit responsibility could be consolidated with that for highways in the Senate, and the committees responsible for railroads could develop close working relationships with those with jurisdictions over highways and ports. Annual joint authorizing committee meetings and more frequent joint staff meetings to hammer out legislation that reflects the actual intermodal connections of the transportation system are other options.

Investment and Financing: Who Pays and How

> [the State's duty includes] . . . erecting and maintaining certain public works and certain public institutions . . . because the profit could never repay

[10] A detailed discussion may be found in Office of Technology Assessment, op. cit., footnote 6, p. 49.

Table 1-4-Federal Outlays, 1960-90 (in percent)

	1960	1970	1975	1980	1985	1990[d]	1995[d] (projected)
National defense	52	42	26	23	27	25	22
Human resources	28	39	52	53	50	51	56
Physical resources[b]	9	8	11	11	6	7	4
Net interest	8	7	7	9	14	15	9
Other[c]	3	4	4	4	3	2	9
Total Federal outlays (in billionsof current dollars)	$92	$196	$332	$591	$946	$1,197	$1,477

[a]Includes Medicare, income security, and social security.
[b]Includes transportation, natural resources, and environmental and community development.
[c]Includes general government and undistributed offsetting receipts.
[d]Estimated.

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

> the expense to any individual. . . though it may frequently do much more than repay it to a great society.[14]

Federal infrastructure programs have developed over many years to meet the concerns of the period, usually for purposes of national defense and economic development. As industrial and societal patterns have changed, the Federal Government has, with a few exceptions, found it far easier to add programs and requirements than to refocus or eliminate the existing ones. (Presidents Carter and Reagan were among the exceptions; each was quite successful in reducing the number of Federal support programs.) Although the importance of modem, well-maintained public works systems to National, State, and local economies should be a powerful impetus for changing outdated Federal policies, tremendous unmet needs accumulate well before Federal programs can be restructured to take account of them.

While several national studies over the past decade have recommended substantially greater investment in public infrastructure,[15] no sense of emergency has developed to spark the kinds of changes in social and fiscal policies and political attitudes that could make this happen. Over the last 30 years, Federal budget priorities have emphasized payments to individuals for social and health programs (see table 1-4) over investment in infrastructure. To ensure that some support for public works continues, dedicated trust funds fed by Federal user fees have been developed for transportation projects. Despite these funds, however, the overall trend in Federal policy and budget decisions has been to turn, slowly but steadily, to greater cost sharing by States and local governments.

Investment Issues

Federal programs have long supported economic development by providing capital support for construction of new facilities and heavily subsidizing some types of infrastructure while leaving States and local governments responsible for others. Never robust, Federal support for environmental public works, has dropped steadily, while at the same time, numerous strict environmental requirements affecting suppliers of municipal service providers have been enacted. **Laws mandating Federal standards for environmental public works that dramatically raise local government costs while simultaneously phasing out most remaining Federal aid seem perverse. Moreover, the emphasis on capital construction and the prohibition of assistance for improving operations in most Federal transportation programs is outdated.** Lack of space, high costs, and environmental considerations sharply limit the opportunities to build new highways or airports in urban areas where more capacity is most needed. Other solutions are called for. As Congress considers refocusing Federal investment policies for public works, the following issues are important to keep in mind.

14A&In Smith, *The Wealth of Nations* (Bungay, Suffolk, England: The Chaucer Press, 1979), p. 379.

15National Council on Public Works Improvement, *Fragile Foundations: A Report on America's Public Works* (Washington, DC: February 1988) is the most recent. The Council called for up to a doubling of public works expenditures, a general guideline which has since been supported by several studies of special segments of public works, particularly the U.S. Environmental Protection Agency, Office of Municipal Pollution Control, 1988 Needs *SurveyReport to Congress* (Springfield, VA: National Technical Information Service, February 1989).

Photo credit:Ameffcan Consulting Engineers Council

As communities in the South and West, such as Las Cruces, NM, grow at a rapid rate, expansion of environmental public works becomes necessary.

Fiscal Capabilities

State and local governments must balance their budgets annually, and right now, many face serious budget problems, exacerbated by the economic slowdown in late 1990 and early 1991.[13] Competition for revenue is keen among State agencies, with costs for Medicaid consuming a full 30 percent of some State budgets—in New York and Massachusetts, for example. Major population shifts and economic changes, such as the growth in the sunbelt States and the losses in some "rustbelt" cities and farm and prairie States, mean that some States will have much greater difficulty than others increasing their support for public works.

State fiscal problems can have a devastating effect on local governments, although some jurisdictions are in more vulnerable positions than others. Financing public works improvements is difficult for major urban areas, where public funds must meet other urgent demands, such as adequate housing, police protection, and schools. For some older cities where populations and tax bases are declining, maintenance has been deferred because of tight funding, causing serious decay in public works. As a consequence, public facilities provide inadequate service or function inefficiently, and are very costly to rehabilitate (see box l-B). These cities need help, but not every State is willing or able to provide it.

In other large urban areas, particularly in the South and West, rapid suburban growth and weak planning and land-use requirements have made developing an efficient transportation network seem impossible. In many such cities traffic congestion has slowed rush hour highway travel to 10 miles per hour averages. While their infrastructure needs are growth-related, they are likely to be as great as those of older cities. However, the economic base they can tap for funding is both broad and deep-and it includes private sector firms eager to participate in a growing market (see box l-C).

Another type of problem marks the poorest States and those with many small, rural systems. These barely have the resources to maintain existing systems and will find new construction to meet Federal environmental requirements prohibitively costly. (States in this category are indicated in figure 1-2 shown earlier.) Because Federal transportation grants have targeted capital construction and because of population and economic changes, some States have more of some types of public works than they can afford to maintain-such as the miles of Interstate highways in large Western States like Montana. Both small and large jurisdictions in rural States and large, older jurisdictions with huge public works backlogs and inadequate economic bases need more financial and technical aid.

As it reexamines public works investment policies, Congress could consider giving more Federal support to those States (and cities) where economic resources are limited and service needs are very high. How high a tax burden a State already places on its citizens (see table 1-5 for a summary) is another factor that could be considered. **OTA concludes that Federal investment in selected segments of public works must be increased to leverage State and local investment in growth areas and supplement resources in economically weak areas. Otherwise, the gap between local jurisdictions' ability to provide essential public services and the need for the services will continue to grow, with potentially serious consequences for the National, State, and local economies. The** most important targets for higher Federal

[13] Office of Technology Assessment, op. cit., footnote 6, pp. 57-61.

Box I-B—Predicaments of art Older City

The condition of public works in Philadelphia epitomizes the predicament of many large, older central cities. Capital outlays needed to replace and upgrade its public works contrast starkly to the city's fragile fiscal condition.

Water and Sewer Needs-Parts of the city's drinking water and wastewater treatrnent systems are over 100 years old and need extensive restoration and replacement. The City Water Department has proposed a $456-million capital improvement program for 1991 -96.1 Although drinking water currently satisfies U.S. Environmental Protection Agency regulations, officials are concerned about the feasibility and costs of meeting anticipatedFedmal standards for byproducts of corrosion (lead arid copper) and disinfection. Under court order since 1979 to improve its wastewater treatment system, the city has rebuilt and upgraded treatment plants and eliminated ocean dumping of sludge, but the system, especially the supply piping, still needs major rehabilitation.

To finance the sewer and water improvement package, the Water Department must raise an additional $44 million annually beginning this year. The department initially proposed a 56-percentrate hike on top of a 20-percent raise in 1986, but recently adopted a plan to raise $27 million through increased rates and to cut expenditures by $16 million.[2] The department's high percentage of low-income customers makes covering all improvement costs through rate increases practically impossible. In fiscal year 1990, department collections fell $20 million below expenditures.

Transportation **Needs—The** capital cost to maintain and improve the regional highway and transit system and build some additional capacity is estimated at $14 billion spread over the next 20 years.[3] Projected operating costs, which include maintenance, are $4 billion for highways and $19 billion for transit. The city must bear most of the cost because many central city highways and subway facilities are in poor condition, exacerbated by years of inadequate maintenance. A 1985 study showed the city investing only 35 percent of the funds needed annually for street and highway maintenance and rehabilitation and 62 percent of those for mass transit's capital and maintenance needs. Comparing current outlays for regional transportation with recent needs estimates, the region will have a 40-percent investment shortfall.[4]

Fiscal Status--Philadelphia's fiscal problems are as serious as its infrastructure deficit. While employment in Center City Philadelphia continues to expand the jobs are increasingly for high-level executives, managers, and technical support personnel, many of whom live and pay their taxes outside the city. The city's tax base is eroding, and fully 60 percent of all work trip travel is now intrasuburban.[5] In August 1990 the city's chief accounting officer warned that in 9 months the city might not have enough money to pay its bills, despite plans to borrow heavily.[6] The city's bond rating has been downgraded to junk-bond level, precluding new long-term borrowing and forcing officials to put together short-term credit packages to avoid insolvency.[7] To reduce expenditures, officials have cut operating programs; the police force is down 2,200 officers from its high in 1977,[8] for example. For help, local officials are looking for State and Federal aid and authority to raise local taxes and fees.

[1] Standard & Poor, "Philadelphia Water and Sewer System," *Creditweek — Credit Analyses*, August 1990.

[2] Timothy Tattam, Standard & Poor, personal communication, Jan. 31, 1991.

[3] U.S. Department of Transportation, *National Transportation Strategic Planning Study* (Washington, DC: 1990), p. 7-2.

[4] Ibid., p. C-5.

[5] "Septa Studies Cross-County Commuting," *Railway Age*, vol. 191, No. 7, July 1990, p. 82.

[6] "Controller Warns on Philadelphia Funds," *New York Times*, Aug. 15, 1990, p. A-24.

[7] Frank Shafroth, National League of Cities, personal communication, Jan. 30, 1991.

[8] "Philadelphia's Jails and Courts Are Overwhelmed," *New York Times*, Aug. 15, 1990, p. A-24.

spending for infrastructure are indicated in table 1-6; those with **stars** need the largest relative increases.

Although budget negotiations are always arduous, a 20-percent increase in total national infrastructure investment seems both achievable and relatively modest. Congress increased Federal appropriations for transportation by about that amount in the 1990 budget, which should raise State expenditures, since most Federal appropriations require State matches. Moreover, State and local public works administrators should be able to spend 20 percent more without being overwhelmed, as they might be by a sudden, giant leap in funding.

Box 1-C—Keeping Up With Growth

Population in the Houston metropolitan area more than doubled between 1960 and 1980 and now totals about 3.2 million, although the rate of growth has moderated. Houston has no zoning regulations, and unregulated development and unswerving devotion to private automobiles have created a low-density land-use pattern hard to serve efficiently with public transportation and sanitary facilities and have overloaded local streets and highways.

Highways and Public Transit—In 1980 voters approved a l-percent sales tax to support the struggling Metro Transit Authority (METRO). Now 10 years later, METRO is spearheading a voter-approved metropolitan ''mobility plan,' that includes purchase of new buses to replace the existing, aging fleet, completion of a system of transit ways to speed bus service, and a $600-million roadway improvement package to widen and resurface existing streets and build overpasses and underpasses at congested intersections. The roadway improvements were started first, and over 70 of 200 street projects are complete or under way, financed by the dedication of 25 percent of the sales tax revenues.[1]

Development of a rail transit system is the most controversial plan element. Critics complain that a rail system is not needed in Houston and that ridership can never justify the $1 billion investment, but METRO officials point to Los Angeles' freeway gridlock and air pollution problems as an example of what happens when a growing city relies exclusively on automobiles and highways for too long. The alignment for the rail line is still under discussion but a decision is expected in spring 1991; the financing package includes Federal funds ($115 million has already been committed), private sector contributions, and METRO funds.[2]

Drinking Water—During its years of rapid growth, Houston relied heavily on developer-built groundwater-based systems, but when subsidence (a sinking of the earth caused by groundwater loss) problems became acute, the State stepped in, setting up a regional authority to regulate water withdrawal from aquifers. Houston must switch to drawing its drinking water predominately from local lakes and rivers and is investing millions of dollars, in new facilities, including a new treatment plant and miles of additional pipelines to transport water to the city. Furthermore, costs for electrical power for treatment plants and chemicals used in treatment are expected to increase,[3] In addition, the city is replacing lead paint-lined storage tanks and 2,500 miles of small (less than 6-inch) pipe with larger more reliable lines.[4] To finance these improvements, Houston has increased user charges steadily:

[1] Anthony W. Hall, Jr., ''We Don't Need Another Vote on Rail,'' *Houston Chronicle*, May 27, 1990, p. 1F.

[2] Gunter Koetter, "W Can Help Houston Avoid Los Angeles' Mistake," *Houston Chronicle*, June 24, 1990, p. 5F.

[3] City of Houston, Texas, ''Preliminary Official Statement,'' regarding Water and Sewer System Revenue Bond Issue, Aug. 15, 1990.

[4] City of Houston Public Utilities Department, "Water Production" August 1990.

Regulations and Compliance

EPA estimates that total annual costs for the Nation's municipalities must rise from about $33 billion in 1987 to at least $54 billion (in 1988 dollars) by 2000 to meet some, but not all, of the new and proposed solid waste, water supply, and combined sewer overflow standards.[14] Small systems, serving fewer than 10,000 people, will be required to fund $6 billion in capital improvements to meet just one set of requirements, those of the 1986 amendments to the Safe Drinking Water Act. Many will need financial assistance to do so,[15] and meeting the standards or deadlines may be impossible.[16] However, the legislation gives little flexibility for responsible Federal, State, local, or private sector officials to develop innovative or cost-effective ways to comply. Policies that make local governments responsible for meeting Federal environmental mandates without commensurate Federal investment raise questions of fairness.

User Fees

Policy makers at all levels of governments must continually balance the objective of user pays with development goals and issues of ability to pay. To encourage development and because public works are regarded as a necessary service, user charges

[14] Apogee Research, Inc., *The Cost of Environmental Protection* (Washington, DC: U.S. Environmental Protection Agency, Office of the Comptroller, January 1990), p. 14.

[15] U.S. Environmental Protection Agency, Office of Drinking Water, republished summary data based on the Regulatory Impact Analyses prepared in accordance with Executive Order 12291, Nov. 27, 1989.

[16] Office of Technology Assessment, op. cit., footnote 6, p. 117.

21 percent in 1987,9 percent in 1988, and 6 percent in both 1989 and 1990. The typical residential customer uses 7,000 gallons per month.[5]

While the scale of Houston's water system requires enormous capital investment, its size also supports the scientific and management capability to cope with Federal and State compliance requirements, which can overwhelm smaller systems. After finding that local laboratories could not provide the sophisticated water quality tests required by the U.S. Environmental Protection Agency (EPA) at a reasonable price, the city expanded its own laboratory, increased staff, and invested in automated equipment to do the testing. A special research and regulatory evaluation group evaluates the effects of proposed regulations on Houston's system, investigates technologies, and develops new treatment schemes. City officials maintain the staff work has paid off, because their unit costs are down,[6] but they remain concerned about complying with proposed standards for contaminants such as radionuclides and disinfection byproducts.

Wastewater Treatment—In 1987 the Texas Water Commission issued an administrative order fining the city $500,000 for permit violations and sewer overflows and establishing a compliance schedule for operational and capital improvements to meet Federal effluent discharge limits.[7] Since then, Houston has invested about $800 million in plant upgrading, consolidation, and new construction, and extensive sewer expansion and rehabilitation.[8] While the system now meets all EPA and State standards, the city plans to spend an additional $1.1 billion between 1991 and 1995 to replace narrow, worn-out lines and rebuild lift stations. These improvements are being financed by EPA grants, revenue bonds, developer impact fees, and user charges. As part of its financing package, the system will issue approximately $174 million in low-interest revenue bonds through the EPA-financed State Revolving Fund in 1990. User charges, which back the bonds, are set annually by the city council and currently average $19 a month.[9] Rates climbed 22 percent in 1985 and 1986 and more recently have risen about 8 percent a year-a trend that is expected to continue unless new Federal environmental regulations for cyanide, pesticides, and toxic metals require larger increases.

5City of Houston, op. cit., footnote 3.

6Ibid.

7Ibid.

8City of Houston Public Utilities Department, "Improvements in the City's Wastewater System 1982- 1990," August 1990.

9Prior to 1974, Houston charged a flat household rate of 75 cents for wastewater treatment.

have traditionally been set below full capital, operating, maintenance, and replacement costs.[17] General revenue subsidies are usually necessary to cover capital costs, although in growth areas, beneficiaries may contribute land or cash to capital projects, reducing government costs. **While** user fees can be increased by every level of government to correct existing underpricing, Federal and/or State financial assistance for local governments will be essential for most capital projects, especially for those jurisdictions with low per-capita incomes and large public works backlogs.

Privatization and Private Sector Financing

Under circumstances where demand for certain services is likely to be high, private entities find investment in public works, particularly environmental services, attractive. Private water supply companies, for instance, have long flourished in many jurisdictions, as have private solid waste disposal companies. If private companies providing environmental public services can meet EPA and State standards, overcome public opposition on issues such as siting for waste disposal facilities, and make a reasonable return on investment, they can find multiple market opportunities.

However, private firms succeed in providing low-cost services primarily in situations where the market is large, and stable or growing. Many communities that must make major investments in public works are simply unable to generate adequate revenue from user fees to attract private capital. In other areas, private firms capture the lucrative segments of the market, leaving the less profitable ones for public agencies.

17U.S. Congress, Congressional Budget Office, *New Directions for the Nation's Public Works* (Washington, DC: U.S. Government Printing Office, September 1988).

Table 1-5—State Fiscal Summary

State	Per-capita income, 1989 (in dollars)	Fiscal effort rank, 1988 (1 = highest effort)	Personal income tax revenue per capita 1987	Sales tax rate, 1988	Gas tax rate, 1990 (in cents)	Number of Interstate miles rated deficient, 1988	Wastewater[c] needs, 1988
Alabama	$13,625	31	Average	Low	13¢	Low	Average
Alaska	21,656	3	No tax	No tax[b]	8	High	Low
Arizona	15,802	29	Average	Average[b]	17	High	Average
Arkansas	12,901	48	Average	Low[b]	14	Low	Low
California	19,929	27	High	Average[b]	14	High	High
Colorado	17,553	36	Average	Low[b]	20	Low	Low
Connecticut	24,683	49	Low	High	22	Low	High
Delaware	18,483	37	High	No tax	16	Low	Low
District of Columbia	23,491	2	High	High	18	Low	Low
Florida	17,647	46	No tax	High[b]	10	Average	High
Georgia	16,053	26	Average	Low[b]	8	High	Average
Hawaii	18,472	8	High	Low	11	Low	Low
Idaho	13,707	24	Average	Average[b]	18	Average	Low
Illinois	18,824	35	Average	Average[b]	19	Average	High
Indiana	15,779	30	Average	Average	15	Low	High
Iowa	15,487	4	Average	Low[b]	20	Average	Average
Kansas	16,498	15	Average	Low[b]	16	Average	Low
Kentucky	13,743	43	Average	Average[b]	15	Low	High
Louisiana	12,921	28	Low	Low[b]	20	Low	Average
Maine	16,248	22	Average	Average	17	Low	Low
[illegible]	21,013	19	High	Average	19	Low	Average
[illegible]	22,174	44	High	Average	17	Low	High
[illegible]	17,444	7	Average	Low	15	High	High
[illegible]	17,657	5	High	High[b]	20	Low	Average
[illegible]	11,724	10	Low	High	18	High	Low
Missouri	16,292	47	Average	Average[b]	11	High	Average
Montana	14,078	18	Average	No tax	20	Average	Low

(continued on next page)

Table 1-5-State Fiscal Summary-Continued

State	Per-capita income, 1989 (in dollars)	Fiscal[a] effort rank, 1988 (1 = highest effort)	Personal income tax revenue per capital 1987	Sales tax rate, 1988	Gas tax rate, 1990 (in cents)	Number of Interstate miles rated deficient, 1988	Wastewater needs, 1988
Nebraska	$15,446	12	Average	Low[b]	22)	Low	low
Nevada	19,269	50	No tax	High[b]	18	High	High
New Hampshire	20,267	51	No tax	No tax	16	Low	Average
New Jersey	23,778	34	Average	High	11	Low	High
New Mexico	13,401	17	Low	Average[b]	16	Low	Low
New York	21,073	1	High	Low[b]	8	Average	High
North Carolina	15,198	39	Average	Low[b]	22	Low	High
North Dakota	13,563	11	Low	High[b]	17	High	Low
Ohio	16,373	25	Average	Average[b]	20	High	High
Oklahoma	14,154	33	Low	Low[b]	16	High	Low
Oregon	15,919	16	High	No `tax	18	High	Average
Pennsylvania	17,269	36	Average	High	12	Average	High
Rhode Island	17,950	23	Average	High	20	Low	Low
South Carolina	13,654	20	Average	Average	16	Low	Low
South Dakota	13,685	32	No tax	low[b]	18	Low	Low
Tennessee	14,694	42	No tax	High[b]	21	High	Average
Texas	15,702	45	No tax	High[b]	15	High	High
Utah	13,079	9	Average	Average[b]	19	Low	Low
Vermont	16,371	21	Average	Low	16	Low	Low
Virginia	18,927	40	Average	Low[b]	18	High	Low
Washington	17,649	13	No tax	High[b]	22	Low	High
West Virginia	12,345	41	Average	High[b]	20	Low	Average
Wisconsin	16,449	6	High	Average[b]	21	High	High
Wyoming	14,508	14	No tax		9	Low	Low

a Fiscal effort measures how much a State chooses to tax its revenue base compared with other States. (See app. A for a full explanation.)
b Local option sales tax permitted.
C Estimates of the relative State cost t. build all needed publicly owned wastewater treatment facilities to meet the requirements of the Clean Water Act.

SOURCE: Office of Technology Assessment, 1991, based on variety of Federal and State data summaries.

Table 1-6-Priorities for increased Annual Federal Infrastructure Spending

(*) Star indicates priorities for largest increases.

	1989 Federal spending[a] (In billions of dollars)	Priorities	20-percent increase in spending[b] (in billions of dollars)
Surface transportation total	*$17.9*		$21.5
Highways and bridges	13.8	*Maintain and improve condition of existing facilities. *Expand system capacity through implementation of existing traffic management techniques, HOV and smaller lanes, signalization, and automated toll facilities. R&D on advanced teohnologies, e.g., intelligent vehicle/highvvay systems. improve intermodal connections.	
Mass transit	3.5	Expand transportation system capacity and efficiencybyadding transit ways and improving intermodal connections, stations, terminals, and parking facilities. Modernize equipment and rehabilitate rails.	
Rail (passenger)	0.6	Modernize oapital equipment. *implement high-speed rail in overcrowded corridors.	
Airports and airways total	6.6	Complete National Airspaoe System Plan. Expand system capacity through other advanced surveillance, guidance, and communications technologies. Expand system capacity with airport and runway construction. *improve intermodal connections.	7.9
Ports and waterways total	1.0	Continue to maintain and rehabilitate existing facilities. Expand capacity on a selective basis. improve landside (intermodal) connections. Address environmental issues	1.2
Transportation total	*25.5*		30.6
Environmental public works, Including wastewater and drInking water	*2.8*	*Construct, rehabilitate, and upgrade treatment facilities and collection and distribution systems, especially in large, eider cities and small communities. *R&D of low-met technology and technical assistance for small communities and to overcome widespread resistance to innovation. Data collection and analysis of environmental system risk and assessment of regulatory consequences.	3.4[c]
Total Federal spending	*28.3*		34.0
Total all levels of government	140.0		168.0

a Federal spending totals include some noninfrastructure expenditures, such as for safety.
b A 20-percent increase is hypothetical. However, for surface transportation, it approximates the impact of spending the current Highway Trust Fund balance over a 5-year period.
C Because Federal budget projections forecast decreased funding for environmental public works, the $3.4 billion would be more than a 20-percent increase over current plans for Federal spending.

SOURCE: Office of Technology Assessment, 1991.

The". . . potential advantages of privatization are probably slightly greater in solid waste disposal than toll roads, . . ."[18] and transportation may or may not provide equally appealing private investment opportunities. The elapsed time between project conception, approval, and completion of construction is often a matter of years; work has just begun on publicly funded highway reconstruction projects that have been on the drawing boards for more than a decade, for example. This lengthy and uncertain timeframe poses difficulties for private investors. In addition to acquiring a site or right-of-way, the challenges facing private entrepreneurs wishing to participate in the large public works market include meeting Federal environmental requirements and obtaining approval of State supervisory bodies. Developers seeking to build a private toll road in Virginia, for instance, encountered numerous delays, first, in acquiring State permits, and subsequently in the Federal environmental impact assessment process. In addition, a real estate slowdown made some land owners, who had been eager to donate land for the highway hoping to reap returns on future development, much less interested in the deal, and some have held out for payment.[19]

Nonetheless, California plans four private transportation projects for construction on State-owned rights-of-way; arrangements permit return on investment from tolls and the value added by the privately developed transportation facilities.[20] Time will tell in both States whether the returns will be adequate to satisfy the private investors and also acceptable to State administrators charged with protecting the public interest.

Financing Transportation

The Federal trust funds for highways, mass transit, aviation, and waterways provide States and localities with more substantial Federal support for transportation projects than environmental public works enjoy. However, the variety of ways that Federal aid supports each transportation mode has led to different modal infrastructure problems (see table 1-7). When the Federal Government takes financial responsibility for maintenance and operations as well as assisting with capital costs for construction, transportation infrastructure has generally been kept in good condition. Infrastructure for harbors, inland waterways, and aviation falls into this category. While delays occur on the most heavily used portions of these (basically Federal) systems, more active demand or traffic management techniques can eliminate most of these capacity problems.

Surface Transportation

Surface transportation has drastically different characteristics, because Federal financing and investment have shaped actions taken by the State and local governments and some private entities (in the case of railroads and transit) that are responsible for infrastructure. State governments provide slightly more than 50 percent of highway funds, with about 22 percent coming from the Federal side, and the remainder from local governments. The emphasis in Federal programs on capital construction has made the State and local governments the owners of a far flung road system and a number of bridges, all of which need regular maintenance if they are to provide acceptable service. However, operations and maintenance are left almost entirely to the State or local owner (for further details, see chapter 3), and fiscal constraints have caused almost universal cutbacks and deferrals for maintenance and rehabilitation programs.

Because their revenue raising options are limited by State laws, many local governments have not been able to fired road and bridge maintenance programs adequately. Many systems need operating improvements, too, to relieve delays caused by increases in traffic. But most large cities simply have not invested adequately in basic operational improvements, such as advanced traffic signal systems, largely because Federal grants are not available for the purpose.

Intercity passenger rail (Amtrak) receives Federal support for capital expenditures and about 30 percent of its operating costs. Intercity freight rail receives virtually no Federal support, except for

[18] Jose A. Gomez-Ibanez and John K. Meyer, "The Prospects for Privatizing Infrastructure: Lessons From U.S. Roads and Solid Waste," paper presented at the Conference on The Third Deficit: The Shortfall in Public Investment, sponsored by the Federal Reserve Bank of Boston, Harwich Port, MA, June 27-29, 1990.

[19] William H. Allen, vice president, Parsons Brinckerhoff Quade & Douglas, Inc., unpublished remarks at the OTA Workshop on Transportation Infrastructure Technologies, July 25, 1989.

[20] California Department of Transportation, Office of Privatization "Privatization," unpublished document, October 1989, p. 1.

Table 1-7—Major Issues and Problems in Transportation Public Works

Transport mode	Condition	Capacity	Environment	Management and investment
Highways and bridges . .	10 percent of roads and 42 percent of bridges rated deficient.	Congestion and delays increasing in many urban and suburban areas; excess capacity in rural areas.	Air quality; land use; noise	Life-cycle management needed; large capital investment would be required to expand urban roadways to meet demand-a temporary solution, at best.
Mass transit	Structural deterioration of rail systems in older, urban areas.	Excess capacity available in most rail and bus systems.	Bus emissions	Roadway management enhancement needed to improve bus transit; life-cycle management and financing for rail transit; little recent R&D investment.
Rail	Generally good for large railroads; problems due to deferred maintenance on some regional and shortline railroads.	Excess capacity on most lines.	Waste disposal on Amtrak trains; for high-speed trains: noise, land use	Federal operating subsidies are needed for Amtrak to ensure reliable commuter rail services. Adequate, stable capital equipment funding could be established to help modernize the fleet and to expand capacity.
Ports and waterways . . .	With a few exceptions, locks, dams, protective works, and channels are generally in good condition.	Locks are the bottlenecks on the inland waterways; delays can exceed 2 days at a few locks.	Dredging and dredged material disposal; noise, land use, and surface traffic problems at ports	Transportation users, especially on the inland waterways, require much greater General Fund subsidy than other transport modes; no cost sharing by non transportation beneficiaries of navigation projects.
Airports and airways	The condition of airport and airway facilities rarely impedes traffic.	The number of available runways at the busiest airports is the greatest capacity constraint. The staffing levels and technological capabilites of certain airway sectors can be sources of delay.	Aircraft noise in communities surrounding airports; surface traffic congestion due to airports	Constructing new airports or physically expanding existing airports will be difficult for most immunities. Technology advances could effectively expand existing capacity by up to 20 percent.

SOURCE: Office of Technology Assessment, 1991.

small amounts to construct safety improvements at grade crossings and intermodal transfer facilities, where highway monies have been used for some construction. Services provided by both Amtrak and freight railroads help relieve road congestion in major metropolitan areas.

Federal Grant Programs-Existing categorical grant programs for highways, which require only a 10 percent match for Interstate highway construction and up to a 25 percent match for other types of projects, have made States target capital construction and Interstate projects in particular, even when these may not be their most pressing requirements. To ensure that States also increase their own funding and that Federal funds are used for projects that are local priorities, Congress could establish larger **and more uniform match requirements for grants. For example, if the State and local match were set at 70 percent for all projects, from Interstate highways and railroad improvements to mass transit and airports, local priorities would not be skewed by the availability of Federal money for capital construction or for one mode over another. A slightly higher Federal match could be made available for States with the fewest resources. Still** a further possibility is to recognize the level of effort expended by each State to fund public works programs. For a profile of State resources and expenditure levels, see table 1-5 again. Some economists suggest that significantly higher State match requirements should be accompanied by open-ended Federal grants to provide maximum leverage for State spending; however, such a program would be politically very difficult to shape.[21]

User Pays v. General Fund Subsidies

Many major capital projects could never be built without Federal support, but the wide variation in Federal support for transportation modes has meant that some projects have been constructed that will never bring adequate financial return on investment measured in strict economic terms. Some of these projects, especially mass transit, commuter rail, and intercity passenger rail, bring transportation system and other societal benefits that justify even greater public subsidies. However, users of heavily subsidized systems that have excess capacity, such as many ports and waterways, and those that provide premium service, such as peak-hour aviation and commuter expressways, could pay more of their own way.

A comparison of the transportation problems summarized in table 1-7 with the funding patterns in table 1-8 highlights the need for revising Federal transportation investment and program policies. One option is to raise waterway user fees, particularly for recreational boaters, who are not now subject to the Federal marine fuel tax. Imposing a Federal axle-weight tax on heavy trucks is an equitable way to recoup the costs these vehicles impose for highway maintenance and rehabilitation above the amount they pay in fuel taxes.[22] Other options include eliminating restrictions on highway tolls and other forms of user funding for public works constructed with Federal funds. Tax treatment of parking and mass transit subsidies for employees could be equalized.

A Federal transportation pricing policy reflecting the full spectrum of system costs would incorporate operating and maintenance costs, as well as calculation of pollution and other indirect costs. It would encourage higher capacity passenger transport operations, such as car pooling, mass transit, and commuter rail, and mechanisms to reduce total energy use and environmental damage.

Fuel Taxes-are the major source of Federal revenues for transportation. Ideally, raising the Federal gasoline tax would encourage higher vehicle occupancy and more efficient use of the highway system, help address traffic congestion and air pollution problems, and reduce the need to build new highways. However, politically the Nation does not seem ready to accept fuel tax hikes of the magnitude necessary to make these sorts of impacts. Slow, steady, annual increases are more acceptable politically than large, sporadic escalations, especially when coupled with plans to raise appropriations yearly. Furthermore, annual Federal fuel tax increases could assure States of a more reliable funding stream and enable them to do better long-range transportation planning. For example, a 4-cents per gallon increase in Federal motor fuels taxes could be followed by increases of 2 cents per

[21]Edward M. Gramlich, "Financing Infrastructure Investment: Should Money Be Thrown at the Third Deficit?" paper presented at the Conference on The Third Deficit: The Shortfall in Public Investment, sponsored by the Federal Reserve Bank of Boston, Harwich Port, MA, June 27-29, 1990, p. 5.

[22]Kenneth A. Small et al., *Road Work* (Washington, DC: The Brookings Institution, 1989), p. 21.

Table 1-8-Federal Expenditures and User-Fee Revenue for Transportation, 1988 and 1989

	Federal expenditures (in millions of dollars)		User-fee revenues[a]		Revenues as percent of expenditures	
	1988	1989	1988	1989	1988	1989
Highway	$14,424[b]	$13,898[b]	$14,288	$15,856	99%	11470
Transit	3,316'	3,595'	1 ,019[d]	1 ,017d	31	28
Rail	570"	594"	NA	NA	NA	NA
Aviation	5,192[1]	5,748[f]	3,189	3,664	61	64
Ports and waterways	1,3839	1,4369	203[h]	223[h]	15	16

a Does not include interest received on trust fund balances.
b Includes funds outlayed for Federal Highway Administration, National Highway Traffic Safety Administration, Forest service for forest roads and trolls, and Bureau of Indian Affairs for road construction.
c Includes capital and operating grants and limited research and development (R&D) spending.
d Revenue source is 1 -cent per gallon from motor fuel tax.
e Amtrak funding and limited Federal R&D spending.
f Does not include expenditures for National Aeronautics and Space Administration, National Transportation Safety Board, or Department of Transportation Office of the Secretary.
9 Corps of Engineers outlays for harbors waterways. Does not include Maritime Administration, Federal Maritime Commission, CoastGuard, or Panama Canal Company outlays.
h Includes Inland Waterway Trust Fund, Harbor Maintenance Trust Fund, and St. Lawrence seaway Tolls.

SOURCE: Office of Technology Assessment, 1991, based on U.S. Department of Transportation, Office of Economics, *Federal Transportation Financial Statistics, Fiscal Years 1979-1989* (Washington, DC: May 1990).

year until the **amount** dedicated to transportation doubles the current 14 cents.

Because user-pays policies can adversely affect some classes of users, Federal decisions about raising user fees may require complementary actions to ensure that transportation is available to all. For instance, if an axle weight or other special tax were enacted for heavy trucks, this should be considered when other surcharges affecting trucks are evaluated.

Trust Fund Balances

Regardless of other steps taken to equalize national transportation support, Congress will need to find a way to address the issue of the transportation trust fund balances. Set up to be reliable mechanisms for financing highways, mass transit, aviation, and ports and waterways, transportation trust funds currently have large balances that are constant irritants to State and local officials facing massive project backlogs. Simply stated, Federal budget problems have so restricted expenditures that trust fund revenues (user fees paid for transportation services) have substantially outpaced allocations for transportation programs. Congress took a step toward addressing this issue when it raised 1991 spending ceilings for transportation programs; highway appropriations for 1991, for example, are close to 20 percent higher than those for 1990. By sustaining Federal spending for transportation at a level above trust fund revenues, fund balances can be effectively eliminated over 4 or 5 years. However, the overall domestic spending limits set in the 1990 Omnibus Budget Reconciliation Act require transportation to compete with other domestic programs for increased dollars. Thus, continued controversy seems inevitable unless a new budget agreement is forged.

Spending Priorities

The biggest problems for transportation infrastructure are inadequate capacity in major metropolitan regions and substandard conditions in many facilities across the country. For the short term, the top priorities are to redirect Federal investment toward programs for maintaining, upgrading, and extending the lives of existing systems and for increasing system capacity through technologies and management techniques. Under some circumstances, capital construction may be the best option. Broadening categorical grant programs to per**mit** greater flexibility for State and local governments in using trust fund monies, especially **for maintenance programs, is probably the best way to ensure that short-term capacity and condition needs are met.**

Next in importance are reshaping Federal policies so that they encourage fair pricing and efficient infrastructure use and increase State and local spending, thus raising the total national investment. Making more Federal monies available for passenger and commuter rail and mass transit are options for improving the efficiency of transportation system use. Although commuter rail and transit have long been considered primarily regional or local services, a compelling case can be made for their importance to interstate commerce, since each represents an alternative way to increase highway capacity in urban areas. Congress could also permit States and jurisdictions to use surface transportation grant funds for mass transit and passenger and freight rail improvements, if doing so is a priority to their regional or State transportation system plans. Because Amtrak provides an invaluable alternative in heavily urbanized **regions that have crowded highways and airports, a portion of an increase in Federal surface trust fund monies could be allocated to Amtrak for capital expenditures to enhance rail service. Surface access improvements that smooth connections to ports and airports and intermodal connections and transfers are other potential projects. Traffic signal improvements using some of the advanced vehicle and highway technologies reviewed in chapter 3 could reduce surface traffic congestion somewhat in urban areas. For rural areas, special attention could be paid to the mobility and freight transport needs of small communities, where no alternatives exist to private vehicles.** Table 1-9 shows the trade-offs associated with the choices.

For the longer term, an intensive Federal effort should be started now aimed at developing and implementing a strategic policy and applied research agenda for transportation to evaluate the trade-offs of alternative ways of addressing overcrowded intercity corridors and urban traffic congestion. This program must have funding support and participation from all the transportation modal administrations and from the industries that will benefit.

Financing Environmental Public Works

As Federal support for environmental public works has declined and new environmental requirements have become effective, many local governments will be hard pressed to meet the costs of upgrading their systems (see box l-D). Costs will more than double for about 20 percent of small, rural systems and some older, urban areas, the very jurisdictions that are least attractive to private investment and are hardest hit by declining Federal funding.[26] Under these circumstances, such cities are likely to find the aggregate fiscal impacts of combined sewer overflow control, solid waste disposal, and hazardous waste requirements more than they can handle in the immediate future. Funding for programs to comply with the new standards will compete with higher costs for schools and mandated social programs.[27] Moreover, real interest costs for public infrastructure have more than tripled over the last two decades, creating a bias toward short-lived, lower cost alternatives, which may cost more over the long term.[28]

OTA concludes that EPA has not come to grips with the compliance issues likely to occur because of the fiscal impacts of multiple new requirements on public works providers. Furthermore, widespread noncompliance with the new regulations is likely, especially among small systems and the Nation's oldest and largest cities, unless State and Federal financial and technical assistance is increased.[29] Options for technical assistance include development and field demonstrations of new, durable, and cost-effective technology options for both small and large systems and development by EPA of guidelines, based on addressing the most serious health and safety problems first and staging those projects where no unreasonable health risk exists (see chapter 4 for further details). Such guidelines could be useful for EPA, States, and local jurisdictions alike for setting priorities to schedule compliance and avoid enforcement actions.

Dedicated Revenue

Federal budget constraints notwithstanding, OTA concludes that the costs of compliance will be so burdensome that a congressional effort to address the issue is warranted. Congress could consider establishing a dedicated source of Federal revenue to support State programs that assist localities in complying with EPA standards. The source could be a broad-based tax, such as a dedicated income tax surcharge, or a special-purpose fee, such as a carbon product or waste generator surcharge. If

[26] Policy Pltinning and Evaluation, Inc., "Municipal Sector Study: Impacts of Environmental Regulations on Municipalities," unpublished report prepared for the U.S. Environmental Protection Agency, September 1988, p. ii.

[27] Office of Technology Assessment, op. cit., footnote 6.

[28] According to estimates by the U.S. Army Corps Of Engineers, L. George Antle, chief, Navigation Division, Institute for Water Resources, U.S. Army Corps of Engineers, personal communication, July 20, 1990.

[29] Environmental Protection Agency officials consulted by OTA are concerned about potential noncompliance, but warn of the difficulty of making accurate predictions. One agency expert estimated that the number of jurisdictions in noncompliance might quadruple.

Table 1-9-Policy Choices for Transportation

Goal	Action	Trade-offs
Coordinate national transportation policies and treat transportation as a system.	Institutionalize "a multimodal system by restructuring the Department of Transportation (DOT). Consolidate policymaking along broad modal lines (aviation, surface, and water) or functional categories (metropolitan passenger and inter-city freight). Make commensurate changes to congressional committees.	Could reduce the number and extent of conflicting Federal policies and encourage decisions that address both competing and complementary aspects of transportation systems. *But* Structural change is difficult and can be disruptive in the short term. No guarantee of effectiveness.
	Transfer fiscal and management authority for water transportation from the Army Corps of Engineers to DOT.	Would consoilidate all civilian transportation authority within DOT. Problems in integrating Corps functions should disappear overtime. *But:* Water resources aspects must be considered.
Encourage proper maintenance and management of existing and future public infrastructure. improve condition and ensure longevity of systems.	Modify spending restrictions on Federal funds to favor maintenance over new construction, where appropriate; establish incentives for implementation of systematic maintenance programs.	Would encourage local authorities to give priority to maintenance. Using Federal funds for operations and maintenance, training, and supporting technologies could reduce total infrastructure costs over the longterm. *But* Does not address capacity issues.
	Give State and local authorities flexibie options for generating revenues for transportation.	Could elicit substantial funds from tolls on federally funded highways, passenger facility charges at airports, congestion pricing, direct charges for infrastructure wear. *But* Programs would require dose oversight to ensure that new charges are equitable and that the monies are invested in transportation.
Ensure that future transportation investments reflect economic and social needs but are cost-effective.	Link Federal General Fund payments for transportation more dosely to national transportation benefits and needs.	Would provide Federal incentives for more effident system use. But would require new revenue sources to keep aviation and water systems operating. Service for hardship communities depends on continued general subsidies.
	Tie Federal capital investment to long-term planning and financial support of system.	Should encourage transportation system construction appropriate to the financial resources of users and other non-Federal interests. *But* Requires State and regional planning and funding.
Reduce congestion and delay, and increase capacity.	Encourage physical expansion of infrastructure.	Could be a cost-effective option for increasing capacity. *But* Environmental concerns, land-use restrictions, and high capital costs limit this option. in congested areas, delay reductions maybe temporary as latent demand fills the new capacity.
	Support technology development and implementation to increase capacity of existing systems with technologies.	Can provide marginal (generaly less than 20 percent total) gains in infrastructure capacity. *But* in most cases, users would need to invest in new equipment.
	implement market policies that change transportation demand patterns, such as congestion pricing, access restrictions on low-occupancy vehicles, and eliminating tax bias in favor of parking lots and employee parking.	Could shift traffic to underused times and locations and carry the same passenger or cargo volume on fewer vehicles. *But* Complementary actions and Federal oversight to ensure affordable transportation options to all users would be necessary.

SOURCE: Office of Technology Assessment, 1991.

financial assistance is not feasible, a search for other solutions should be undertaken.

State Revolving Funds

Short-term options include expanding funding and functions for EPA's State Revolving Fund (SRI?) program. Rather than phasing out Federal contributions by 1994 as currently scheduled, Congress could double the remaining authorization to $7 billion and expand the programs eligible for funding from SRFs to include drinking water and solid waste management. Although both water supply and solid 'waste have traditionally been financed locally, the scale of investment needed to meet new standards is beyond the capacity of many communities and their State governments.

Planning and Training

OTA'S research also indicates that environmental public works planning for facilities and resource management is inadequate in most localities, and that many States and localities have difficulty attracting adequately trained personnel. Without a firmer commitment by States to planning and to implementing a coordinated land-use planning and capital budgeting requirement, local environmental problems are likely to worsen. Ensuring adequate and safe water supplies and providing wastewater treatment capacity in fast growing regions are among the types of issues that must be addressed. A Federal requirement for State funding support for planning and training is one option. If agreement is reached on a dedicated source of funds for environmental public works, a requirement for each State to use a certain percentage for these purposes could be included. Table 1-10 summarizes a variety of legislative options and their trade-offs.

Technologies and R&D—Making Public Works Work Better

Countless new technologies, such as system condition assessment and maintenance tools, communications, navigation, and information systems, and field construction techniques and better materials, have been developed in national laboratories, universities, and industry research departments. Many of them, with some adaptation, could help public works officials address both condition and capacity problems, do their jobs more productively, and make their systems operate more efficiently (see table 1-11). However, the technologies are often expensive to acquire, require expertise and special programs to implement and educating and training personnel to use them, and inevitably will bring new and unforeseen difficulties with them.

Despite the costs of purchasing and implementing new technologies, over the long term, they can play a major role in extending the lives of public works structures and provide substantial cost savings. For example, electronic control and data acquisition systems installed in water and sewer facilities permit operators in a central location to monitor remote flows and distribution system conditions in real time. Operators can use the electronic systems to optimize pumping operations and bring additional facilities online to avoid overloading the system and causing damage. (For further information, see box 4-D in chapter 4.)

Maintaining a Healthy Infrastructure

Although technology needs vary dramatically by public works category, common factors ensure healthy infrastructure across environmental services and transportation modes. The essential elements are rigorous approval standards from the outset of planning to the beginning of operations, regular inspection, quality workmanship and materials, preventive maintenance, and timely repairs. Meeting these requirements, even using current technologies, can save substantial sums of money; indeed, constructing quality facilities and maintaining them may provide the highest return on infrastructure investment.[27] If construction quality is poor and repairs are needed constantly, or if repairs to well-constructed facilities are postponed until major reconstruction is needed, the costs of providing alternate service or of traffic diversion and delays can equal the capital costs, doubling the total expense of a given project.

Calculations by the Army Corps of Engineers on the cost-effectiveness of maintaining and rehabilitating locks and dams indicate that regular maintenance and structural repair have effectively doubled the lifetimes of these large structures. "Barring a catastrophic event, these structures could last forever with good maintenance."[28]

Management Information and Communications Systems

Cost-effective public works management is based on accurate, current information about the location and condition of the basic infrastructure. Environmental public works managers need to know where the leaks are and must understand the contaminants in local drinking water, the contents of landfills, and the chemical components of industrial wastewater. State transportation officials must have similar information about highway and road systems and bridges, so they can plan and budget properly.

[27] U.S. Congress, Congressional Budget Office, op. cit., footnote 17, pp. 14-15.

[28] James E. McDonald, research civil engineer, Coastal Engineering Research Center, Waterways Experimental Station, U.S. Army Corps of Engineers, personal communication% Oct. 10,1989.

50X I-D—Small Towns and Big Public Works Problems

Rockspring, Texas, is a remote agricultural community (population 1,350) 80 miles north of the Mexican border.[1] The average per-capita income of residents is under $6,000, and the city's annual budget is $221,000. How to provide wastewater treatment and solid waste disposal facilities that meet new Federal standards are pressing dilemmas for Rocksprings.

Rocksprings has no community wastewater collection and treatment system, and residents are trying to finance a $3.5-million wastewater treatment plant to meet State and Federa1 requirements. The city applied for a $2-million wastewater treatment plant construction grant (representing 55 percent of the project's costs) from the U.S. Environmental Protection Agency (EPA). The rest of the $3.5 million would be financed with a Farmers Home Administration (FmHA) grant for 20 percent of the remaining costs, and an FmHA loan for the balance. However, FmHA will not anounce grant and 1oan recipients until after the EPA decision is made. If Rocksprings does not receive the FmHA funds, it will not be able to proceed with the project and will have to return the EPA grant money. Worse, the city will have spent $43,000 on preliminary engineering work and will have no source of funds to pay the bill. The alternative to constructing a major wastewater treatment facility would be to continue to permit individual treatment systems, but require upgrading to meet State standards at a cost to each homeowner of $12,000 to $15,000-more than the value of the average Rocksprings house.

Since 1931, Rocksprings has maintained a landfill just inside the city limits where waste material is burned weekly and the remaining garbage covered with dirt whenever possible. These procedures became illegal in September 1989, when Texas terminated all burning permits. Because of its unusual geology--solid rock 1,500 to 2,500 -above sea level-the city does not have enough dirt to cover the waste, and if it complies with the order not to burn, its landfill will be little more than an open dump-equally illegal. The town does not have enough garbage to incinerate efficiently or to recycle in saleable quantities, nor are private companies available to provide disposal service. The area's Council of Governments is trying to develop a regional plan, but the great distances between cities, and differing standards between communities make this solution unlikely.

[1]Material on Rocksprings from Mary Simone, mayor, Rocksprings, Texas, at OTA Workshop on State and Local Infrastructure Financing and Management, July 7,1989.

However, since many infrastructure systems are old and were constructed in sections over long periods of time, much of this data must be collected and stored now. Many factors complicate the collection of good data about infrastructure condition, including the sheer size of many large systems, the fragmentation of management responsibilities, and inadequate personnel and technical expertise in many jurisdictions.

Technologies to acquire, sort, file, store, and analyze condition assessment information include robotics and television for remote and long-distance scanning, photologging and computer imaging of the results, and management information and communications systems. A host of nondestructive evaluation technologies can provide information about system condition, and when tied to computerized management information systems, permit targeting repairs, maintenance, and reconstruction to areas of greatest need. (See chapter 5 for further details.) Managers find these management tools invaluable; indeed recent calculations indicate that 40 percent[32] of State capital budgets are spent on information and communications technologies.[33] Yet few Federal grant programs directed at public works permit monies to be used for purchase of hardware and technology equipment.

Field Construction

Field construction and rehabilitation techniques, such as casting large segments of a facility near the site, then placing them at night so as to minimize disruption of normal service, are usually developed on a project-specific basis, often by the contractor. Public sector research into this vital segment of public works is almost nonexistent, and industry expenditures, estimated at less than 0.3 percent of

[32]This does not include construction; the figure falls to 25 percent of capital equipment expenditures when construction costs are incorporated.

[33]Bradley S. Dugger, "Technology as a Management Tool," unpublished remarks, Governor's Infrastructure Conference: Managing for Environmental Quality, Nashville, Tennessee, Jan. 17, 1991.

Rocksprings could solve the problem by unincorporating. State law mandates that all counties with a population of 30,000 or more and all cities, no matter how small, must provide for the disposal of solid waste within their jurisdictions. Because Rocksprings' county has fewer than 30,000 people, the city could un incorporate, close its landfill, and be in compliance with State regulations. However, the cost of closing the landfill is $400,000, almost double the city's annual budget. Rocksprings is a stunning example of the dilemmas associated with establishing appropriate national environmental standards.

Ionia, **Michigan,** a rural community of 6,000 located midway between Grand Rapids and Lansing, was served by two rail lines until about 10 years ago. However in the early 1980s the Grand Trunk Western Line sold out to its competitor, Central Michigan Railway (CMR), and now local officials and businesses are fighting to retain the one remaining line and the two trains a day that connect Ionia to Owosso, a regional center 41 miles to the east. Last year CMR, a small class III railroad petitioned the Interstate Commerce Commis sion (ICC) for permission to abandon the segment of track connecting Ionia to Owosso, including six stations along the way. The railroad claims the line's high operating costs and low projected revenues make service uneconomic and that local businesses can ship by truck; when the company offered to sell the line to the State on a leaseback basis, the State declined.

Ionia and its surrounding townships boast close to 1,000 industrial jobs. Local industries produce tires and automotive components on a contract basis for major automobile manufacturers, most of whom require their contract suppliers to have access to rail service as an option to truck transport-"no rail; no contracts." Owners of the lumber companies, the fertilizer plant, and grain elevator claim they cannot switch to truck transport because specialized trucks and equipment needed to handle their products are not available locally.[2] Many of the town's jobs could be lost and the prospects for modest growth in the region changed dramatically by the proposed abandonment;[3] towns east of Ionia fear the proposed abandonment would eventually cut off their rail service.

Local governments are already borrowing to finance a regional wastewater treatment plant, and while the area's business community has formed an alliance to fight abandonment, they cannot afford to buy the line. The region's economy is currently too good for it to qualify for hardship aid from Federal or State sources, because several State corrections facilities in Ionia provide stable service jobs. Civic leaders do not know whereto turn for help.

[2] James Mooney, president Of the Kent, Ionia & Clinton Rail Association, statement prepared for the Interstate Commerce Commission, June 11,1990,

[3] Ruth Hewitt, executive director, Ionia Chamber of Commerce, personal communication, Aug. 14,1990.

gross annual sales in 1987, have continued to drop.[31] Keeping any facility operating in as close to normal a manner as possible during repair is a top priority for public works officials. Consequently, more systematic attention to techniques for in situ work is warranted in public sector research programs.

Materials

Materials selection, both for new construction and for rehabilitation, can make a major difference in long-term facility condition and costs, if adequate corrosion protection is ensured. Corrosion problems affect both concrete and steel, the two most commonly used construction materials. Attention to corrosion in the design, materials selection, and construction phases of a project and investment in protection up front at small additional cost can save millions of dollars in repair and maintenance costs.[32] Using cathodic protection and protective coatings and controlling stray electrical currents help prevent corrosion and prolong lives of public works structures. (For further information, see chapter 5.)

Preliminary results from the Strategic Highway Research Program (SHRP) indicate that paving materials perform differently in diverse parts of the country, and assumptions about the long-term performance of many concrete and asphalt pavement additives are premature (for further details, see chapter 5). Research on the effect of tire wear on highway pavement life is ongoing, and before conclusions are reached about changing truck weight limits, the long-term effects of different tire configurations and truck weights on pavement must be analyzed. Economists have begun to note the

[31] 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 Program and the Energy and Materials Program, June 1987, p. 1-11.

[32] National Bureau of Standards, *Economic Effects of Metallic Corrosion in the United States: A Report to Congress by the National Bureau of Standards, NBS* Special Publication 511-1, SD Stock No. SN-003-003-01926-7 (Washington DC: 1985).

Table I-l O-Options for Federal Environmental Public Works Policies

Goal	Action	Trade-offs
Increase national investment and assist communities in meeting costs of complylng with Federal environmental public works standards.	Extend and fully fund SRF (State Revolving Loan Fund) authorization past 1994 (current expiration date).	Helps States meet local needs, provide expected ands, and ease planning. But: Requires additional Federal outlays. These could be raised by new broad-based or special-purpose taxes.
	Amend Clean Water Act or enact other legislation to expand SRF project eligibility to drinking water and solid and hazardous waste facilities; increase appropriations.	Increases local access to funds for facilities required by new Safe Drinking Water Act, wastewater treatment and solid waste regulations; could build on existing SRF program structure. *But:* Requires more outlays and intervention into area of traditional local government and private sector control.
	Increase State match to leverage more State investment.	Encourages larger State commitment; gives incentives for better State program management. But Poor States may be unable to meet higher match; may discourage program participation.
	Develop and implement a risk management approach for environmental public works to guide enforcement, and permit local immunities to address most serious risks first.	Makes local compliance more likely because communities can adapt solutions to local needs and renditions. *But* Success depends on local risk assessment and planning, and availability of State supervision and technical assistance.
	Earmark a Federal revenue source for financing environmental public works-a share of an existing tax or a new tax (e.g., carbon or other product related to environmental pollution).	Ensures financing for resolving long-term environmental problems that are not suitable for annual budgeting. But Reduces Federal flexibility by earmarking funds.
	Combine Federal community environmental loans and grants into a State block grant program administered by EPA.	Increases efficiency by combining administration of programs now scattered throughout agencies; reduces Federal administration of detailed project requirements and cuts local costs. *But:* Adds responsibility for EPA, which is already over burdened. Eliminates most Federal control over spending; agencies often resist losing programs.
	Establish Federal bond guarantee program for small communities for environmental facilities.	Provides many communities with access to private credit market; limits Federal role. *But:* Program costs due to defaults hard to estimate; requires new administrative entity.
Encourage greater use of technologies to bolster efficient operation of facilities.	Combine scattered Federal technical assistance efforts and form an Environmental Technical Assistance Program, administered by the States.	Fills a pressing need for engineering, planning, and financing expertise, especiallyamong small communities; cost-effective.
	Provide financial incentives or regulatory requirements that communities initiate and adhere to facility maintenance programs and provide additional funds for facility planning in conjunction with regional planning organizations.	Increases efficiency and performance by encouraging maintenance and attention to life-cycle costs. Efficiency gains from planning environmental facilities on a regional basis.
Use market Incentives in addition to regulations to address environmental problems.	Impose charges or taxes on pollutants to discourage use and to raise revenue (e.g., taxes on carbon products or waste generation).	Offers alternatives to achieve environmental goals more flexibly and at lower cost than traditional regulations; a logical extension of the polluter pays philosophy. *But:* Unpopular with the producers and users.
	Reward local effort to impose user fees that cover full cost of service as a means of financing facilities and limiting demand.	Addresses current undercharging for environmental services. (EPA requires full cost fees for wastewater facility loans program.) *But:* Provisions would need to be made for low-income users.
Encourage EPA to develop risk management guidelines for public works and systems approach to environmental and health issues.	Develop policy statement for Inclusion in pending legislation to elevate EPA to Cabinet status.	Gives EPA a clear legislative directive to evaluate enforcement priorities for public entities and to pursue cross-media regulatory programs, research, and planning, with potential to break down program barriers and reduce conflicts. But: Media-segmented bias will be hard to change; no guarantee of success.

SOURCE: Office of Technology Assessment, 1991.

Table 1-1 l—Technology Priorities for R&D for Maintaining Infrastructure Condition

Technology	Uses	Status	Comments
Nondestructive evaluation equipment; sensing and measurement	Measure various physical properties for monitoring and control; examine physical or mechanical properties of equipment or structure without affecting it permanently.	Developed for industrial use; public works market is secondary for many suppliers, often tied to preventive maintenance programs and automated inspection systems.	Many private sector users; cost and expert interpretation of results limit local government use; harsh public works environment and cost of high-tech equipment are limiting factors. *Most useful for highways and bridges, ports and waterways, water, wastewater treatment, rail systems.*
Information and decision systems	Providesdatabaseorganization and manipulation capabilities for the wide range of data and information needed for public works management.	Many database systems are readily available.	Cost and technical capabilities are limiting factors; value of good data is difficult to evaluate. *Useful for highways and bridges, transit, rail, water, wastewater treatment, solid waste.*
Communications and positioning systems	Traffic management and control and remote infrastructure monitoring.	Technology exists for nearly every need; private sector use is increas-ing. Well established in aviation; crucial to future air traffic enhancement.	Microprocessor improvements have increased reliability and performance and lowered costs. Great potential in all fields. *Most useful for ports, water, air, highways.*
Field construction technologies	Improve ease and speed of construction or minimize disruption in developed areas.	Numerous technical opportunities.	Industry is slow to adopt new methods; some methods require new technical skills. *Useful for highways, transit, rail, water, wastewater systems, solid waste disposal.*
Materials and corrosion prevention	Improve durability and resistance to operating stress and protect against premature deterioration and failure.	Many new materials and techniques have been tested and applied; their use and use of corrosion prevention is increasing but still is not widespread.	Industry is slow to adopt new materials and methods; designers are reluctant to consider approaches that are not well established. *Useful for highways and bridges, ports and waterways, water, wastewater treatment systems, solid waste.*

SOURCE: Office of Technology Assessment, 1991.

importance of materials and to calculate user charges that could offset the costs of thicker, more durable pavements, for example.[36]

The key for policymakers in making technology-based decisions is to remember that any technology change must be accompanied by the appropriate policy change, or the benefits may not be realized. Furthermore, changes in operations by any industry segment, such as airlines or the trucking industry, to optimize its operations within a new policy and technology framework may alter the long-term impacts of any new technology-based standards and policies. Federal and State decision-makers would do well to keep in mind the need to revisit policies on a regular basis because of the dynamic nature of the way public works services are used.

Technologies To Increase Capacity

While the poor condition of the physical system is the dominant problem for public works in many urban and most rural areas, highways, airports, and wastewater treatment systems in large, urban jurisdictions also have capacity problems. These manifest themselves in restrictions on development and in traffic congestion and delay. Perhaps the most difficult aspect of capacity problems is that technology can make relatively little long-term impact, increasing capacity by between 10 and 20 percent at most. In many cases, any capacity created by new technology is likely to be consumed immediately by users who had been finding other means of meeting their needs. The policy and political decisions to manage or shift demand, which must accompany technologies to ensure adequate capacity, are far more problematic.

[36] Clifford Winston, The Brookings Institution, "The Case for Efficient Infrastructure Policy," paperpresentedat the Conference on The Third Deficit: The Shortfall in Public Investment, sponsored by the Federal Reserve Bank of Boston, Harwich Port, MA, June 27-29,1990.

Photo credit: American Society of Civil Engineers

Attention to corrosion protection in the design, materials selection, and construction phases of a project can save millions of dollars in maintenance and repair costs-and help ensure safer infrastructure.

Environmental Public Works Capacity

For environmental public works, the most promising technologies to address capacity issues are those that detect leaks and permit repair without disrupting service, those that can prevent water loss to evaporation, and those that reduce demand. Among technologies applicable to these needs are a variety of trenchless technologies (see chapter 5); low flush toilets; dual water supplies that provide separate household and outside water; and recycling, reuse, and source reduction for municipal solid waste.

Although available now, most of these technologies are not in widespread use, because Federal and State public policy decisions that would make them cost-effective options have not yet been taken. Policy tools include full cost of service pricing, with appropriate consideration of ability to pay, and a

Photo credit: American Society of Civil Engineers

As water shortages of the magnitude now felt in southern California become more widespread, conservation is likely to become a more attractive choice.

larger commitment to resource conservation in all user segments. If water shortages of the magnitude now felt in southern California become more widespread and the cost of new technology-based facilities increases (desalinization is again under discussion in California), conservation is likely to become a more attractive choice, and the technologies will be understood as being cost-effective.

Transportation System Capacity

Technologies that can increase transportation system capacity, such as radar, improved traffic flow procedures and signal equipment, computers, and electronic communications systems, are available for waterways, mass transit, and highways, but are not yet widely used, except in aviation. Moreover, the expansion possibilities they offer (20 percent at most) are not likely to be large enough to meet demand for long in fast growing regions. **Nonetheless, the short-term benefits in reducing congestion make improving traffic flow a top priority.**

Where construction of larger facilities is impossible, planning and land-use controls and pricing or other incentives to shift demand will also be required to cope with the expected growth in both highway and air travel. While substantial investment in system analysis, equipment, and personnel training will be necessary, these costs will be offset by reducing the need for acquisition of expensive, additional land and construction. Some intermodal technologies are under research in the private sector, but the work does not address the broader needs of a national transportation system.

Technology Priorities

Safety and public health concerns and the impact of a major facility, such as a large, new harbor development project, on land transportation, on the environment, and on community life are major issues that affect public works. The technologies offering the most potential for shedding light on these and other complex public works problems are management information and condition assessment tools, maintenance-related technologies, and techniques for increasing capacity where new construction is not feasible. **OTA concludes that these are top priorities for immediate attention as Congress considers how to reshape infrastructure programs.** As a practical first step, Federal grant programs could be expanded to permit the purchase of management equipment, including hardware and software. However, without investment in complementary programs (now missing in almost every public works program) to ensure a sufficiently prepared work force, no technology will fulfill its potential role. Any changes to Federal programs must take these indispensable adjuncts into consideration.

Education and Training

Technologies are useless without an adequately educated and trained work force to manage, operate, and maintain them, and the scarcity of trained public works managers and technicians was a recurrent theme throughout the course of this study. Managers and officials hold that the public works sector is losing its best-trained people to the private sector, with its higher salaries, and to retirement much faster than they can be replaced. Moreover, new technologies often require skills that are not taught in vocational or high schools, and in some cases, not even in universities. In fact, most university civil engineering departments, the training grounds for many public works managers, do not teach courses in nondestructive evaluation or maintenance management, which will eventually be basic tools for public works departments. Every level of government needs to give more attention to these problems. The Federal Government could target funds to support university research for public works to attract students back to civil engineering. Federal programs that support university engineering programs (such as that of DOT's University Centers) could require courses in maintenance management and capacity enhancing technologies and management technique.

States, too, can play larger roles through their universities and public works agencies. To cite one model, Tennessee uses the University of Tennessee, a land-grant school, as an effective public works technology-sharing arm for its local governments.[34]

Technology Management in the Public Works Arena

Exciting as new technologies are, **OTA concludes that better system management and making good use of existing technologies can also help public works managers improve the efficiency and productivity of their operations.** For instance, the procurement processes used by public agencies at all levels of government are generally rigid and inflexible. Developed over time to ensure honesty and fairness, they have become very effective barriers to adoption of new products and procedures. The low-bid procurement process does not always ensure the most cost-effective or highest quality purchase, especially if prequalification requirements are lax. Federal grant requirements need to be reexamined and reshaped to encourage public officials to make greater use of procurement approaches, such as competitive negotiations and concurrent design-build, which have proven successful for private projects. States may need to revise their requirements as well. (For further details, see chapter 5.)

Operational Testing and Demonstration

Public works services are expected to be reasonably priced and reliable; they do not lend themselves to trial-and-error methods of selection. heal officials use tried and true technologies, because they do not have the analytical resources to assure the performance of a new technology and cannot afford the political or operational risk of failure. Thus, liability concerns haunt suppliers, manufacturers, and public officials as well, and manifold difficulties confront the developer of a new technology for public works. Many a technology entrepreneur is frustrated by rejection of numerous attempts to have

[34]Thomas A. Ballard, assistant vice president, Institute for Public Service, University of Tennessee, personal communication, Jan. 17, 1991.

Table I-12—Environmental Protection Agency Laboratories

Office	Number of laboratories	Number of staff	1989 budget (in miliions 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.

a development tested so a track record can be established.

Cooperative, joint efforts between private sector suppliers and government to demonstrate and evaluate new technologies for safety, durability, and long-term costs are excellent ways to spread the risk and overcome some of the difficulties of the procurement process for new technologies. OTA concludes that supporting such development and evaluation programs is an essential Federal function that has been inadequately supported in every public works field except aviation and water transportation. Increasing DOT investment in such programs for highways, mass transit, and passenger rail by 50 percent and doubling or tripling EPA's spending would bring substantial returns in improved public works performance. SHRP's cooperative approach provides a model.

Public works R&D—Almost an Oxymoron

Although the total dollars spent by the Federal Government on research for public works are substantial, a closer look reveals that some areas have been grossly neglected. Federal R&D has always targeted specific problems identified by the funding agency; consequently, research in federally funded laboratories and institutions is oriented toward the concerns of the sponsor and usually involves numerous, disparate projects. For example, the Department of Defense has supported development of artificial intelligence systems for defense purposes, and the Corps of Engineers has done a great deal of work on maintenance for waterways. (See chapter 6 for further details.) EPA research laboratories each focus on providing technical support for apart of the regulatory process (see table 1-12); even the technology demonstration programs do not target the needs of public works providers (see chapter 4 for further details). Finally, each DOT agency funds studies to carry out its mission (as shown in table 1-13). No agency has focused on R&D programs to make public works services more cost-effective and productive.

Moreover, State and local public works officials, those who stand to benefit most from the results of Federal R&D, do not utilize research products until they have been through a long process of development, evaluation, and modification. This length of time and the lack of investment in technology development and evaluation have made public works an unattractive target market for both public and private research facilities, leaving large gaps.

The Federal Role

The Federal Government is the one entity with sufficient scope and resources to fund additional public works R&D, an especially important role for it to fill since State and local governments are the primary service providers. However, Federal investment in R&D to address the condition and capacity problems faced by public works providers across the country is inadequate. Commitment of substantial additional Federal resources for R&D is called for, **with the focus on both immediate problems and long-term alternatives.**

Some additional funding could be provided by private sector beneficiaries through assessment programs. Care is needed, however, when pursuing private funding for R&D, and private funds can never substitute completely for public support. The R&D agendas for private entities are different than those of public agencies, and finding the appropriate ways to capitalize on private sector interest and resources without skewing public goals presents a challenge.

Furthermore, to enable even small jurisdictions to benefit from R&D results, technology transfer and technical assistance efforts must be stepped up. To increase financing for **R&D, Congress could require that recipients set aside a percentage of Federal grant monies to be used for R&D into**

Table l-13—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]	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	115[b]	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	*$444*[c]		

a Total funds for the Highway planning and Research (HP&R) Program are about $153 million, most of which is used for planning. The portion used for research 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 Transmutation Systems Center, and the U.S. Department of Transportation.

technologies, with an emphasis on those applicable to maintenance. Resources are also needed for long-term planning (with a stipulation that plans be based on a system needs analysis and tied to a capital budget), and for technical assistance, education, and training. The amount of Federal money currently available for environmental public works projects is too small to provide for any of these priorities. If a decision is made not to increase Federal environmental grants, special attention to these needs is warranted during the next legislative authorization cycle.

Large, Complex Systems Research

A closer look at the research programs of EPA and DOT highlights the woeful neglect of data collection and systems-level research for public works problems, especially on the impacts of transportation on the environment. These are important subjects for Federal attention, and Congress could consider requiring both DOT and EPA to develop and implement comprehensive system data collection and research programs. Because transportation and environmental problems are so tightly interconnected by government planning and land-use requirements, the two agencies could also be asked to develop and fund jointly an interagency research program through the Volpe National Transportation Systems Center and one of EPA's existing laboratories.

Some efforts to integrate research are currently under way in both agencies. Rigorous top-level review of long-range research plans developed by sections of each agency is called for to ensure that new goals encompass more than a reshuffling of existing research and address top-priority current problems. A broad-based outside advisory committee including State and local government and industry officials could be formed to review any interagency programs.

R&D for Environmental Public Works

Over the long term, EPA could develop and implement a comprehensive, strategic approach to setting standards and facilitating compliance, based on addressing the most serious risks first. A vigorous research, development, and technology transfer program is needed into alternative technologies for meeting standards, particularly for small systems, where there is "no unreasonable risk to health."[35]

Transportation R&D

Transportation R&D has its own noteworthy shortcomings. First, with the exception of some DOT programs under FAA and FHWA sponsorship, only limited Federal investment has been made in research into alternatives to existing technologies. Field construction and maintenance techniques, high-speed trains of several types, and longer lasting surfaces for highways are among the many possible technology alternatives already available in other countries. However, evaluating the case for a major shift to a new technology, intelligent highways, tiltrotor aircraft, or magnetic levitation rail for example, requires strategic planning for technology development and careful thought as to the appropriate Federal role, if any. Such a change in a substantial part of an already large transportation system would require commitment of Federal funds and consideration of how to tie new infrastructure facilities in with existing system components. Such tasks cannot be undertaken quickly or lightly (or cheaply).

It is time for Federal officials to think seriously about the best ways to capitalize on technology options for addressing public works problems and develop research and action programs. When alternatives become essential in this country, the United States may find it cost-effective to purchase foreign technologies and adapt them to domestic needs. The long-term costs and trade implications of R&D policy decisions could be very large and seem to warrant a greater investment now in R&D.

Huge discrepancies characterize R&D funding among the DOT agencies; FAA and FHWA have the only research budgets worth mentioning. FAA's R&D appropriations have held steady because modernizing air traffic control equipment has been a top Federal priority, and most of the agency's expenditures have been for that purpose. The agency has a well-structured R&D program that is regularly reviewed by an outside advisory committee.

Although the FHWA research budget looks large, a closer look shows that most of the funds come out of the Highway Trust Fund and are funneled through the States via the Highway Planning and Research (HP&R) Program. State DOTS use HP&R funds primarily for a variety of planning analysis and evaluation projects; a tiny amount of incremental R&D and some demonstration programs also benefit from these funds in some States.

Finally, much more must be done in the area of transportation systems research. R&D expertise is narrowly focused in the modal areas. The FAA R&D program and perhaps SHRP (for highway research) are two efforts that are somewhat more systems-oriented than any others. However, SHRP reflects the concerns about pavement durability of the highway engineers who developed the program, and does not address traffic engineering, construction, or other crucial highway performance issues. A truly strategic program would need to incorporate exactly such items and address intermodal issues as well.

Using Federal Resources Efficiently

Considerable duplication of research into common public works problems exists in Federal agencies. For example, the Corps of Engineers has major pavement test facilities and scale models and computer programs that address water scour and erosion problems of the types that concern FHWA engineers. Under ideal conditions, these could supplement FHWA's much less extensive facilities. However, OTA found that with few exceptions, if an agency such as FHWA requests another entity, such as the Corps, to undertake R&D, the requesting agency ends up dissatisfied, regardless of the quality of the technical expertise and facilities, because its research is given low priority. The requesting agency often finds itself with project results that are late and over budget. To stretch Federal dollars, Congress could require Federal operating agencies to develop better mechanisms to avoid duplication and to coordinate and carry out cooperative research. Including as part of an agency's formal mission the responsibility to carry out R&D **for other agencies is one way to do this. No matter what coordinating method is chosen, ensuring stable funding by the requesting agency for a project is a priority.**

[35] The Safe Drinking Water Act, in Sections 1415 and 1416, allows for such alternatives. David Schnare, Office of Drinking Water, U.S. Environmental Protection Agency, personal communication, July 15, 1990.

CHAPTER 2

Institutional Framework

Photo credit: Dan Broun, OTA Staff

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CHAPTER 2

Institutional Framework

. . . it is very hard to get your hands on this interface between transportation policy and environmental policy. ..1

Public works stakeholders include individual citizens, public officials, and politicians at every level of government; congressional committees, at least five major Federal agencies; environmental organizations; and industry, trade, and professional groups of every stripe. Their number and diversity make developing a coherent framework for either transportation or environmental public works seem an unattainable dream.

Moreover, the task of coordinating transportation and environmental concerns to address their combined impacts on lifestyles and economic vitality is clearly staggeringly difficult. The year-long process initiated by Transportation Secretary Samuel K. Skinner in 1989 of developing a national transportation policy[2] did create fresh dialog about issues between transportation interest groups, such as the automobile and highway lobbies and mass transit agencies, which had traditionally clung to their individual views. Discussion of elevating the Environmental Protection Agency (EPA) to Cabinet status could provide an opportunity for the same type of dialog about environmental public works issues. This chapter describes the actors and the setting for the complex theater of public works policy development.

Federal Role

Federal authority for public works—roads and bridges, mass transportation, ports and airports, waterways and water supply, wastewater treatment and solid waste disposal-has been evolving since shortly after the Nation was born, when a body of national engineers was formed. (See table 2-1 for Federal legislative benchmarks.) Responsibility is now distributed, often with considerable overlap and conflicting missions rooted in history, among a number of departments and agencies. The major players are the Department of Transportation (DOT), EPA, the Department of Defense, through the Army Corps of Engineers (Corps), the Bureau of Reclamation (BuRec) in the Department of the Interior, and the Soil Conservation Service in the Department of Agriculture. Some of these agencies issue regulations with which State and local officials must comply; others have tiding, programmatic, or operating functions; still others have all or some combination of these responsibilities. Other executive branch agencies also have an impact, and courts play a role as well. Congress shapes policies and programs through the legislative authorization and appropriations processes and regulatory mandates.

Many of the Federal entities responsible for managing the Nation's vast collection of public works infrastructure have recently experienced or are about to undergo major shills in their missions—from development and growth to management and preservation. This fundamental change is evident at the Corps, which is undertaking more environmental restoration projects than flood control projects, and BuRec, which announced in 1987 that it would no longer be a construction-oriented organization and would become a water resources management agency.[3]

The Federal role shifted in other ways, too, in the 1980s, with the transfer of a number of programs to the States and reductions in Federal support for most types of infrastructure (see table 2-2). For example, EPA's construction grant program for wastewater treatment plants is scheduled to end in 1994, with the States slated to takeover responsibility.[4] At DOT, as the Interstate highway system nears completion and

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[1] J. Craig potter, former Assistant Administrator fo, Air and Radiation, U.S. Environmental Protection Agency, in National Transportation Policy Alternatives, *Proceedings of a CRS Congressional Seminar* (Washington, *DC: Congressional* Research Service, June 12, 1990), p. 25.

[2] The process culminated in the release of the first national transportation policy and strategies document. See U.S. Department of Transportation *Moving America: New Directions, New Opportunities (Washington DC:* February 1990).

[3] U.S. Department of the Interior, Bureau of Reclamation, *Assessment '87, New Directions for the Bureau of Reclamation* (Washington, *DC:* U.S. Department of the Interior, September 1987), pp. 1-2.

[4] For further discussion, see U.S. Congress, Office of Technology Assessment, *Rebuilding the Foundations: A Special Report on State and Local Public Works Financing and Management,* OTA-SET-447 (Washington, DC: U.S. Government Printing Office, March 1990), chs. 2 and 3.

Table 2-l—Public Works Legislation Landmarks

1824	Rivers and Harbors Act authorized the Army Corps of Engineers to improve navigation by clearing channels and constructing harbors.
1850	Federal land grants to the Illinois Central-Mobile Ohio Railroads allowed the companies to expand westward. This was the first of massive grants to railroads seeking to reach the Pacific.
1887	Interstate Commerce Commission (ICC) established with limited authority to set rail rates. Legislation passed in 1903, 1906, and 1910 strengthened ICC'S regulatory powers.
1916	Federel-Aid Road Act authorized grants to States from the general treasury, through the Department of Agriculture, to help construct postal roads.
1925	AirMall Act authorized the Post Office Department to contract for air mail service with private operators. The 1926 Air Commerce Act gave aviation regulation authority to the Department of Commerce.
1938	Civil Aeronautics Act created the Civil Aeronautics Authority.
1941	Defense HighwayAct appropriated $200 million for the construction and rehabilitation of roads needed for the national defense, including access roads to military and defense industry sites.
1944	Federal-Aid Highway Act authorized the construction and building of a secondary and urban system of roads. The act also designated a national system of Interstate highways.
1946	Federal Airport Act initiated Federal financial assistance to States and municipalities for aviation.
1956	Federal-Aid Highway Act and Highway Revenue Act authorized completion of the Interstate system. The acts also established the Federal Highway Trust Fund to finance improvements in Federal-aid system roads. Truck weight and size limits were also set for Federal-aid roads.
1963	Clean Air Act asserted Federal interest in controlling air pollution.
1964	Urban Mass Transportation Act established the Urban Mass Transportation Administration (UMTA) within the Department of Housing and Urban Development. In 1968, UMTA was placed under the jurisdiction of the Department of Transportation (DOT).
1966	Department of Transportation Act created DOT from 35 transportation-related programs.

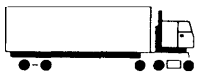
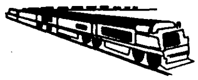
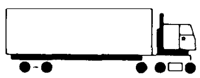
Continued *on next page*

Table 2-l—Public Works Legislation Landmarks-Continued

1967	Clean Air Act amendments authorized Federal standards and enforcement.
1969	National Environmental Policy Act required impact statements on all major Federal actions.
1970	Environmental Protection Agency (EPA) formed to administer numerous media programs.
	Airport and Airway Development Act expanded Federal support and established the Airport and Airways Trust Fund.
1971	Amtrak formed as a Federal corporation to provide passenger service. In 1973, the Regional Rail Reorganization Act established the Consolidated Rail Corporation (Conrail) for freight service.
1972	Water Pollution Control Act (Clean Water Act) set minimum wastewater treatment standards and established construction grants.
1973	Federal-Aid Highway Act increased the federally funded portion of transit capital projects and allowed expenditure of Federal-Aid Urban Systems highway funds for qualifying transit projects.
1974	Safe Drinking Water Act set standards for water quality.
	Mass Transportation Assistance Act expanded Federal support for transit.
1976	Resource Conservation and Recovery Act (RCRA) supported recycling and discouraged landfills.
1977	Clean Air Act Amendments strengthened EPA enforcement.
1978	Airline Deregulation Act abolished the Civil Aeronautics Board and its authority over domestic fares and mergers,
1980	Staggers Rail Act deregulated rail with the goal of improving the economic health of the railroads.

Continued on next page

Table 2-1—Public Works Legislation Landmarks-Continued

1980		Motor Carrier Act deregulated the trucking industry.
1981		Northeast Rail Service Act required DOT to look at ways to return Conrail to the private sector and to sell it if it achieved profitability. It was sold in 1987.
1982		Surface Transportation Assistance Act (STAA) boosted the gas tax, giving 1 cent to a Mass Transit Trust Fund. Truck weight and size limits were also raised, forcing States to permit all trucks meeting size standards to operate on Federal-aid roads.
1984		Hazardous and Solid Waste Amendments of the RCRA targeted hazardous waste management.
1986		Safe Drinking Water Amendments strengthened Federal requirements.
1987		Surface Transportation and Uniform Relocation Assistance Act provided the necessary funds to complete the Interstate system.
		Clean Water Act Amendments required that wastewater construction grants be phased out by 1991 and replaced until 1994 by capitalization grants to State Revolving Loan Funds.
1990		Clean Air Act reauthorization with additional controls on autos, buses, and trucks.

SOURCE: Office of Technology Assessment, 1991.

Table 2-2—Federal Infrastructure Expenditures, 1980-89
(in millions of 1982 adjusted dollars)

	1980	1982	1984	1986	1988	1989
Total	$29,863	$24,473	$24,425	$26,237	$24,328	$23,609
Transportation:						
Highways	10,584	8,284	10,438	12,934	12,188	11,392
Mass transit	3,732	3,930	3,639	3,007	2,754	2,838
Rail	3,531	2,199	1,405	798[a]	486	483
Aviation	4,334	3,526	4,145	4,722	5,048	5,378
Ports, harbors, and waterways	1,365	1,242	1,262	1,046	1,140	1,137
Environmental;						
Water supply	1,017	1,033	700	650	573[b]	284[b]
Wastewater	5,300	4,259	2,836	3,080	2,139	2,097

[a]Drop in expenditure reflects sale of Conrail.

[b]Low spending figures for water supply in 1988 and 1988 reflect repayments of Farmer's Home Administration water supply loans.

SOURCE: Office of Technology Assessment, 1991, based on Congressional Budget Office estimates from the Budget of the United States Government, various years, and from unpublished Office of Management and Budget data. Estimates for ports, harbors, and waterways based on Army Corps of Engineers data.

urban traffic congestion makes intermodal transfers ever more difficult, further changes are likely.

Department of Transportation

The regulatory and programmatic reach of DOT extends over the Nation's vast network of roads and railroads, ocean shipping, airways, and pipelines. DOT policies and regulatory actions affect State and local governments directly, influencing land-use planning, transportation facilities and service choices, energy conservation, environmental quality, and technological developments.

Formed in 1966 from 35 transportation-related programs spread throughout the Federal Government, DOT was envisioned by then President Johnson as a single unifying entity for managing the water, rail, airway, and road networks.[5] The new agency's five operating divisions included the following: the Federal Railroad Administration (FRA), an amalgamation of the Bureau of Railroad Safety, the Alaska Railroad, and the Office of High Speed Ground Transportation; the Federal Highway Administration (FHWA), formerly the Bureau of Public Roads and Federal-Aid Highway Programs; the Federal Aviation Administration (FAA), formerly an independent agency; the Saint Lawrence Seaway Development Corp from the Commerce Department; and the U.S. Coast Guard, from the Treasury Department. In 1967, the Urban Mass Transportation Administration (UMTA) was transferred from the Department of Housing and Urban Development to DOT. Later additions include the National Highway Traffic Safety Administration, the Maritime Administration (MARAD), and the Research and Special Programs Administration (RSPA), the only intermodal agency within DOT. RSPA manages some DOT research and regulates hazardous materials transportation, oil pipelines, and emergency preparedness.

Despite President Johnson's goal, the DOT Act, a political compromise, created strong modal administrators, as Congress wanted, thus maintaining separate programs for each transportation mode. However, it also established a strong office of the secretary, as the President had proposed.[6] Modal administrators have authority to regulate and manage their organizations, extending from budget formulation to field operations. This independence, the fact that authority over inland waterways was retained by the Corps, and the regional administration of key modal programs have worked to prevent intermodal coordination. To this day, congressional committee and subcommittee structure and industry and carrier interests have helped keep the autonomy of the modal or operating administrations intact.

Situated on top of the DOT organizational chart, the secretary's office recommends the department's budget to the Office of Management and Budget (OMB), formulates national transportation policies, evaluates programs, and attempts to coordinate the activities of the modal administrations. Assistant secretaries serve primarily as staff officers interposed between the secretary and the modal administrators. Since its formation, DOT has had 10 secretaries, several of whom tried to restructure the department along functional lines to facilitate intermodal strategies and establish a means for disbursing funds more equitably among modes. However, their average tenure of 2 to 4 years was too short to leave a permanent mark. Thus the agency has never implemented a multimodal national transportation policy requiring a high degree of cooperation between the separate operating branches. The current DOT initiative to implement the national transportation policy statement[7] seems unlikely to make a permanent impact on deeply entrenched modal interests unless the intermodal cooperation stressed by Secretary Skinner is somehow institutionalized so it survives under succeeding executives.

With a 1990 budget of $28 billion and 64,000 civilian employees, DOT administers user-supported trust funds of considerable size, including the highway and transit trust funds and the airport and airway trust fund.[8] At present the management of each mode rests firmly with the Federal Highway

[5] "Message From the President of the United States, Transmitting a Proposal for a Cabinet-Level Department of Transportation Consolidating Various Existing Transportation Agencies," in U.S. Congress, House Committee on Government Operations, *Creating a Department of Transportation, Part I: Hearings Before a Subcommittee of the Committee on Government Operations* (Washington, DC: U.S. Government Printing Office, 1966), pp. 38-39.

[6] "Department of Transportation Act," Conference Report No. 89, House Report No. 2236, Oct. 12, 1966 to accompany H.R. 15963.

[7] U.S. Department of Transportation op. cit., footnote 2.

[8] Two additional transportation trust funds, the Inland Waterway Trust Fund and the Harbor Maintenance Trust Fund, fall under the purview of the U.S. Army Corps of Engineers.

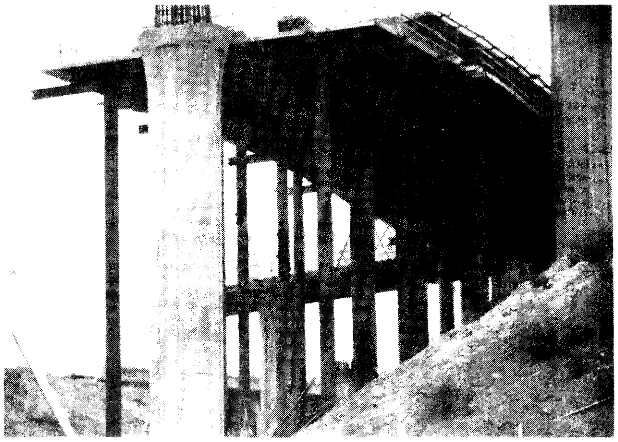


Photo credit: *Tom Burke*

The Federal Highway Administration in conjunction with State officials develops safety standards for the design, construction, and maintenance of bridges and highways on the Federal-aid system.

Box 2-A—Highways: From Postal Roads to Interstate

Systematic Federal assistance for highways began in 1916, with grants to States for construction of roads used to deliver the mail. Roads receiving Federal highway aid were to be free of tolls, and all proposed roads and methods of construction had to be agreed on by the Secretary of Agriculture and State highway departments.

Federal and State investment of more than $8 billion in the 1920s and 1930s boosted total mileage of paved roads from 387,000 in 1921 to 1.4 million by 1940. During World War II, appropriations for roads needed for national defense, including access roads to military sites, funded hundreds more projects totaling more than 2,200 miles.[1]

In each of the first 3 postwar years, $500 million in Federal funds was authorized for construction and funding of secondary roads to connect farms and small communities to the highway network and an urban system located in and around major cities+ An Interstate highway system was designated for connecting principal cities and industrial centers and connecting with routes in Canada and Mexico. Today's highway system, while retaining marks of all this history, is overlaid by legislation passed in 1956 authorizing completion of the Interstate system under the direction of the Department of Commerce and State highway departments, To speed travel, the system was to have no railroad crossings, traffic signals, or stop signs. In 1988, the system was 99 percent complete and consisted of 44,590 miles.[2] The cost of the system, intimated at $25 billion in 1956, will exceed $100 billion (in current dollars) before completion, expected in 1991.

[1] Bob Carpenter, "In the Early Days, Everyone Was a Roughrider," *Windows (Texas Engineering Experiment Station, Texas A&M University)*, summer 1988.

[2] Federal Highway Administration, *Highway Statistics 1988* (Washington, DC: U.S. Department of Transportation, 1989), p. 132.

Administration, the Urban Mass Transportation Administration, the Federal Railroad Administration, the Federal Aviation Administration, the Maritime Administration, the IJ.S. Coast Guard, and the Saint Lawrence Seaway Development Corp.

Federal Highway Administration

FHWA has primary jurisdiction over highways and bridges in the Federal-aid system and sets safety standards for their design, construction, and maintenance and for motor carriers engaged in interstate commerce. It has divisions responsible for engineering and traffic operations; safety and traffic engineering; research, development, and technology; planning and policy development; right-of-way and environment; administration; and motor carrier safety.

FHWA also administers the Federal-aid highway program (see box 2-A), which distributes funds to the States to construct and rehabilitate the 843,000-mile Federal-aid highway system. Through the Highway Trust Fund, the government pays 90 percent of construction costs for Interstate highways; 75 percent for primary, secondary, and urban road construction; and 80 percent for bridge replacement and major rehabilitation. Federal funds cannot be used for highway or road operation or maintenance, and responsibility for these and the remainder of the road system rests with States and local governments. The Highway Bridge Replacement and Rehabilitation Program, also administered through States, is the major funding source for repairing and rehabilitating 'deficient bridges. States develop program needs and set priorities based on information from State bridge inventories and biennial inspections. Although States and communities that receive Federal matching funds must follow FHWA rules and regulations, flexibility permits nonuniform practices among the States. For further details, see chapter 3.

The Federal highway program is largely supported by the Highway Trust Fund under the jurisdiction of the U.S. Treasury, which invests funds not necessary for current expenditures and credits the interest to the Fund. Annual congressional appropriations to the Federal highway program are managed by FHWA and used to reimburse States for improvements to their Federal-aid highways. User fees supporting the Federal Highway Trust Fund in 1990 included a 9-cents-per-gallon tax on gasoline and special fuels used in highway vehicles (except gasohol, which is taxed at 3-cents-per-gallon), 1 cent of which is dedicated to mass transit; a 15-cents-per-gallon tax on diesel fuel; a graduated tax on tires over 40 pounds; a 12-percent fee on new trucks and trailers, and a heavy-vehicle use tax on trucks over 55,000 pounds. As part of the 1990 deficit reduction package, the fuel tax will rise 5 cents per gallon, with 2.5 cents of the increase going to the Trust Fund (0.5 cent of which is for mass transit) and 2.5 cents to the General Fund. This marks the first formal designation of Federal fuel tax revenues for purposes other than replenishing the Trust Fund. From its establishment in 1956 to 1989, the Trust Fund accumulated $220.1 billion, including interest on unspent balances, and has made available $209.5 billion to the States (as of Sept. 30, 1989).[9] The present legislation is scheduled to be reauthorized in 1991 for fiscal year 1992.

Urban Mass Transportation Administration

UMTA is the key Federal agency with responsibility for public transit. Through its grants program, it administers capital planning and operating assistance grants and loans (see box 2-B), and monitors the efficiency and environmental impacts of transit projects. UMTA also provides contracts, cooperative agreements, and grants for developing, testing, and demonstrating new technologies.

Legislation in 1982[10] provided for 1 cent of a 5-cent increase in the Federal motor fuels tax to be placed in a mass transit account for capital projects, increased funding for the formula grant program, and altered the allocation formula to include transit service data as well as population data.[11] In 1988, public transit accounted for 89 percent of all vehicle-miles operated by transit systems and 96 percent of all passenger trips by transit,[12] but transit agencncies have never realized the promise offered by a dedicated revenue source; most trust fund revenue remains unallocated.

Box 2-B—Mass Transportation: The Youngest Federal Transport Assistance Program

Federal capital grants for mass transit began with the Housing Act of 1961,[1] which provided funding for demonstrations ($25 million) and loans ($50 million) for mass transit projects to bolster the private transit industry. The Urban Mass Transportation Act of 1964[2] established the Urban Mass Transportation Administration (UMTA) within&@ Department of Housing and Urban Development to administer capital grants to transit systems on a two-thirds Federal, one-third local matching basis. This sparked a rapid conversion of failing, ***privately*** operated mass transit firms into public properties. The fraction of publicly owned transit system increased from 5 percent in 1960 to 55 percent in 1980, with the share of publicly owned vehicles rising from 36 to 90 percent over that period. In 1968, UMTA was moved to the newly created Department of Transportation, and the Urban Mass Transportation Assistance Act of 1970[3] authorized a $3. l-billion capital grants program Highway and transit legislation in 1973 and 1974 increased the federally funded portion of transit capital projects from **67 to 80 percent, allowed expenditure of some** highway funds for qualifying transit projects, and increased authorizations for discretionary capital funding. A population-based, formula grant program for cities was created, which could be used for either operations or capital projects. Increases in Federal transit funding came to an end in the early 1980s, reaching a peak of $4,7 billion in 1981.[4]

[1]75 Stat. 149 et seq.

[2]Title 49, secs. 1601-1611.

[3]84 Stat. 962.

[4]Urban Mass Transportation Administration, *1989 Statistical Summaries: GrantAssistance Programs* (Washington, DC: V,& Department of Transportation% 1990), p, 11.

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[9]The Road Information Program, "The Federal Highway Trust Fund," *Transportation Quarterly*, vol. 44, No. 1, January 1990, pp. 25-35.

[10]96 Stat. 2140-2154 et seq.

[11]American Public Transit Association, *1989 Transit Fact Book* (Washington, DC: 1989), p. 73.

[12]Ibid., p. 14.

The Federal Railroad Administration

FRA has primary jurisdiction over the Nation's railroads, promulgating and enforcing safety regulations, administering limited financial assistance programs (see box 2-C), and conducting research and development (R&D) for improved railroad safety. FRA's Office of Safety implements regulations covering railroad track maintenance and inspection, equipment signals, railroad locomotives, safety appliances, power brakes, hours of service, transport of hazardous materials, and operating practices. The office also directs FRA's R&D program and investigates accidents. FRA's safety jurisdiction does not apply to light rail or rapid transit systems in urban areas. In fiscal year 1988, FRA spent about $40 million on safety activities. About one-half of this amount was used for regulatory enforcement-providing salaries for about 325 Federal rail safety inspectors and assistance for some 104 State inspectors-and about one-third of this amount went toward R&D.[13]

Through its Office of Passenger and Freight Services and Office of Northeast Corridor Improvement Project and Engineering, FRA administers a program of Federal assistance for national, regional, and local rail services that includes: rail freight service assistance programs, rail service continuation programs and State rail planning, labor/management programs, and Amtrak.

In 1980, Congress passed the Staggers Rail Act to improve the economic health of the railroads and ensure effective competition. Some freight rate regulation was retained in consideration of captive shippers,[14] but carriers were given greater flexibility to react to market forces[15] and greater freedom to abandon track. This has spurred significant growth in the number of shortline and regional freight railroads, most of which operate as private entities. (For further information, see chapter 3.)

Passenger Rail

The Federal Government now dominates intercity passenger rail through Amtrak; it even owns most of the track and structures along the northeast corridor between Boston and Washington. In other parts of the country, Amtrak's agreements with freight railroads permit its trains to use their track in return for fees based on miles traveled and other considerations, including upkeep of the track, bridges, and signals.

The Federal Government owns all of Amtrak's preferred stock, controls the appointment of its board of directors, and has a lien on most of its assets, including all locomotives and rolling stock. Amtrak generated over 5.86 billion passenger-miles in 1989.[16] The corporation receives yearly Federal grants of about $500 million from the Federal Government through FRA to cover its operating deficit.

Federal Aviation Administration

FAA has regulatory authority across the entire aviation system-airports, airways, aircraft, industry, and people, and FAA itself owns and operates one of the most complex transportation networks in the world, the U.S. National Airspace System. Industry participation in regulatory activities has a long history (see box 2-D) and has continued to grow since the 1950s, when Congress authorized Federal aviation agencies to designate part of the certification and inspection processes to the private sector.

While Federal aviation regulatory enforcement activities are relatively decentralized, with regional and district offices having considerable autonomy and independence, FAA is currently consolidating some activities in its Washington headquarters.[17] Although aviation maintains an enviable safety record, dramatic growth in air travel, turmoil associated with the firing of air traffic controllers in 1981, major changes in technology, and Federal budget constraints have left FAA scrambling to modernize

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[13] Congressional Research Service, *Railroad Safety: Selected Options That Might Promote Safety*, issue brief (Washington, DC: Feb. 2, 1988), pp. 1-4.

[14] Senator Ernest F. Hollings, opening statement, hearings before the Senate Committee on Commerce, Science, and Transportation, Subcommittee on Surface Transportation@ Oversight of the Staggers Rail Act of 1980, July 26, 1983.

[15] Federal Railroad Administration, *Deferred Maintenance and Delayed Capital Improvements On Class II and Class III Railroads* (Washington% DC: U.S. Department of Transportation, 1989), p. 14.

[16] W. Graham Claytor, Jr., President and Chairman of the Board, National Railroad Passenger Corp., testimony athearingsbefore the House Committee on Appropriations, Subcommittee on Transportation and Related Agencies, Mar. 22, 1989, p. 1.

[17] Michael Zywokarte, project manager, Engineering, Federal Aviation Administration, personal Communication% J@ 12, 1990.

Box 2-C—Railroads and Government: A Difficult Relationship

Federal assistance to railroads began as the industry sought to expand westward. Starting in 1850, land grants were made to railroads as they attempted to reach the Pacific. Federal regulatory power, however, was not *established until* 1887, when the Interstate Commerce Commission (ICC) was created and given authority to set some rail rates. Between 1893 and 1921, Congress passed several rail safety acts and gave ICC responsibility for implementing and enforcing the regulations. Little important railroad legislation was passed during the next 40 years, and railroad dominance in transportation declined, as Federal aid spurred expansion of the highway system and growth in the trucking industry.

Starting in 1965, legislation gradually transferred all safety responsibility from ICC to the Department of Transportation, including responsibility for regulations, inspection, enforcement, accident investigation and recordkeeping, and some hazardous materials functions. However, ICC retained authority for railroad accounting and costing procedures, construction and abandonment of rail lines, mergers, acquisitions, and issuance of securities. ICC also enforced the 'common carrier obligation," which requires a carrier to provide service to anyone who seeks it and is willing to pay the charge shown on rate schedules filed with the commission.[1]

ICC requirements constrained railroads' abilities to compete economically with trucks and played a crucial role in declining rail economic performance. By the early 1970s, seven railroads that had provided freight and passenger service in the Northeast and Midwest were bankrupt. From their remnants, Federal action created the Consolidated Rail Corporation @mi.ii), a private freight railroad company with government financing and oversight. At the same time, the quasi-public National Rail Corporation (Amtrak) was created to provide passenger service on the routes served by the bankrupt railroads; Amtrak, however, also incorporated the passenger service of other major railroads serving the rest of the country, to ensure a nationwide passenger system.

Federal funds compensated the bankrupt carriers, rebuilt track and equipment, and covered operating losses. Subsequent legislation allowed Conrail to make the changes necessary to make a refit, which it did in 1981 and succeeding years. Conrail was sold in 1987 through a public offering of its stock,[2]

[1] U.S. General Accounting Office, *Problems in Implementing Regulatory Accounting and Costing Systems for Railroads* (Washington, DC: July 17, 1980), p. 1.

[2] Nancy Heiser, Congressional Research Service, "Federal Aid to Domestic Transportation: A Brief History From the 1800s to the 1980s," Report 88-574, Aug. 16, 1988, pp. 5-7.

the system. Ongoing concerns center on whether FAA has the institutional capability and resources to carry out its operating, standard setting, rulemaking, and technology development functions effectively and to guarantee compliance through its inspection programs.[18]

To provide support for air traffic control (ATC) facilities, an Airport and Airway Trust Fund, financed mostly from taxes imposed on airline tickets and aviation fuel, was created in 1970. Economic deregulation in 1978 removed Federal controls over routes, fares, and new entries and transferred all remaining economic functions to DOT.

Non-Federal organizations, primarily local governments and regional authorities, own and operate most public airports, and local governments bear most of the responsibility for land-use planning and coordinating the surface transportation links to airports. The Airport and Airway Trust Fund provides about one-third of the capital for public airport improvements.[19]

International agreements establish minimum standards for aviation systems to ensure compatibility throughout the world. Historically, U.S. requirements, with the exception of security items, have been adopted worldwide. However, future communication, navigation, and surveillance technologies will permit precise traffic monitoring and control well beyond domestic borders, possibly worldwide. These advances may require new forms of international coordination, such as satellite system protocols, and require negotiation of sensitive issues such

[18] U.S. Congress, of ffice of Technology Assessment, *Safe Skies for Tomorrow: Aviation Safety in a Competitive Environment,* OTA-SET-381 (Washington, DC: U.S. Government Printing Office, July 1988), p. 45.

[19] For further details on financing and management, see Office of Technology Assessment, op. cit., footnote 4.

Box 2-D—Government and Aviation: A Close Marriage

The Air Mail Act of 1925 authorized the Post Office Department to contract for airmail service with private operators, greatly stimulating the growth of commercial air carriers, some of which evolved into today's major airlines. However, despite strong industry support for Federal aviation safety legislation, Congress was unable to reach agreement on a statute until 1926, when the Air Commerce Act was passed. The legislation charged the Department of Commerce with both regulatory authority over aviation and responsibilities aimed at promoting the fledgling industry. The major provisions of the act authorized the regulation of aircraft and airmen in interstateand foreign commerce, provided Federal support for airways and weather services, authorized aeronautical research and development (R&D) programs, and provided for the investigation of aviation accidents. Airport development was left to local governments.

During the 1930s, industry expansion and increasing traffic prompted a group of airlines to establish an air traffic control (ATC) system, which was transferred to the Department of Commerce in 1936. Economic regulation began in 1938, with the creation of the Civil Aeronautics Authority, responsible for safety programs, route certificates, airline tariffs, and air mail routes. Federal responsibilities for airway and airport development grew tremendously during World War II and came to include Federa1 financial assistance to States and municipalities. Surplus military airplanes and pilots and higher performance passenger transports brought enormous commercial aviation growth during the next decade. However, Federal support for ATC and airport development did not keep pace; some control towers and communications facilities were abandoned and R&D efforts curtailed.

The impending introduction of jet aircraft and a 1956 midair collision between two airliners led to the creation of the Federal Aviation Agency in 1958, with responsibility for fostering air commerce, regulating safety, ATC and navigation systems, and airspace allocation and policy. In 1966, the Federal Aviation Agency became the Federal Aviation Administration and was transferred to the newly formed Department of Transportation.

as whether U.S. ATC should monitor U.S. carrier traffic overflying other countries.

Maritime Administration

Established in 1950 and made a part of DOT in 1981, MARAD administers programs to support the development, promotion, and operation of the U.S. merchant marine. It administers programs to subsidize U.S. shipping and shipbuilding costs, funds training for seafaring personnel, and supports industry efforts to develop ports, facilities, and intermodal transport. In addition, MARAD maintains a National Defense Reserve Fleet of U.S. ships that it operates when required for national defense.

U.S. Coast Guard

The U.S. Coast Guard has a dual role; it is at all times a branch of the military services, operating as part of the Navy in wartime, and it is an operating agency of DOT during peacetime. Its responsibilities center on the safe and orderly operation of the Nation's waterways and ports, including sea search and rescue operations, law enforcement (e.g., suppression of smuggling and drug trafficking), pollution control, and aids-to-navigation and boating safety programs.

Saint Lawrence Seaway Development Corp.

The corporation was established in 1954 as an operating division of DOT responsible for the development, operation, and maintenance of that part of the Saint Lawrence Seaway between Montreal and Lake Erie. Coordinating its activities with Canadian authorities, the corporation administers all phases of Seaway daily operations as well as planning and capital improvements. Its goal is to encourage traffic through the seaway and fully develop its commercial potential.

U.S. Army Corps of Engineers (the Corps)

Responsible for operating and maintaining the Nation's waterways and born during the American Revolution, when army engineers built bridges and harbor fortifications, the Corps is one of the oldest Federal agencies. The need for a permanent cadre of military engineers led to legislation in 1802 creating the Corps, which has evolved continuously over the ensuing years to meet national engineering needs. Since 1977, the Corps has been a major military command of the U.S. Army, overseen by the assistant secretary for civil works. The Civil Works Program directs public waterways infrastructure activities, hydroelectric power generation, flood control, and water supply.

The Corps' field organization, one of its most important groups for public works, consists of 9 division offices, which supervise geographic areas based on river basins, and 36 relatively autonomous districts responsible for operations, maintenance, construction, preparation of design studies, and real estate acquisition. The Corps produces nearly 30 percent of the Nation's hydropower and 3.5 percent of the total electric energy; 115 Corps' lakes store water for agricultural, municipal, and industrial use.[20] The agency supports some work of other Federal organizations, providing design, evaluation, and construction management assistance on a fee basis when its schedule permits.[21]

The Corps and Public Works

The Corps' involvement in water projects began in 1824, when it was charged with clearing channels and constructing harbors. Subsequent legislation expanded Federal water transport management and funded the Corps to deepen and widen inland waterways, ports, and harbor channels. In 1899, the Corps was authorized to issue permits governing discharge into navigable waterways, a power it retains to this day, although now the permits must comply with EPA regulations.[22]

Because most Corps undertakings have promoted local and regional economic growth and large projects were heavily federally funded[23] its agenda has always been warmly received by Congress. Throughout the 19th century, the Corps constructed flood control facilities, including dams, where they would not interfere with navigation, but the importance of water transport for freight declined significantly in the late 19th century, as railroads expanded their networks. In 1917, Congress permitted the Corps to build hydropower facilities at Federal dams and authorized a Corps flood control program in the mid- 1930s. Corps authority for navigation improvements was modified in 1944 to include recreation, erosion control (especially for beaches), water supply, and water quality.

Environmental Concerns

The Corps traditionally used structures such as jetties and groins to fortify harbors, and levees and flood walls to control rivers. However, following passage of the National Environmental Policy Act (NEPA) in 1969, Corps' activities came under acute scrutiny. Environmentalists charged that the Corps' construction-especially the massive flood-control dam projects-caused irreparable ecological damage and destroyed wildlife habitats. Nonstructural solutions were made eligible for Federal funds in 1974[24] (although costs have prohibited most communities from exploring such options), and Clean Water Act Amendments in 1972 and 1977 extended the Corps' responsibilities to include all water affecting the commerce chain.

Nonetheless, new project starts ground to a halt between 1976 and 1986[25] because of growing Federal budget difficulties, concern about environmental degradation, disputes about cost sharing between Congress and the Administration, and demands from the public and local governments for participation in the formulation of projects. Legislation in 1978 established modest user fees for barge operators in the form of a marine fuel tax, and money began to accumulate in the Inland Waterway Trust Fund to help pay for lock and darn construction.

Passage of the Water Resources Development Act of 1986 finally allowed new construction to resume but increased cost sharing for non-Federal project sponsors, a provision that scaled back projects[26] and transformed project planning and implementation. Cost-sharing requirements depend on project type, ranging from 100 percent for hydroelectric projects and municipal and industrial water supply from

[20] U.S. *Army Corps* of Engineering, ***Secretary of the Army' sReport on Civil Works Activities, Fiscal Year 1987,*** vol. 1 (Washington, DC: 1987).

[21] Ibid.

[22] U.S. Army Corps of Engineers, *Digest of Water policies and Authorities* (Washington, DC: February 1989).

[23] Historically, large flood control and inland navigation projects were federally funded, while water supply and hydropower facility costs were repaid by users. Local contributions of land, easements, and right-of-way provided a share of small, local flood control project costs. The 1986 Water Resources Development Act revised the Corps' cost-sharing policy.

[24] Jean Nienaber and David Mazmanian, *Can Organizations Change?* (Washington, DC: The Brookings Institution, 1979), p. 13.

[25] Lawrence Mosher, "The Dwindling Federal Role," ***Forum for Applied Research and Public Policy,*** vol. 2, winter 1987, p. 44.

[26] Steve Hughes, Congressional Research Service, "WaterResources Development Act: Implementing the Omnibus Project Reforms," updated Aug. 15, 1989.

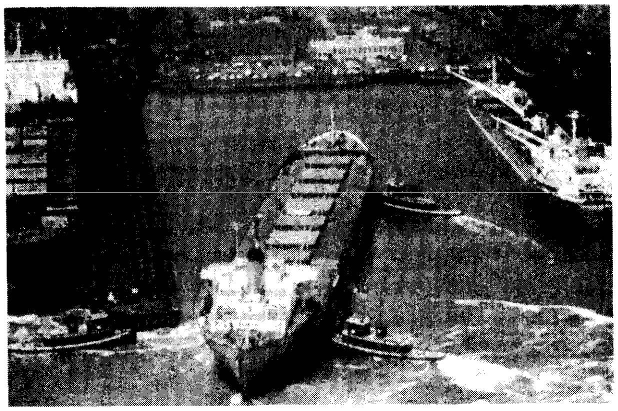

Photo credit: American Society of Civil Engineers

Harbor maintenance costs are partially paid from a trust fund supported by an ad valorem tax for operators of tankers and seagoing vessels.

Corps managed reservoirs, through 25 to 50 percent for flood control, to 10 to 50 percent for harbor construction. The Inland Waterway Trust Fund is currently sufficient to support replacement of from four to six projects each decade, only a small percentage of the construction projected as necessary to improve the fuel-taxed waterway system.

The only water-related user fee that can be used for maintenance is a tax established in the 1986 act on the dollar value of the commodities shipped through a port. The tax feeds the Harbor Maintenance Trust Fund, which covers about one-third of dredging costs. Virtually all operating and maintenance expenses for the Inland Waterway System are paid from the Federal General Fund. This contrasts to operations and maintenance for airports, highway, and mass transit, which State and local user fees commonly support.

The 1986 act also required that the Corps mitigate against fish and wildlife losses for each project, provided for wetlands preservation, and reaffirmed EPA's authority to review Corps' permits in navigational waters and wetlands. The divergent agency missions make EPA vetoes of some Corps' permits inevitable. Construction on new projects can begin only after provisions of the NEPA, Clean Water Act, Coastal Zone Management Act, Endangered Species Act, Fish and Wildlife Act, and National Historic Preservation Act have been satisfied.

The Corps' Future

Over the years the Corps has successfully metamorphosed to address changes in national priorities, and today represents a rich and valuable civil engineering resource. Nonetheless, Federal budget constraints and the national shift to reconditioning facilities rather than constructing new ones have dramatically reduced its civil works efforts.[27] These factors and environmental difficulties with many major water projects mean that the agency must again look toward change. Drawing on its in-house talent to assist other Federal agencies is one element of the Corps' strategy. It considers its support of EPA's hazardous waste disposal (Superfund) and wastewater treatment plant construction grant programs to be its most significant cooperation effort.[28] The Corps also assists States and territories in comprehensive water resource planning by providing land-use planners with information on flood hazards and technical assistance for dealing with floods. Agency officials have offered the Corps' assistance for the Department of Energy's radioactive waste cleanup program.

Environmental Protection Agency

Although local governments manage most of the Nation's environmental public works, EPA's guidelines and standards affect Cabinet departments (DOT, the Corps, and the Bureau of Reclamation), every sector of the U.S. economy, and virtually every category of public works managed by State and local officials. An independent agency headed by an administrator, EPA's activities include research; standard setting; monitoring and enforcement for safe drinking water, air quality in large urban areas with air pollution problems, and operation of wastewater treatment plants; and hazardous waste disposal. EPA, a White House initiative, was established by an executive order in 1970[29] to "organize rationally and systematically" the Federal Government's many disparate pollution-related activities. States had shown reluctance to enforce

[27] Robert W. Page, Assistant Secretary of the Army (Civil Works), testimony at hearings before the Senate Committee on Appropriations, Subcommittee on Energy and Water Development, May 3, 1989.

[28] Ibid.

[29] U.S. Congress, House Committee on Government Operations, Subcommittee on Executive and Legislative Reorganization, *Reorganization Plan Number 3 of 1970 (Environmental Protection Agency) (Washington DC:* U.S. Government Printing Office, 1970).

pollution control regulations against industry,[30] and Federal agencies, like the Department of the Interior and the then Department of Health, Education and Welfare (HEW), with longstanding environmental programs, had not actively enforced their own standards.

EPA was established by bringing together nine programs, including the National Air Pollution Administration and the bureaus of Solid Waste Management, Water Hygiene, and Radiology from HEW, and the Federal Water Quality Administraion from the Department of the Interior. When creating the new agency, the Nixon Administration debated whether to organize it into functional programs such as research, monitoring, abatement, and compliance, or to keep intact the disparate media-specific pollution control programs inherited from other departments. The administrative need to create a single agency out of a number of existing Federal programs and the political urgency of vigorous enforcement against polluters pointed to retaining specific control programs, an organizational decision with results that persist today.

EPA's role as a guardian of environmental quality includes both determiningg regulatory guidelines and enforcing compliance with the regulations, known as the ''command and control' approach. The Agency initially monitored the air and water contamination by a small number of pollutants, but as the health effects of chemicals in the environment became better understood, Congress passed laws requiring EPA to regulate more organic and inorganic pollutants, in soil, water, and air (see table 2-1 again). In addition, the 1972 Clean Water Act authorized EPA to make wastewater treatment grants to finance local plant construction.

Today the Agency administers 10 major laws, including the Clean Water Act, the Safe Drinking Water Act, the Clean Air Act, the Resource Conservation and Recovery Act, and the National Environmental Policy Act, and the environmental provisions of a number of other statutes. EPA's regulatory actions follow directly from the many laws it must enforce (with sometimes inconsistent results). Air quality standards, for example, are established by the need for protecting public health; Clean Water Act guidelines are linked to the technology capable of removing trace contaminants from wastewater.[31] EPA's divisions include Water, Air and Radiation, Solid Waste and Emergency Response, and Pesticides and Toxic Substances, each monitoring pollution control efforts in air, water, or soil. Although the divisions are not autonomous, their programs and activities are highly compartmentalized. Little effective coordination occurs between divisions,[32] despite a statement in EPA's fiscal year 1990 budget book that the Agency's interdisciplinary R&D program cuts across programmatic lines to consider environmental problems affecting several media.

Debate about EPA continues as a move to elevate it to Cabinet status gathers steam. As far back as 1970, proponents of a reorganization plan had argued that for the effective control of pollution, "... the environment must be perceived as a single, interrelated system. '[33] But Congress never passed a law giving EPA statutory authority to view the environment as a whole, and recent administrators point out that each division devotes itself to removing toxic chemicals from a single medium, diminishing the Agency's effectiveness enormously. "The single medium approach is setup like concrete in the practical day-to-day administrative operations of EPA. . . . We have to accept the fact that this general environmental strategy may be flawed."[34] Pollutants migrate from air to water and from water to soil or follow any number of other routes among the separate media. Municipal wastewater treatment plants generate air pollution as well as create sludge contaminated with toxic chemicals, and the cross-media impacts pose often serious compliance problems for municipal public works officials.

Studies released by the Agency in 1987 and in September 1990 assert that EPA is not adequately concentrating on problems of long-term threats to

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[30]Council on Environmental Quality, *Environmental Quality, The 16th Annual* Report of the Council on Environmental Quality (Washington DC: 1985).

[31]James Q. Wilson (ed.), *The Politics of Regulation (New* York, NY: Basic Books, Inc., 1980), p. 277.

[32]Lee M. Thomas, "Systems Approach: Challenge for EPA,'' *EPA Journal,* September 1985, p. 22.

[33]House Committee on Government Operations, op. cit., footnote 29.

[34]Thomas, op. cit., footnote 32, p. 21.

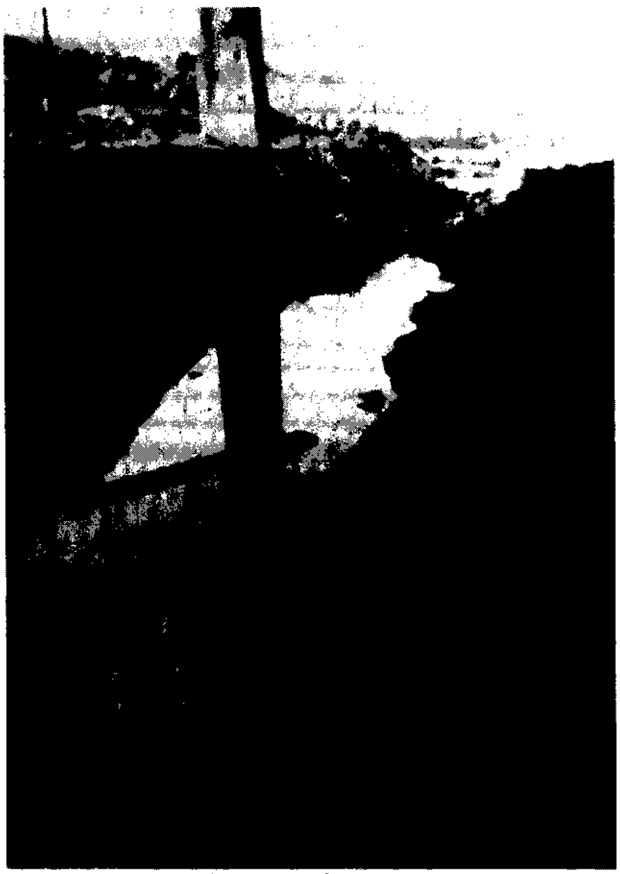

Photo credi American Society of Civil Engineers

D scha ge e a e ove a g pe d me a e amo g g e m e vi me al rea d ki g wate ppl e

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The National Envıronmen Policy Ac (NEPA ena ted ın 969 requıre Federal agen ıe to on sider the environmental consequences of their actions, and Federal agencies must file an environmental impact statement with EPA before approving major projects. NEPA has had significant impact on DOT's operations,[37] and Clean Air Act Amendments of 1990 increase the requirements for environmental sensitivity in DOT programs.

Bureau of Reclamation

Federal reclamation activities were established by Congress in 1902 as part of the U.S. Geological Survey in the Department of the Interior to turn large, arid Western States into rich farmlands through large irrigation projects. The Reclamation Service was renamed the Bureau of Reclamation in 1923, and by the 1930s, as expertise was gained from a number of irrigation dam projects, the agency began supplying municipal water. Eventually the Bureau's tasks came to include hydroelectric power, flood control, municipal and industrial water supply, recreational uses of lakes and rivers, and fish and wildlife conservation. The agency's golden age came during the Roosevelt Administration,[38] when huge river basin projects, combining irrigation, water supply, hydroelectric power generation, and flood control were conceived and built. The Bureau's largest projects—Hoover and Grand Coulee dams-required solutions to complex engineering problems (a steady water flow for navigation and power production, periodic and seasonal water releases for both irrigation and flood control) and established world records.

As the number, size, and geographical reach of the Bureau's water projects increased, so did their environmental impact, and criticism grew on the basis of safety, doubtful economic benefits, destruction of historic and scenic areas, and harm to fish and wildlife habitats. Conservationists began to work actively against project authorizations, succeeding for the first time in 1956 with the prevention of Echo

[35] U.S. Environmental Protection Agency, *Unfinished Business: A Comparative Assessment of Environmental Problems* (Washington, DC: 1987); and U.S. Environmental Protection Agency, Science Advisory Board, *Reducing Risks: Setting Priorities and Strategies for Environmental Protection* (Washington, *DC:* September 1990).

[36] Science Advisory Board, op. Cit., footnote 35.

[37] Martin Convisser, "Transportation and the Environment," *Current Issues in Transportation Policy,* Alan Altshuler (cd.) (Lexington, MA: Lexington BooIs, 1979).

[38] Michael C. Robinson, *Water for the West: The Bureau of Reclamation, 1902-1977* (Chicago, IL: Public Works Historical &X2@, 1979).

Park Dam.[39] Similar activism blocked construction of two dams in the Grand Canyon section of the Colorado River in the 1960s.[40] Congress responded by requiring consideration of water quality, wildlife and endangered species protection in project planning, and the filing of environmental impact statements. Nonetheless, recent assessments have shown groundwater degradation and surface water pollution from fertilizers and pesticides as byproducts of Bureau projects,[41] problems that can affect drinking water quality and complicate the tasks of State and local public works officials.

Recognizing that the Bureau had met its original objectives of harnessing the major rivers of the West to meet water demands, its officials undertook an internal assessment culminating in 1987 with a radical reordering of priorities.[42] Henceforth, water conservation, environmental protection and restoration, and improving system reliability and project optimization would take precedence over construction of large water projects. Future activities would be smaller in scale or designed to obtain maximum efficiency from existing projects and involve non-Federal partners. The new mission includes managing resources, promoting water conservation, removing legal and institutional barriers to water conservation, and creating more usable water supplies from existing projects. Still under way are two major water projects—the Central Arizona and the Central Utah-which will absorb a major portion of the Bureau's budget in the coming years. But beginning in the mid-1990s, the Bureau's task will increasingly be operations and maintenance of existing projects, with possible transfer of these responsibilities to local beneficiaries.

Department of the Treasury

As the executive agency that formulates tax policy, including rules for tax-exempt municipal bonds, the Department of the Treasury has a major influence on the availability of private capital for local public works projects. Treasury's Office of Tax Policy prepares tax legislation to support executive branch fiscal goals and protect Federal revenues. To reduce Federal revenue losses attributable to tax-exempt bonds, Congress passed Treasury-sponsored legislation, as part of the 1986 and 1988 Tax Reform Acts, to tighten eligibility and reporting requirements for tax-exempt financing and restrict opportunities for arbitrage.[43] Passage of the acts undercut efforts by other executive branch agencies to shift public works financing from Washington to State and local governments. However, OTA could find no evidence of communication over probable impacts on transportation or environmental public works investment between the tax lawyers at Treasury and program administrators at DOT and EPA, or between congressional tax-writing committees and those with jurisdiction for public works.

The immediate impact of the tax code changes was a dramatic drop in tax-exempt financing for private purpose projects such as civic centers and parking garages and a reduction in local use of arbitrage. Traditional governmental-purpose, municipal bond sales for water treatment plants and street improvements have returned to their pre-1986 levels after an initial drop,[44] indicating that results of the tax code changes were not as disastrous to traditional public works financing as local officials had at first feared.

Office of Management and Budget

Through its responsibility for preparing the President's budget and its oversight and review of the organization and operations of executive branch departments and agencies, OMB wields enormous influence over the Federal role in public works. Specifically, the office has authority to negotiate with departments over their budgets, to review proposals that Cabinet departments and agencies want included in the President legislative package, and to enforce spending cuts agreed to in the 1990 deficit reduction package.

OMB in recent years has played a major role in advocating governmental policies and in restraining

39Ibid., p. 93.

40William Warne, *The Bureau of Reclamation* (Boulder, CO: Westview Encore Reprint, 1985), p. 99.

41Mosher, op. cit., footnote 25, p. 45.

42Bureau of Reclamation, op. cit., footnote 3.

43The term arbitrage refers to the practice of investing bond issue proceeds, until they are needed, in securities with interest rates higher than the bond issue.

44Government Finance Research Center, "Federal Tax Policy and Infrastructure Financing," OTA contractor report, Sept. 13, 1989, p. ~-4.

Federal spending. In addition to recommending Federal Program cuts in most areas, OMB has gained virtual veto power over regulations. In 1981, President Reagan issued Executive Order 12291 that required departments to prepare cost/benefit analyses for all proposed Federal regulations and that they be submitted to OMB for review and approval. OMB's hand was further strengthened in 1985 by Executive Order 12498 requiring agencies to submit a calendar of significant regulatory actions they planned to take during the following year, thereby giving OMB more time to shape the development of regulations.[45]

OMB can refuse to consider or accept legislative proposals and departmental policies that do not conform with the Chief Executive's fiscal or policy priorities. Although DOT has a Cabinet officer to advocate its budget and programs, OMB's perspective stimulated modifications in the Federal financing recommendations in the department's long-range policy plan, *Moving America.*[%] As a regulatory agency lacking Cabinet representation, EPA is even more subject to OMB influence.

The Courts

During the last three decades, the Federal judiciary has heard thousands of administrative law cases dealing with the environment and issued a multitude of rulings affecting national health and environmental policies. This judicial activism has affected how Congress drafts legislation, the manner in which department rules are written, and the way the Federal bureaucracy functions. The threads of environmental policy are contained innumerous Federal statutes, rules, and the multitude of orders and rulings of Federal and State judges, making program administration and coordination difficult. EPA, as a regulatory agency, is profoundly affected by court activism,[47] but judicial rulings have an impact on DOT, BuRec, and the Corps, too.

While judicial oversight offers vital legal protections and opportunities for interest groups to be heard, it also lengthens and further fragments the policymaking process and complicates enforcement. Between 1%8 and 1978, Congress passed more regulatory statutes than it had in the Nation's previous 179 years. EPA was established specifically to administer the environmental laws.[48] These laws included the NEPA, the Consumer Product Safety Act, the Occupational Safety and Health Act, and a number of the environmental protection laws (see table 2-1 again). This wave of legislation, aimed at protecting the environment and shielding citizens from the risks of all kinds of pollutants, brought the courts into abroad and contentious arena characterized by scientific uncertainty and conflicting values.

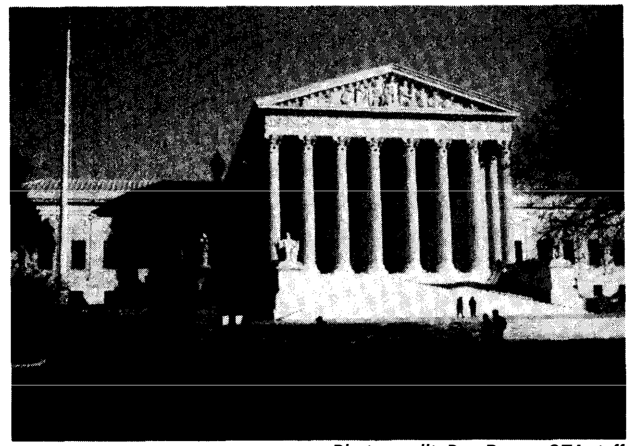


Photo credit: Dan Broun, OTA staff

Court rulings have become an almost inescapable part of the Federal regulatory and enforcement processes.

In most regulatory laws passed in the 1970s, Congress authorized citizens to file suit against administrators either for taking unauthorized action or for failing to perform "nondiscretionary' duties, so as to protect against bureaucratic foot-dragging and industry control.[49] This liberalization of 'standing," or who could sue, gave environmental and other interest groups new power and guaranteed court intervention. Moreover, the regulations gave the courts oversight of a wide range of activities. Statutes stipulated that every highway project using Federal funds must include a detailed environmental impact study; public facilities were mandated to

[45]Norman J. Vig and Michael E. Kraft, *Environmental Policy in the 1990s (Washington DC: Congressional* Quarterly, Inc., 1990), p. 42.

[46]Alyson Pytte, "Bush Transportation Policy Is Non-Starter in Congress," *Congressional Quarterly,* Mar. 10, 1990, p. 746; and David Broder, "Skinner's Moving America: A Cop-Out," *The Chicago Tribune,* Perspective section, Mar. 11, 1990, p.*3.*

[47]Over 80 percent of the 300 regulations the Environmental Protection Agency issues annually wind up in the courts. See Rochelle L. Stanfield, "Resolving Disputes," *National Journal, vol.* 18, No. 46, Nov. 15, 1986, p. 2764.

[48]R. Shep Melnick, *Regulations and the Courts (Washington DC: The* Brookings Institution, 1983), P. 5.

[49]Ibid., p. *8.*

provide access to disabled persons; and every business and facility that produced air pollution, wastewater, and solid waste was regulated to some extent. To counter criticism that it failed to provide enough guidance, Congress wrote detailed statutes requiring specific standards, procedures, and deadlines-creating fertile ground for potential litigants.

Impact of Court Activism

The expanding role of the courts has reduced the discretion of program administrators, lengthened the rulemaking process, expanded the scope of many regulations, and widened the gap between stated program goals and enforcement. Following the congressional lead, agency lawyers have learned to craft very specific regulations". . . for litigation and political reasons, [which] say what they must in order to satisfy those concerns. ' '[50] However, such specificity deprives Federal agencies of management latitude; the deadlines written into the Clean Water Act, for example, give EPA officials no flexibility to work with communities that have special compliance or fiscal problems.

Judges, removed from the daily operation of administrative agencies and exposed to a variety of scientific advice, often have difficulty adjudicating the complexity and ramifications of specific issues. In response to legislation and court rulings, particularly at the appellate level, agencies have expanded regulatory programs beyond the limits contemplated by administrators and scientific experts and seemingly without regard for the costs and the feasibility of enforcement. Setting standards has turned out to be easier than administering and financing an effective enforcement program, such as recent drinking water regulations that require local testing for 83 contaminants, many of which occur in amounts too small to measure. The result is a widening gap between program requirements and what agencies can reasonably expect to accomplish, a difficulty compounded by shrinking budgets for administration and implementation. Adjusted for inflation, EPA's operating budget has increased from only $1.4 billion in 1975 to $1.5 billion in 1990,[51] but its program responsibilities have burgeoned.

Court intervention has multiplied the time and money required to prepare regulations. Agencies that face frequent court challenges become risk sensitive and institute complex, time-consuming rulemaking procedures, diverting resources from research and enforcement. Furthermore, when opposing groups are focused on creating a record for litigation, negotiations are difficult. Although agencies pursue informal, negotiated rulemaking on those rules amenable to negotiation, and some disputes are settled out of court, the likelihood of litigation is a deterrent to negotiating hard issues.

Congress

Almost one-half of the 303 committees and subcommittees of the 10lst Congress claimed jurisdiction over some aspect of public works, inhibiting development of coordinated public policy and ensuring continuing Federal program gaps and conflicts for State and local governments. (See table 2-3 for a list of committees.) This fragmentation has characterized the long history of Federal involvement in public works. It continues because transportation and environmental infrastructure underpin and affect a wide range of activities essential to the economy and public health of every district. Furthermore, congressional history shows that, in most cases, Congress has chosen to decentralize and spread decisionmaking, rather than to consolidate and coordinate the Federal legislative process.

Evolution of the Committee System

Originally established in 1789 on an ad hoc basis to draft specific legislation, congressional committees have evolved into permanent bodies with authority to propose legislation, an independence that has given committees almost unassailable power over legislation in their specialized areas.[52] During the 19th century, standing committees proliferated, gaining more independence from chamber and party control and acquiring most of their present day powers; by 1913, the House operated with 61 standing committees and the Senate with 74. Committee chairs wielded enormous power after the "House revolution of 1910" decentralized leadership, limiting the role of the Speaker by establishing

[50] James Q. Wilson, *Bureaucracy (New York, NY:* Basic Books, 1989), p. 285.

[51] Vig and Kraft, op. cit., footnote 45, p.19.

[52] Judy Schneider, updated by Carol Hardy, The *Congressional Standing Committee System—An Introductory Guide* (Washington, w: Congressional Research Service, May 1989), p. 2.

Table 2-3-Partial List of Congressional Committees With Jurisdiction Over Public Works

	Jurisdiction over environmental legislation	Jurisdiction over transportation legislation
House committees:		
Agriculture Subcommittee on Conservation, Credit, and Rural Development	X	X
Appropriations Subcommittees:		
Energy and Water Development	X	X
VA, HUD, and Independent Agencies	X	X
interior	X	—
Rural Development, Agriculture, and Related Agencies	X	X
Transportation	X	X
Banking, Finance, and Urban Affairs Subcommittees:		
Housing and Community Development	X	X
General Oversight and investigations	X	—
Policy Research and Insurance	X	X
Economic Stabilization	X	
Budget Committee	X	X
Energy and Commerce Subcommittees:		
Energy and Power	X	—
Health and the Environment	X	—
Oversight and Investigations	X	X
Transportation and Hazardous Materials	X	X
Foreign Affairs Subcommittee on Western Hemisphere Affairs	X	—
Government Operations Subcommittees:		
Environment, Energy, and Natural Resources	X	X
Government Activities and Transportation	X	X
Government Information, Justice, and Agriculture	X	.
Interior and Insular Affairs Subcommittees:		
Energy and the Environment	X	—
General Oversight and Investigations	X	—
Water, Power, and Offshore Energy Resources	X	—
Merchant Marine and Fisheries Subcommittees:		
Coast Guard and Navigation	X	X
Fisheries and Wildlife Conservation and the Environment	X	—
Oceanography and Great Lakes	X	—
Public Works and Transportation Subcommittees:		
Economic Development	X	X
Water Resources	X	X
investigations and Oversight	X	X
Aviation	—	X
Surface Transportation	—	X
Science, Space and Technology Subcommittees:		
Natural Resources, Agriculture Research, and Environment	X	—
Science, Research, and Technology	X	X
investigations and Oversight	X	X
Transportation, Aviation, and Materials	—	X
Senate committees:		
Agriculture, Nutrition, and Forestry Subcommittees:		
Agricultural Credit	X	—
Rural Development and Rural Electrification	.	X
Appropriations Subcommittees:		
Agriculture and Related Agencies	X	X
Energy and Water Development	X	X
Transportation	—	X
VA, HUD, and Independent Agencies	X	X
Interior	X	X
Banking, Housing, and Urban Affairs Subcommittee on Housing and Urban Affairs	X	X
Budget Committee	X	X
Commerce, Science and Transportation Subcommittees:		
Aviation	—	X
Merchant Marine	—	X
Science, Technology, and Space	X	X
National Ocean Policy Study	X	—
Surface Transportation	—	X

(Continued on next page)

Table 2-3-Partial List of Congressional Committees With Jurisdiction Over Public Works-Continued

	Jurisdiction over environmental legislation	Jurisdiction over transportation legislation
Energy and Natural Resources Subcommittees:		
Energy Regulation and Conservation	x	—
Energy Research and Development	x	—
Water and Power	x	—
Environment and Public Works Subcommittees:		
Water Resources, Transportation, and Infrastructure	x	x
Environmental Protection	x	—
Superfund, Ocean, and Water Protection	x	—
Toxic Substances, Environmental Oversight, Research and Development	x	—
Foreign Relations Subcommittee on International Economic Policy, Trade, Oceans, and Environment	x	—
Government Affairs Subcommittee on Oversight of Government Management	x	—

SOURCE: Office of Technology Assessment, 1991, based on material from *Congressional* Yellow Book (Washington, DC: Monitoring Publishing Co., fall 1989).

seniority as the major criteria for determining committee chairmanship and moving up in the ranks.[53]

Largely because the decentralized committee system hampered efficient policy development during World War II, Congress eliminated minor committees and merged many with related functions under the Legislative Reorganization Act of 1946. The act defined for the frost time the jurisdictions of each committee and established uniform procedures, including hiring of permanent committee staff. These committee jurisdictions, as they have been modified since 1946, are part of House rule X and Senate rule XXV.

Responding to the upsurge of socioeconomic, environmental, and foreign policy issues in the 1960s and 1970s, Congress gradually expanded the power of committees and their chairs and created a number of specialized subcommittees. The Legislative Reorganization Act of 1970 opened committee work sessions to the public, permitted committee chairs selection based on factors other than seniority, authorized subcommittees to hire separate staffs, and set the stage for further organizational reforms (see box 2-E).

Congress' internal party organizations in each house assign members to committees, considering their preferences, party needs, and the geographical and ideological balance of each committee. In the 10lst Congress, the Senate had 16 standing committees and 87 subcommittees; the House operated with ***22*** committees and 146 subcommittees.[54] The average Senate committee had five subcommittees, compared with seven in the House. Every House member, except top party leaders, served on at least one standing committee, and Senators served on at least two committees.

Committee Functions

Committees propose and review legislation, including bills to raise and spend public funds. Most bills are referred by the House or Senate leadership, in cooperation with the Parliamentarian, to one standing committee, but the complexity of public policy issues means that major bills are often sent to multiple committees with overlapping jurisdictions. Individual committee rules determine a bill's subcommittee assignments, which also can overlap. See table 2-4 for those committees with important legislative jurisdiction over public works.

Committees and subcommittees are also responsible for overseeing Federal agencies and programs under their jurisdiction. As part of oversight activities, agency officials are called to Capitol Hill to testify. EPA and DOT officials annually testify before numerous committees, each with a unique perspective and objective.

Authorizations and Appropriations

Authorizing committees in both houses report annual or multi-year authorization bills for Federal programs under their jurisdiction, thereby setting the maximum amount of money an agency may spend

[53]Ibid., p. 3.

[54]In addition, the 101st Congress has 9 special or select committees with 11 subcommittees and 4 joint committees with 8 subcommittees whose functions are primarily investigative.

Box 2-E—Anatomy of Recent Congressional Reforms

The most recent broad changes in House committee jurisdiction and procedures occurred in 1974, under the auspices of the House Select Committee on Committees, The committee's preliminary proposal called for cutting into the broad jurisdictions of Ways and Means, Commerce, and Education and Labor, while adding to the jurisdictions of Foreign Affairs, Public Works, Science and Astronautics, and for eliminating several narrow-purpose committees. The proposal also suggested a mechanism for referral of bills to multiple committees. The recommendatiom drew immediate fire from committee members, staff, and interest groups, who saw years of accumulated seniority or political connections threatened by committee dissolution or jurisdictional reduction. Responding to this pressure, the House chose not to eliminate any committees but required committees with 20 members or more to form subcommittees; it retained provisions for multiple referrals and for increased committee staffs.[1] Power, particularly in the House, shifted from full committees to subcommittees.

A year later, additional reform measures were adopted, primarily reducing the power of committee chairs. Election of Appropriations subcommittee chairs was shifted from the committee to the party caucus, an acknowledgment of their status as tantamount to full committee chairs.[2] In 1977 and 1979, the House rejected further attempts to reform committee organization, such as the consolidation of energy jurisdictions into one committee, although the jurisdiction of the Committee on Interstate and Foreign Commerce was broadened and it was renamed Energy and Commerce.

Senate committee reorganization has been somewhat more successful. In 1977, the Temporary Select Committee to Study the Senate Committee System recommended a reduction to 12 standing committees organized along functional lines. The proposal Called for anew Energy and Natural Resources Committee, consolidating most energy-related functions. Although the proposals required substantive committee restructuring and dissolution of several committees, the reorganization plan was carefully orchestrated by Senate bipartisan leadership and passed--with compromise amendments-by an overwhelming margin.[3]

Political muscle blocked several key consolidations, however. A recommendation to shift jurisdiction over the coastal zone management program from the Commerce Committee to the new Committee on Environment and Public Works was eventually rejected by the Rules Committee after strenuous objections by Commerce; jurisdiction over oceans, weather, and atmosphere was also retained by Commerce.[4] In addition, special interest groups lobbied sucessfully to preserve the Veterans' and Select Small Business committees and stopped plans to consolidate transportation legislation into one committee.[5] This 1977 realignment has not been changed.

1 Steven S. Smith and Christopher J. Deering, *Committees in* Congress (Washington, DC: Congressional Quarterly, Inc. 1984), p. 46.

2 Ibid., p. 47.

3 Ibid., p. 49.

4 Congressional Quarterly, Inc., *How* Congress *Works* (Washington, DC: 1983), p, 84.

'Ibid., p. 99.

on a specific program. The exceptions are entitlement programs, such as social security and Medicaid, which operate under permanent authorization and are effectively removed from the authorizing process. Authorizations are also linked to a budget resolution, prepared by House and Senate committtees on the budget, establishing an overall ceiling and limits for major spending areas, like health or transportation. Authorizing, or legislative, committees and subcommittees are influential through their oversight functions when major new legislation is first passed, when an agency is created or its program substantially modified, and in setting funding authorizations. During the 1980s, deficit reduction laws and trends restricting spending, shortcomings in the budget process, and new programs greatly expanded the roles of the "money" committees-Appropriations, Budget, and Ways and Means on the House side and Appropriations, Budget, and Finance in the Senate-at the expense of authorizing committees.

Appropriation bills originate with the House Committee on Appropriations and its 13 subcommittees and effectively control spending, since authorized funds may not be spent unless they are also appropriated. EPA's State Revolving Loan Funds are authorized at much higher levels than have been appropriated, for example. Although, in theory, program policy and oversight is reserved for

Table 2-4-Congressional Committees and Their Roles in Public Works Programs

[Ap = appropriations, Au = authorizes major program areas, a = authorizes specific programs, b = sets funding guidelines, o = oversight of programs, t = jurisdiction over funding sources such as trust funds]

	Highways	Mass transit	Aviation	Railroads	Water resources	Drinking water	Wastewater	Solid and hazardous waste
Senate committees:								
Agriculture	a/o	a/o	a/o	a/o	a/o	a/o	a/o	a/o
Appropriations	Ap/o	Ap/o	Ap/o	Ap/o	Ap/o	Ap/o	Ap/o	Ap/o
Banking, Housing, Urban Affairs	—	Au/o			—	—	—	—
Budget	b/o	b/o	b/o	b/o	b/o	b/o	b/o	b/o
Commerce, Science and Transportation	Au/o	Au/o	Au/o		Au/o	—	—	—
Energy and Natural Resources	—	—			—	a/o	a/o	a/o
Environment and Public Works	Au/o	—	Au/o	Au/o	Au/o	Au/o	Au/o	Au/o
Finance	t/o	t/o	t/o	—	t/o	—	—	—
Governmental Affairs	o	o	o	o	o	o	o	o
House committees:								
Agriculture	+:		a/o	a/o	—	a/o	a/o	a/o
Appropriations	0	Ap/o	Ap/o	Ap/o	Ap/o	Ap/o	Ap/o	Ap/o
Banking		a/o	—	—	a/o	a/o	a/o	a/o
Budget	b/o	b/o	b/o	b/o	b/o	b/o	b/o	b/o
Energy and Commerce	a/o	a/o	—	Au/o	S/o	Au/o	a/o	Au/o
Governmental Operations	o	o	o	o		o	0	o
Interior			—	—	A/o	—	—	—
Public Works and Transportation	Au/o	Au/o	Au/o		Au/o	Au/o	Au/o	a/o
Science, Space and Technology	a/o	a/o	Au/o		a/o	Au/o	Au/o	Au/o
Ways and Means	t/o	t/o	t/o	—	t/o	—	—	—
Joint Economic Committee	0	0	o	o	0	0	o	o

SOURCE: Office of Technology Assessment, 1991.

authorizing committees, appropriations committees, which have parallel subcommittees, frequently insert legislative provisions and funding for special projects into bills. Members, responding to district and constituent interests, direct appropriations to public works such as flood control dams, parking garages, and airport or mass transit facilities. The environmentally controversial Tennessee-Tombigbee Waterway in Alabama and Mississippi, built during the early 1980s with Federal funds, was financed in part with appropriations added by the House Appropriations Subcommittee on Energy and Water Development.[55] The appropriations committees' control over spending and tendency to add to previously authorized legislation creates tensions and intensifies intercommittee rivalries, particularly in the House where a smaller proportion of members serve on the Committee on Appropriations.

Jurisdictional Fragmentation

In Congress, jurisdiction or turf can mean additional staff, publicity, and power, prompting committees to seek broad jurisdictions and resist moves to narrow them, and perpetuating conflicts and overlaps. Transportation and environmental issues are particularly susceptible to fragmentation and competition because, while they cut a broad swath across national life, the concept of system integration is relatively new. Historically, each segment developed independently based on different goals and objectives and established supportive committee connections and constituencies that are hard to alter. For example, at least five House authorizing committees have responsibility for water pollution policy, regulation, and support programs, while authority over transportation is spread among three Senate committees and numerous subcommittees (see table 2-4 again). In addition, House and Senate appropriations, budget, and governmental operations committees have broad authority over most governmental programs.

Because of jurisdictional fragmentation and competition, committees have difficulty dealing comprehensively with either transportation or the environment, much less treating them as interrelated systems. Policy and funding levels are set separately for highways, aviation, mass transit, ports and waterways, and railroads and applied to each environmental medium, i.e., drinking water, wastewater, air, and solid waste (see table 2-5). Carefully targeted lobbying by special interest groups reinforces this pattern. Furthermore, executive branch bureaucracies that have grown up with each mode or medium fiercely protect their independent power. Congress has not found a good legislative mechanism to buck traditional allegiances and promote needed linkages, both physical and institutional, among rail, highway, and water transport, and lacks incentive to fund research, planning, or demonstrations for intermodal operations.

Overlapping committee jurisdictions can slow and even stall policy development and send mixed signals to the executive branch and lower levels of government. In 1989, EPA officials testified at 150 committee hearings and responded to 5,000 committee inquiries, enabling executive agencies to play one committee off against the other and in many cases maintain an independent path. Committees that try to develop comprehensive public works policies are frustrated by the vested interests of their sister committees, executive branch agencies, and powerful industry lobbying.

Interest Groups

Interest groups play major roles in the formulation of Federal public works funding and regulatory policy. Of an estimated 6,000 public and special interest groups active in Washington, at least one-third probably have a stake in some aspect of the diffuse public works activities[56] They employ technical experts and lawyers to press their cases to Congress, testifying at hearings, providing privileged information, drafting model legislation, publishing and distributing reports,[57] and meeting with congressional members and staff. Political Action Committees (PACs), the political arm of private interest groups, make campaign contributions. The number of interest groups increased dramatically during the 1970s and 1980s, at least in part because of the expansion of congressional subcommittees, which provided more opportunities for lobbying,

[55] Diane Granat, "Special Report: House Appropriations Committee," *Congressional Quarterly*, June 18, 1983, p. 1216.

[56] Deborah M. Burek et al. (eds.), *Encyclopedia of Associations*, vol. 2 (Detroit, MI: Gale Research, Inc., 1989).

[57] At least six national interest groups, including the American Association of State Highway and Transportation Officials, the American Public Transit Association and the American Transportation Advisory Council, have published policy plans for transportation in preparation for the renewal of the Surface Transportation Act in 1991.

Table 2-5-Number of Committees With Jurisdiction Over Public Works

Functions	Number of committees
Highways	16
Mass transit	15
Aviation	14
Railroads	10
Water resources	16
Drinking water	14
Wastewater	14
Solid hazardous waste	14

SOURCE: Office Office of Technology Assessment 1991.

and greater public participation in executive agency rulemaking.

An established, well-financed interest group can be very effective in presenting its case to Congress. However, the diverging points of view represented by interest groups concerned with public works divert policymakers from long-range, comprehensive governance issues and reinforce the existing policy framework. Executive agencies like EPA and DOT have become accustomed to the tenacious oversight of interest groups and to their active participation in rulemaking hearings-and to the lawsuits that ensue when interest groups are dissatisfied with Federal legislation or agency regulations.

Industry and Labor

The most numerous interest groups are industry and labor associations, representing public works equipment manufacturers, builders and contractors, facility owners and managers, professional and employee groups, suppliers, and users. (See table 2-6 for a partial listing.) In addition, a growing number of corporations employ their own lobbyists.

Industry clearly has an enormous stake in Federal public works spending and regulatory policies. At the most basic level, industry relies on public works systems for essential facilities (water supply and sewer service), and for transportation (highways, transit, airports, railroads, ports, and waterways) of workers and materials and the distribution of goods and services. International competitive position and

Table 2-6--A Selection of Major Industry Interest Groups

Highways	***Railroads***	***Mass transportation***
American Association of State Highway and Transportation Officials	Association of American Railroads	American Public Transit Association
Highway Users Federation	American Short Line Railroad Association	United Bus Operators of America
American Trucking Association	Regional Railroads of America	American Bus Association
National Private Truck Council	United Transportation Union	Amalgamated Transit Union
American Road and Transportation Builders Association		international Brotherhood of Teamsters, Chauffers, Warehousemen, and Helpers of America
international Bridge, Tunnel, and Turnpike Association		international Mass Transit Association
international Brotherhood of Teamsters, Chauffers, Warehousemen, and Helpers of America		
Airports	***Ports and waterways***	***Drinking water***
American Association of Airport Executives	American Association of Port Authorities	American Water Works Association
Airport Operators Council international, Inc.	American Waterway Operators	American Public Works Association
National Association of State Aviation Officials	National Waterway Conference	American Society of Civil Engineers
Air Transport Association of America	American Bureau of Shipping	Association of State Drinking Water Administrators
Aircraft Owners and Pilots Association	Inland Rivers, Ports, and Terminals	Association of Metropolitan Water Agencies
National Business Aircraft Association	Propeller Club of the U.S.	American Academy of Environmental Engineers
Air Line Pilots Association	Rivers and Harbors Congress	American Clean Water Association
Allied Pilots Association	international Longshoremen's Association	Water and Wastewater Equipment Manufacturers Association
National Association of Air Traffic Specialists		
Wastewater treatment	***Solid waste***	
Water Pollution Control Federation	National Solid Wastes Management Association	
American Public Works Association	Association of State and Territorial Solid Waste Management Officials	
Association of State and interstate Water Pollution Control Administrators	Governmental Refuse Collection and Disposal Association	
Association of Metropolitan Sewerage Agencies	American Recycling Association	

SOURCE: Office of Technology Assessment, 1991.

profit levels are tied to manufacturing and distribution speed, efficiency, and flexibility, all of which are dependent on high levels of infrastructure services. Second, the construction of roads, bridges, sewer treatment plants, and other public works facilities, and the manufacture of construction and operating equipment, are pivotal segments of the national economy, employing millions and generating contracts worth billions of dollars. Finally, Federal safety and environmental regulations have profound impacts on industry operations and profits.

Associations less frequently initiate action than work to influence and shape prospective governmental policy changes. Although their positions vary on specific issues, their representatives uniformly work to increase benefits to their own industries and to minimize the impacts of Federal actions on their members. Trucking groups, for example, support increases in truck size and weight limits as a trade-off for fuel tax hikes, and contractors opposed the 1986 Tax Reform Act because they feared it would curb construction of quasi-public projects like parking garages and civic centers. Some accommodation must be reached between opposing industry and user groups if major legislation is to pass. Thus, while many industries engage in and benefit from intermodal transportation, only a handful support intermodal improvements.

Public Interest Groups

Special public interest groups are fewer in number and organize around issues rather than an industry. While some are long established, like the National Wildlife Federation or the Sierra Club, others rose out of the political ferment of the 1960s. Groups like the Environmental Defense Fund and Center for Auto Safety focus on public welfare issues such as environmental protection and motor vehicle safety. (See table 2-7 for examples of these groups.) They are vigorous and often effective advocates for increased Federal support for environmental and safety programs and for enforcement of antipollution and public health regulations, positions that often put them at odds with industry groups.

Governmental Interest Groups

State and local governmental organizations, like the National Governors' Association, the National League of Cities, the National Association of Towns and Townships, and the National Conference of State Legislators, forma small but influential group

Table 2-7-Selected Public Interest Groups Concerned With Public Works

Airline Passengers Association of America
Aviation Consumer Action Project
Center for Study of Responsive Law
Center for Auto Safety
Center for Concerned Engineering
Citizens for Reliable and Safe Highways
Environmental Defense Fund
Environmental Policy Institute
Environmental Action
National Association of Rail Passengers
National Audubon Society
National Wildlife Federation
Natural Resources Defense Council
Nature Conservancy
Professional Drivers Council for Safety and Health
Sierra Club

SOURCE: Office of Technology Assessment, 1991.

on Capitol Hill. Busy with their own agendas, they are often less assertive than industry in pressing their views in Congress. However, recently they have argued effectively for changes to the 1986 Federal tax law and for grant and regulatory flexibility. These groups have a major common concern: the impact on State and local governments of unfunded Federal mandates coupled with rising social service responsibilities and costly infrastructure needs.

The State Role

Although for much of this century, the State role was limited to financing and constructing roads and highways, the States have assumed both greater programmatic and technical leadership and more financial responsibility for public works in recent years. To encourage economic development and compensate for Federal program cutbacks, States have invested heavily in transportation-funding about 50 percent of highway needs and, in many cases, transit, air, rail, ports, and harbors as well. As required by Federal legislative and regulatory actions, all States have expanded their participation in drinking water and wastewater treatment programs, and some have assumed a role in addressing solid waste disposal problems.

At present, State governments administer a variety of State funded and Federal-aid programs for public works and enforce a myriad of Federal and State regulations; many offer substantial financial and technical assistance programs as well (see chapters 3 and 4 for further details). In fact, many State officials and some experts contend that during the 1990s, institutional and financial innovations are

more likely to be found at the State and local level than in the Federal Government.[58]

States and Public Works Financing

In general, States have increased their fiscal autonomy, generating revenues for expanded programs by broadening general tax bases and increasing benefit and user fees. (Table 2-8 shows the major financing mechanisms.) Furthermore, States have learned how to negotiate public-private partnerships, and most have aggressive economic development programs. They have adopted new financing and management mechanisms, such as State revolving loan funds that leverage seed capital to multiply funds for financing environmental public works, to deal with increasingly complex public service issues. Most States now operate under the guidance of 5-to 6-year capital improvement programs that rank and schedule expenditures for major projects. Backed by well-researched data and with carefully constructed public information programs, States like New York and Iowa have won voter support for long-term transportation improvement plans tied to targeted tax increases. Some States are helping localities to finance public works improvement programs with carefully selected packages of State fees and taxes.[59] Box 2-F describes New Jersey's assistance programs.

However, each State's financial status and fiscal strategies differ, shaped by its unique geographic, political, and economic characteristics (see chapter 1, table 1-10 for a fiscal summary of the 50 States). Large, rural States and others dependent on agriculture or mining did not share the economic expansion of the second half of the 1980s. Their ability to pay for public investments-a capability grounded in economic factors such as per capita income, industrial production, and retail sales-is low, and these States rely on Federal assistance programs. States most dependent on Federal aid for transportation and environmental public works programs are shown in figures 2-1 and 2-2. In contrast, some States with strong, diversified economies have the fiscal capacity to generate additional revenue but elect to keep their tax structure narrow and rates low. (See appendix A for further information on fiscal capacity and effort.) At least 20 States, responding to taxpayer protests, have limited their own fiscal authority to spend and borrow, and many States hold local governments to strict bonding, taxing, and spending limits. Where feasible, they have also made local projects self-sufficient by offering loans rather than grants. (See box 2-G for a profile of the Washington State Trust Fund which offers loans to communities that have made strong self-help efforts.)

The Federal focus on individual transport modes and environmental media is replicated in well-established, independent State bureaucracies and strong industry groups. Local officials must deal with the results of this program segmentation and comply with a variety of specific Federal regulations, some of which may conflict. In addition, local managers must find ways to utilize Federal funding programs that do not mesh for interdependent facilities like highways and airports. Narrow categorical Federal funding programs afford little flexibility for integrated solutions to pressing problems, and programs that promote intermodal transportation are major casualties of these conditions. Although new State levies and tax rate increases are raising more funds than ever before, expenditures are climbing even faster, and the number of States struggling to balance their budgets is rising.[60] In particular, the growth rate of education costs and the State share of entitlement programs are outstripping revenue, necessitating program cutbacks. Medicaid costs already consume as much as 30 percent of some State budgets and are expected to rise to almost 50 percent during the 5 years between 1989 and 1994.[61]

Benefit and User Charges

Because general revenues must be used for entitlement programs, States have turned increasingly to benefit charges, such as user fees, developer impact charges, tolls, and special assessments for financing public works capital. Benefit charges are attractive and effective strategies because of their revenue potential, voter acceptability, and service

[58] David Osborne, *Laboratories of Democracy* (Boston, MA: Harvard Business School Press, 1989).

[59] For further information, see Office of Technology Assessment, op. cit., footnote 4, ch. 3.

[60] National Governors' Association and National Association of State Budget Officers, *Fiscal Survey of the States* (Washington, DC: 1989), p. 3.

[61] Office of Management and Budget, *Budget of the United States Government* (Washington, DC: U.S. Government Printing Office, 1989), historical tables, p. 293.

Table 2-8--Major Infrastructure Financing Mechanisms: Advantages and Disadvantages

	Advantages	Disadvantages
General fund appropriation	*Administrative:* appropriations reflect current legislative priorities. *Equity:* all taxpayers contribute to capital projects. Fiscal: no debt incurred, so projects cost less during periods of inflation.	*Administrative:* infrastructure must compete with other spending priorities each year; cannot plan long-term projects around uncertain funding. *Equity:* no direct link between beneficiary and who pays, and current generation pays for capital projects that benefit future generations.
General obligation bonds	*Equity:* capital costs shared by current and future users. fiscal: bonds can raise large amounts of capital; general obligation bonds usually carry lowest available interest rates.	*Administrative:* States often impose debt ceilings and require voter approval. Fiscal: adds to tax burden, especially if interest rates are high.
Revenue bonds	*Administrative:* do not require voter approval and are not subject to legislative limits. *Equity:* debt service paid by user fees, rather than from general revenues.	*Administrative:* require increased reporting and restricted by Tax Reform Act limitations. Fiscal: usually demand higher interest rates than general obligation bonds.
State gas tax	*Administrative:* established structure allows tax increase without additional administrative expense. *Equity:* revenues are usually earmarked for transportation, so users pay. Fiscal: revenues relatively high compared with other user taxes.	*Administrative:* revenue fluctuates with use of gas. *Equity:* fiscal burdens are not evenly distributed between urban and rural areas. Fiscal: revenue does not reflect differences in infrastructure use which can determine capital needs.
Other dedicated taxes	*Administrative:* voters prefer dedicated taxes. Fiscal: provides relatively reliable funding source not subject to annual budgeting.	*Administrative:* reduces districts' ability to meet changing needs. Fiscal: major economic downturns can reduce revenues significantly.
State revolving funds	*Administrative:* promote greater State independence in project selection. *Fiscal:* debt service requirements provide incentives for charging full cost for services; loans can leverage other sources of funds; loan repayments provide capital for new loans.	*Administrative:* States bear increased administrative and financial responsibility. *Equity:* poor districts cannot afford loans. Fiscal: repaying loans will mean increases in user charges or taxes.

SOURCE: Office of Technology Assessment, 1991.

management opportunities. However, these charges have major socioeconomic trade-offs, including administrative issues, equity, and revenue reliability in the case of a political backlash, an economic downturn, or real hardship. For example, States with low economic bases and/or small populations have great difficulty developing sufficient capital solely from user fees and other benefit charges.[62]

Because of the acceptability of financing transportation with State user fees (gas taxes and vehicle registration fees, primarily), States can provide more financial support for transportation improvements than for environmental public works programs. (See table 2-9 for State gas tax rates and yields.) Highways, aviation, and, to some extent, transit, rely on user-fee financing, while State revenues earmarked for water supply or wastewater treatment programs are unusual. However, inflation has eroded the purchasing power of per-gallon gas and fixed vehicle charges, and more fuel efficient

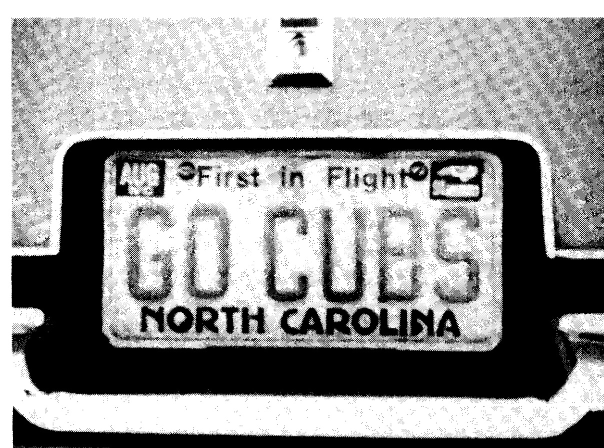


Photo credit: *Dan Broun, OTA staff*

Charges for vanity plates such as this one area popular form of State user fees. Drivers can tailor their own license plates for an extra fee.

[62] See Office of Technology Assessment, op. cit., footnote 4, pp. 114-116 for a more detailed discussion.

Box 2-F—New Jersey Infrastructure Financing

The New Jersey State Legislature enacted three infrastructure financing programs in the mid-1980s. The New Jersey *Transportation Trust Fund*, established in 1984, uses revenue bonds backed by dedicated motor vehicle fuel taxes to fund a $320.3 -million program. The trust fund undertakes direct spending programs and finances State aid to counties and municipalities for transportation system improvements.

The *Resource Recovery and Solid Waste Disposal Program*, first established in 1980 and substantially expanded in 1985, authorizes grants and low- or no-interest loans to local governments to cover 10 percent of project costs for the development of resource recovery facilities and environmentally sound sanitary landfills. The State Department of Environmental Protection manages the program, which is backed by $168 million ($135 in general obligation bonds and $33 million transferred from the general fund). The loans are secured by rate covenants or revenue bond letters of credit. Local payback of the loans commences 1 year after the plant begins operations.

The New Jersey *Wastewater Treatment Trust Fund*, established in 1985, is an independent financing authority with the power to issue bonds backed by the trust's loan agreements with borrower localities. These agreements, in turn, are secured by user-fee covenants, a State-appropriated reserve fund, and municipal bond insurance. Funds to localities come from the Wastewater Treatment Trust, an independent authority, and the Wastewater Treatment Fund, administered by the State Department of Environmental Protection. This program highlights two issues associated with the substitution of loans for grants, First, when a fiscally troubled jurisdiction considers the alternatives of environmental noncompliance and exceeding its debt capacity by applying for a loan, rather than a grant, polluting may well appear the lesser of two evils. Second, although grant allocation decisions are based on environmental priorities, local financial solvency is a major consideration, and a high credit rating often outweighs a top spot on the Federal Clean Water Act priority list.

[1]Material on New Jersey infrastructure financing is based on the following reports: Council on New Jersey Affairs, *New Jersey Issues: Papers From the Council on New Jersey Affairs* (Princeton, NJ: Princeton Urban and Regional Research Center, Woodrow Wilson School of Public and International Affairs, March 1988); and Sophie M. Korczyk, "State Finance for Local Public Works: Four Case Studies," OTA contractor report, Dec. 19, 1988 (available from NTIS, see app. D).

vehicles reduce the taxes received per mile traveled. Over the last 15 to 20 years user-fee revenues per mile have dropped about 50 percent.[63]

Importance of the Federal partnership

Public-private partnerships and higher benefit and user charges are part of the answer for States in meeting their backlogs of public works improvements. However, their contributions are necessarily limited by their rates of local growth and by equity considerations. These limitations and steady growth in social program costs for States underscore the importance of reliable Federal financial support. Although Federal funds contributed less than 20 percent of public works capital investment during the late 1980s, compared with almost 30 percent in the 1960s,[64] this support was essential in assisting States and their local governments to upgrade public works and meet Federal requirements.

Administration and Planning

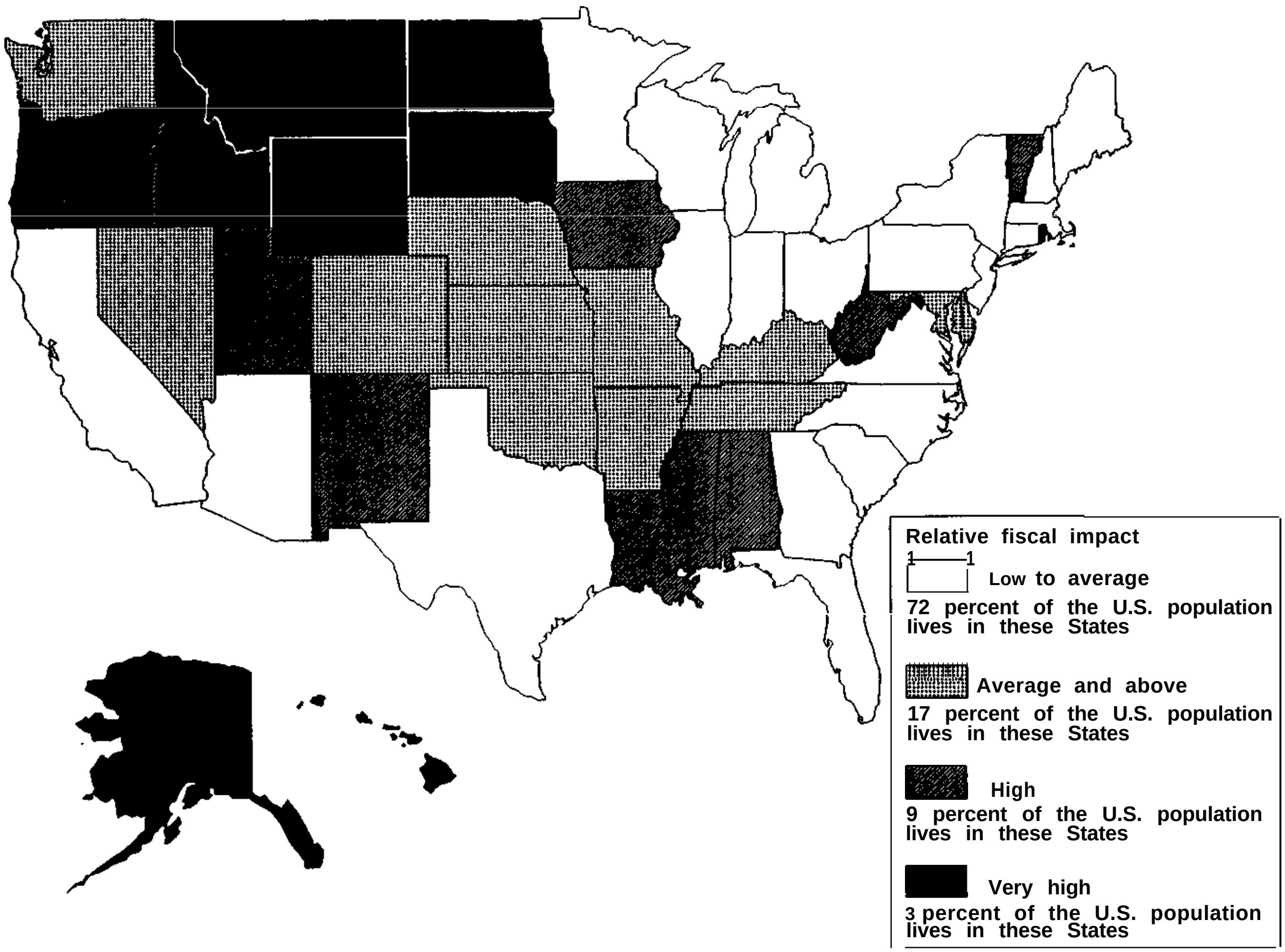
Most States play an active role in administering highway arid bridge programs and in enforcing Federal and State health and safety regulations. Generally, State officials accept the need for Federal regulations and enforcement to protect public health and safety. However, the sheer number of regulations and the frequency with which they change, their inflexibility, and the time and costs compliance adds to the project create administrative difficulties and frustrations.

State successes in achieving public works efficiency through effective land-use planning have been uneven, and most Federal grants that supported State planning efforts ended in the early 1980s. Some States do not have an official State planning program and offer no support for regional or local comprehensive planning. However, a few States, especially those with sustained growth, such as Florida, Georgia, and New Jersey, have taken steps

[63]Jenifer Wishart, vice president, James F. Hickling Management Consultants Ltd., testimony at hearings before the House Committee on Banking, Finance and Urban Affairs, Subcommittee on Policy Research and Insurance, May 8, 1990.

[64]Office of Technology Assessment, op. cit., footnote 4, P- 36.

Figure 2-1—Projected Impact on States of Reduced Federal Aid for Transportation[a]



[a]Impact is defined as the relative level of effort each State would have to make to replace a hypothetical 50 percent cut in Federal aid.

SOURCE: Office of Technology Assessment, 1991, based on information provided by Apogee Research, inc.

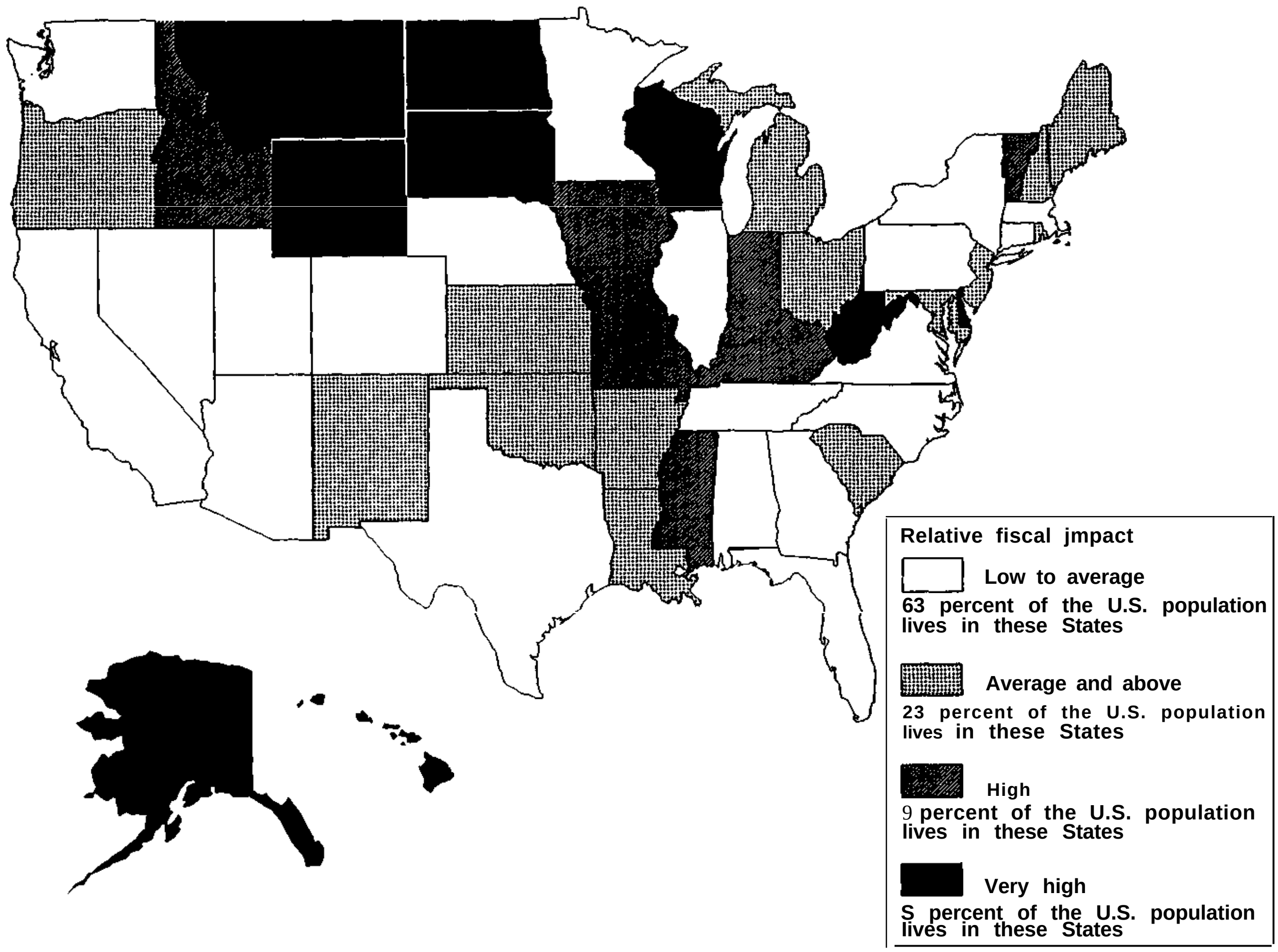
to require coordination between regional land-use policies and infrastructure development. Florida requires planning and development reviews at the State, regional, and local level (see box 2-H).

Pollution and natural resource issues transcend political boundaries and clash frequently with economic development goals. State administrators often must coordinate plans for and mediate disputes over environmental, development, and transportation issues among local jurisdictions, interest groups, State agencies, and other States. Interstate compacts, such as the one among Maryland, Virginia, Pennsylvania, and the District of Columbia to clean up the Chesapeake Bay, and State-supported regional planning programs like Florida's are promising institutional changes.

Local Government Service Providers

Rapidly growing counties, old central cities, and small towns are all caught in the squeeze between unfunded Federal and State environmental and social service mandates and escalating service demands on the one hand and budget constraints, weak institutions, and enforcement policies on the other. Direct links to Washington for grants or revenue sharing have disappeared, and while the best solutions are often local, the most difficult issues are frequently interjurisdictional. The opportunities for dispute have multiplied as communities have become more interdependent and interest groups more vocal and narrowly focused. Local officials must mediate conflicts between economic development and environmental interests (for exam-

Figure 2-2—Projected Impact on States of Reduced Federal Aid for Environmental Public Works[a]



[a]Impact is defined as the relative level of effort each State would have to make to replace a hypothetical 50 percent cut in Federal aid.

SOURCE: Office of Technology Assessment, 1991, based on information provided by Apogee Research, Inc.

pie, airport noise and expansion) and between neighborhoods and other communities over the siting of new highways and landfills. If institutional solutions to disputes are not available, stalemate will aggravate problems of congestion or public health. Even the threat of losing Federal funds or of frees may not be enough to trigger action.

Local Financing

Traditionally, the Nation's 83,000 local governments have financed most capital investment and all of their operating budgets locally, but their customary broad-based taxes, principally on property, no longer produce sufficient revenue to finance essential services. Local officials push property taxes as high as they can, and increase targeted (earmarked) sales, income, and other taxes. Economically strong communities have raised user fees for sewer and water service, established special improvement districts, and charged developers fees for roads and sidewalks (see box 1-C in chapter 1). But communities with weak economies or a large backlog of deficiencies have had to defer upgrading their systems to cut expenditures-about 37 percent of the Nation's cities in 1990.[65] Communities that appeal to their State governments for new or expanded tax authority may be frustrated by State limits on local borrowing and tax rates, and Federal

[65]Douglas D. Peterson, "City Fiscal Conditions in 199@" *Research Reports on America's Cities* (Washington, DC: National League of Cities, 1990), p. v.

Box 2-G—Washington State Public Works Trust Fund[1]

The Washington State Public Works Trust Fund (PWTF) is an example of a successful multipurpose infrastructure funding program. It emphasizes project self-sufficiency, comprehensive planning, and allocation according to ability to pay as well as severity of need.

The PWTF grew out of a 1982-83 statewide survey of Washington State infrastructure needs that pointed to serious gaps in the State's management of infrastructure. Capital spending for public works was at its lowest in 20 years and was expected to continue declining, while projected needs would require at least a 250 percent spending increase. These findings prompted the legislature to direct what is now the Washington State Department of Community Development (DCD) to prepare a plan for replacing and repairing local public works holdings.

As required by its mandate, DCD surveyed over 600 local jurisdictions about their needs and available resources. DCD found that total projected needs reached $4.3 billion, but that local resources could only meet 53 percent of this. The legislature responded by working with DCD to set up a new loan program and reaching out to localities, including them in the program design process, and linking the program directly to local needs and resources. DCD's subsequent report, *Financing Public Works: Strategies for Increasing Public Investment,* provided the design for the Public Works Trust Fund.

Annually DCD invites all Washington cities, counties, and special-purpose districts to apply for low-interest (1 to 3 percent) loans from the PWTF. The PWTF draws its funds from three sources: water, sewer, and garbage collection taxes; a portion of the real estate excise tax; and ultimately, loan repayments. A 13-member Public Works Board evaluates the applications. The Association of Washington Cities, the Association of Washington Counties, and associations of water, public utility, and sewer districts nominate elected officials and public works managers. Three members from each of the lists as well as four members of the general public with special public works expertise are appointed to the board The Governor selects one of these latter four to chair the board.

The board passes its annual project recommendations onto the State legislature. After approving a project list based on the board's list of priorities, the. legislature passes an appropriation from the Public Works Assistance Account to cover the cost of the loans granted. The Governor then signs the appropriation into law.

An important goal in the design of the PWTF was to discourage localities from deferring maintenance and repair, a side effect of traditional grant allocation systems, which dole money out to the neediest localities. The PWTF program calls for the Public Works Board to base less than one-half (40 percent) of a locality's score on needs, and a full 60 percent of the score on the jurisdiction's demonstrated commitment to help itself. The board evaluates local effort by reviewing the jurisdiction's maintenance strategy, the percentage of local funds dedicated to public works, and the overall system of financial management. Since 1986, the PWTF has provided 194 loans totaling $100 million. Local jurisdictions have matched this amount with about $128 million in local funds for the completion of the projects.

Before it can be considered for a loan, a locality must levy at least a 0.25-percent real estate excise tax earmarked for infrastructure spending. It also must develop a Capital Improvement Plan (CIP) for the specific infrastructure category (i.e., roads, bridges, water systems, storm sewers, and sanitary sewers) for which the loan is being sought.[2] For the 1991 loan cycle, DCD will require a comprehensive CIP covering all of the five categories of infrastructure for which loans are offered. To compensate for potential bias in favor of large, wellfunded jurisdictions, DCD offers zero-interest loans of up to $15,000 for the development of local, long-range CIPs. Without comprehensive CIPs, not even small jurisdictions will be able to apply for regular PWTF construction grants after 1991.

Loans are available only to projects that address existing needs; the funds may not be used for growth-related projects, allowing the board to avoid the touchy issue of determining where growth ought to occur. The effects of political interests are further muted by the stipulation that in reviewing the Public Works Board's list, the legislature may delete projects but not add any. This helps preclude pork barrel projects and ensure program integrity.

[1] Material On the Washington State Public Works Trust Fund is based on Isaac Huang, Washington State Department of Community Development, interview, June 1989; and Sophie M. Korczyk, "State Finance for Public Works: Four Case Studies,"' OTA contractor report, Dec. 19, 1988 (available from National Technical Information Service, see app. D).

[2] The Public Works Board defines the minimum elements of an acceptable Capital Improvement Plan as: 1) needs assessment, 2) prioritization of major capital improvement projects for the coming 5 years, 3) project cost estimation, 4) proof that the plan has been updated in the past 5 years, 5) proof that the plan was developed with some general public input, and 6) formal adoption of the plan by a local legal entity.

Table 2-9-State Gas Tax Rates and Yields, 1990

	Gas tax (cents per gallon)	Yield per penny ($millions)		Gas tax (cents per gallon)	Yield per penny ($ millions)
Alabama	13	21	Montana	20	4
Alaska	8	2	Nebraska	22	8
Arizona	17	17	Nevada	18	6
Arkansas	14	12	New Hampshire	16	5
California	14	125	New Jersey	11	34
Colorado	20	15	New Mexico	16	7
Connecticut	22	15	New York	8	55
Delaware	16	4	North Carolina	22	39
District of Columbia	18	2	North Dakota	17	3
Florida	10	61	Ohio	20	44
Georgia	8	35	Oklahoma	16	16
Hawaii	11	4	Oregon	18	14
Idaho	18	5	Pennsylvania	12	46
Illinois	19	44	Rhode Island	20	4
Indiana	15	27	South Carolina	16	18
Iowa	20	14	South Dakota	18	4
Kansas	16	13	Tennessee	21	25
Kentucky	15	19	Texas	15	85
Louisiana	20	23	Utah	19	7
Maine	17	6	Vermont	16	3
Maryland	19	24	Virginia	18	34
Massachusetts	17	28	Washington	22	22
Michigan	15	42	West Virginia	20	10
Minnesota	20	18	Wisconsin	21	20
Mississippi	18	12	Wyoming	9	3
Missouri	11	26			

SOURCE: Office of Technology Assessment, 1991, based on data from The Road Information Program, 1989 State HighwayFundl~Methti(Whingtin, DC: 1990); and Sally Thompson, analyst The Road information Program, personal communication, Oct. 24,1990.

tax reform legislation increased the cost of borrowed capital for some types of local projects. The limits of their fiscal choices make it likely that many communities will be unable to comply with Federal environmental standards (see chapter4).

Management and Planning

Local officials must coordinate and administer a staggering variety of transportation and environmental public works programs. When Federal aid is available, it comes with many strings (environmental impact study and wage rate requirements,for example) that add years to project timelines and raise costs dramatically.[66] Most large android-size communities use a 3- to 5-year capital improvement program (CIP) to schedule and identify financing for major capital expenditures, a concept introduced through the Department of Housing and Urban Development's planning grant program during the 1960s and 1970s. However, most small jurisdictions operate without CIPs, and Federal grants to support their use have been severely cut.

Although most communities are part of regional planning organizations and Federal programs usually have a comprehensive regional planning requirement, these organizations have not been effective in achieving economic and operating efficiencies for public works.[67] Effective regional coordination in highway planning is rare and each jurisdiction fights to maintain its autonomy over land-use decisions. The most successfull regional planning groups have reliable funding,[68] needed to maintain core staff and technical and service capabilities, and clear authority from local governments and State agencies. In California, San Diego's Association of Governments has a major impact because it plays a key role in both transportation planning and financing (see box 2-I), Although local managers recognize their need for more efficient ways of doing

[66] Henry Hulme, former director of Public Works, Arlington County, VA, personal communication, March 1989.

[67] See Mice Of Technology Assessment, op. cit., footnote 4, ch. 4 for* information.

[68] Cutbacks in Federal funding for housing and environmental programs have left Department of Transportation funding as the primary Federal support for regional planning.

Box 2-H—Growth Management and Planning in Florida

Florida grows by an average of 900 new residents each day, and the State endured a fierce political and financial struggle over growth management after enacting one of the Nation's strongest land development regulatory programs in 1985 and taking a stand in favor of comprehensive planning at all government levels. Having survived repeated special interest attacks to weaken the law, the State has completed the required State and regional planning and is halfway through the first phase of the local government planning process. Although State and local officials are having problems finding the funds to implement the new planning and public works requirements, Florida's program can be instructive to other States that are considering a stronger role in growth management.

The State's role in planning began in 1975 with passage of the Local Government Comprehensive Planning Act, which required all local governments to prepare, adopt, and implement local comprehensive plans that included transportation and environmental public works. The initial results of the act were disappointing; most local plans contained only vague goals and policies that made implementation difficult. In 1982, a State study committee identified the absence of strong State and regional planning as a major reason the local plans were ineffective and recommended overhauling the 1975 legislation.[1]

Convinced of the need for strong State and local controls, the legislature adopted the local Government Comprehensive Planning and Land Development Regulation Act of 1985. The keystone provision is the requirement that each of the State's 67 counties, in conjunction with their respective cities, submit a comprehensive 10-year development plan to the State Department of Community Affairs (DCA) for approval. The plans must be consistent with the State comprehensive and regional plans and must spell out in detail what types of development are allowed and where, and where public works systems will go and how they will be financed. Each district must adopt a 5-year capital improvement program and an annual capital improvement budget. The teeth in the legislation is the "concurrency" requirement stipulating that a specified service level for highways, sewers, and other public facilities must be available at the time of the impact accompanying any new development. During the 12 months after a plan is submitted, a local government may not issue a development permit that will result in a reduction in the level of service for any facility identified in the plan.[2] In effect, the State is requiring local governments to provide services according to a comprehensive plan that is tied to a capital improvement budget. Twice a year, local districts may adopt comprehensive plan amendments and submit them to DCA for review. The penalty for noncompliance is a cutoff of State funds, primarily revenue sharing.

Since DCA began compliance review of local plans in April 1988, of the 248 plans received, 119 have been approved. Of the 128 plans currently not in compliance, 80 can be approved once changes agreed to in negotiations with the State have been made.[3] Despite some builders' claims that all development will be stymied unless local standards are lowered or the State substantially increases funding for public works, no county or city has a development moratorium.

Although local and State officials agree on the need for comprehensive planning, local governments want the State to take a bigger and more responsible role in financing needed public works, estimated to cost at least $1.6 billion annually through the year 2000. The State has resisted local pleas for an increase in the State gas tax rate. Local governments frequently have not included transportation projects, funded by the State Department of Transportation (DOT), in their local comprehensive plans, because the funding schedule for the projects has been unpredictable.[4] To remedy this, 1989 legislation enables local governments to count on State monies for the fist 3 years of DOT's 5-year plan and the State has begun to prohibit State funds to support transportation projects that are inconsistent with local plans. The legislature has also given local governments authority to levy a l-cent local sales tax dedicated to infrastructure and a l-cent local gas tax for roads, although both levies are subject to local referenda, which makes them unpopular with elected officials. Currently, 24 counties have passed the sales tax and 10 have defeated it.[5] Furthermore, Florida is establishing new funding mechanisms to help in local plan implementation, such as the Florida Communities Trust Act, which will provide State funds for local purchase of land identified in comprehensive plans as needed for environmental protection.

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[1] Daniel W. O'Connell, "Local Government Comprehensive Planning and Land Development Regulation Act," *Florida Environmental and Urban Issues, vol. 13, No.* 1, October 1985, p. 4.

[2] State of Florida, "Senate Staff Analysis and Economic Impact Statement," accompanying Senate Bill 2A, June 3, 1989, p. 1.

[3] Baker, legislative director, Florida State Department of Community Affairs, personal communication, Nov. 5, 1990.

[4] State of Florida, op. cit., footnote 2, p. 4.

513&~, op. cit., footnote 3.

Box 2-I-SANDAG: Financing Means Planning Power

Although State and local districts are often reluctant to sham authority with a regional organization, San Diego's Association of Governments (SANDAG)is an exception. Designated as the State Metropolitan Planning Organization (MPO), SANDAG plays a key role in both transportation planning and financing. In 1987, San Diego voters approved a general sales tax increase for capital projects identified in the Regional Transportation Improvement Plan (TIP), and the State designated SANDAG as the chief administering agency in charge of allocating the $100-million annual tax revenue. By virtue of its role as San Diego's MPG, SANDAG prepares the TIP, and thus it can develop and finance the implementation of its own plan-an unusually strong role for a regional agency. SANDAG's financial independence has greatly increased its power within the region and may well alter its other roles. Making financing options part Of the planning process ensures that SANDAG gives careful attention to setting priorities among TIP projects, with the result that plans are realistic and likely to have public support. In addition to transportation planning, SANDAG has initiated an effort to identify all regional public works needs and to develop a regional financing plan.

business, most lack fiscal flexibility to experiment with innovative materials, technologies, or procedures. The lack of a technically competent work force, particularly in small and mid-size communities, further deters experimentation with advanced technologies.

Conclusions and Policy Options

The complex institutional setting for infrastructure makes it difficult for the Federal Government to focus on either transportation or environmental public works problems for the two constituencies with the most pressing needs: small, low-density, or remote, rural jurisdictions and large, densely populated metropolitan areas. Many of today's Federal institutions were developed years ago to meet needs that have long since evolved and changed.

During the last decade or more, Federal leadership in public works policy has eroded. Recognizing the need for system changes and new institutions (e.g., for financing, delivering service, planning, and even conflict resolution), States and local governments are making independent plans and decisions. While these may not always be congruent with national interests, except for DOT's recent policy plan, Washington has been passive at a time of enormous economic, technological, and environmental change. Federal transportation programs and standard-setting have not kept up with industry, and trucking companies are integrating with railroads and shipping companies to form powerful new transportation organizations. States and international committees are taking the lead and setting their own policies. This lack of leadership, coupled with Federal spending cuts, has contributed substantially to the poor condition of the Nation's public works systems.

OTA finds the Federal Government has fallen behind industry, world credit markets, State, regional and local authorities, the courts, and international organizations in determining the national public works agenda. Stronger Federal leadership is needed to develop integrated, long-range national water resources, transportation, and environmental policies that will direct and coordinate intergovernmental and private activities. This effort may result in new goals as well as institutional mechanisms for achieving them. Of necessity, new institutions that change the established decisionmaking processes step on the toes of traditional governmental and private sector interests and compromise local decisionmaking and individual choice to some extent. But the alternative is stalemate, characterized by staggering increases in litigation, and steadily growing inefficiency.

OTA concludes that the time is ripe to review the Federal oversight structure and management practices for public works so that policies are better coordinated and more cost-effective, and decisions about priorities are made wisely. Key factors contributing to fragmented Federal infrastructure policies are the splintering of responsibility among congressional committees and Federal agencies. OTA concludes that EPA's and DOT's effectiveness could be improved significantly in the near term if Congress insisted that each agency integrate its programs to reflect the interdependent nature of transportation and environmental public works problems. One option is to require this for EPA as part of legislation elevating the agency to Cabinet status. Another is to direct EPA and DOT to report to Congress annually on their program coordination efforts. Clearly better advance coordination is required in both Congress and the executive branch to avoid such snafus as the conflict between Federal attempts to reduce revenue loss from tax-exempt bonds in 1986, which worked at cross-purposes with efforts to encourage local private investment.

Almost one-half of congressional standing committees and subcommittees claim jurisdiction over some aspect of public works. The overlapping jurisdictions and divisions of power among congressional committees engender divisive turf battles, thwart coordination of Federal public works policy, and lead to the program conflicts and gaps that State and local governments experience. At the same time the current committee structure, crafted by Congress in the 1970s, has decentralized power, strengthened individual members, developed committee and subcommittee expertise on specific topics, and provided multiple forums for the differing points of view of departments, agencies, special interest groups, and constituents.

Congressional leaders could consider restructuring committee jurisdictions. Commonly suggested options for change include restructuring existing committees to consolidate environmental and transportation functions or establishing new committees that focus on metropolitan or rural infrastructure system issues, including public works. One option is to move authorizing and oversight responsibility for mass transit into Commerce, Science, and Transportation or Environment and Public Works, the principal infrastructure authorizing committees. The House may wish to consolidate authority for environmental programs, providing a more unified environmental policymaking structure. However, history shows structural change is exceedingly difficult. A less radical option is the formation of a select committee or task force composed of fictional area subcommittee chairs to explore and report within 12 to 18 months on the feasibility of developing an integrated national policy on public works.

The Nation's thousands of small communities must construct, operate, and maintain public service facilities that impose high per capita costs, but their fiscal resources are limited because their average per capita incomes are low and their populations are generally declining. Although modest Federal-aid programs exist for small systems, most are targeted

Photo credlt:American Society of Civil Engineers

Older municipalities face traffic delays and massive costs for repairs necessitated by years of neglecting public works. Many of these cities are particularly hard-hit because the value of their tax base has declined.

for transportation. **Expanded aid is necessary for these communities, but large rural States and others dependent on agriculture or mining lack the ability to raise large amounts of capital to share with local governments. The Federal Government has a responsibility to consider financial and technical support for the States lacking the fiscal capacity to assist their small jurisdictions (see figures 2-1 and 2-2 again).**

More dramatic in scale, metropolitan area issues include airport and highway congestion, air and water pollution, often deficient planning and coordination of multimodal transportation facilities, and other growth-related problems. Older urban areas face massive costs for facility reconstruction caused by inadequate long-term maintenance and new Federal requirements; for example, the bill for meeting the EPA requirement to correct combined sewer overflows in many cities will cost billions of dollars. The fiscal burden is most severe in older central cities where the value of the tax base is declining. Public works, especially maintenance that can be deferred, has a lower fiscal priority than schools, new jails, and social welfare programs. Growing, economically healthy areas have a sufficient economic base to increase revenues from general taxes and benefit-based fees and taxes and to attract more private investment. **However, older metropolitan areas in which major public works systems are at the end of their design lives need special attention from State and Federal Governments. States must allow local governments authority to raise revenues, borrow capital,**

spend for needed improvements, and pursue new financing strategies. Removal of Federal prohibitions on toll financing and restrictions on some forms of public-private ventures would allow jurisdictions to pursue a wider range of fiscal opportunities.

Despite mounting small system and metropolitan needs, the Federal Government has reduced investment in public works infrastructure. During the 1980s, Federal outlays for all public works categories decreased about 22 percent; and although environmental public works needs are driven directly by Federal regulations, these programs took the largest cuts. **While State and local governments have accepted an increased share of the financing burden, they need a reliable financial partnership with the Federal Government to ensure the renewal and upgrading of their public works facilities.**

Stronger State and regional planning organizations and land-use controls tied to capital budgeting requirements are needed to improve the efficiency of public investment in infrastructure. But local governments resist sharing power, and planning organizations are typically underfunded and lack fiscal or statutory authority to implement their plans. Cutbacks in Federal funds for housing and environmental programs have left DOT funding as the primary support for regional planning, and State commitment to and support for planning varies widely. OTA concludes that the Federal Government can use regulations coupled with financial incentives to encourage effective planning at all governmental levels and **more efficient use of transportation and environmental infrastructure.** Florida's growth management plan and Washington State's Public Works Trust Fund (see boxes 2-G and 2-H again) provide good models.

CHAPTER 3

Transportation Management and Technologies

Photo credit:American Consulting Engineers Council

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CHAPTER 3

Transportation Management and Technologies

We're repairing everything at once because they all need it.[1]

Passengers and goods can move virtually anywhere on the transportation networks in the United States. But much of the basic transportation infrastructure has been in place for at least 20 to 40 years-long enough to need substantial repair or rehabilitation, especially in heavily traveled corridors. In jurisdictions where maintenance has been neglected, deteriorated and congested rail, highway, water, and air facilities slow travel, hinder national productivity, and increase costs. In many metropolitan areas, complete corridor reconstruction or major modification will be required to ensure safety, alleviate congestion, and improve intermodal connections.

Federal responsibility for transportation rests on the government's constitutional mandate to support interstate commerce and provide for the public safety. Transportation infrastructure includes highways, bridges, rail and bus transit systems, freight and passenger railroads, ports, waterways, airports, and airways. Federal assistance for this infrastructure has always been modally oriented, with separate programs providing assistance for intercity passenger rail; mass transit; bridges, highways, and highway safety; water; maritime shipping; and aviation. The Federal agencies that oversee transportation programs are, for the most part, in the Department of Transportation (DOT), although the U.S. Army Corps of Engineers has primary responsibility for harbor dredging and the condition of inland waterways.

Most State DOTS were originally formed to administer Federal highway programs during the 1960s. During the 1980s, State DOTS expanded and diversified, taking on additional responsibilities as Federal infrastructure programs shrank. State spending for transportation rose from $22 billion to $39 billion,[2] and many DOTS took on some responsibility for airports and mass transportation; some States now aid ports and railroads as well. (See table 3-1 for the major transportation components and figure 3-1 for the share of passenger and freight transportation for each mode.) However, highway departments still dominate State DOTS, and almost all administer and finance transportation programs by separate modes to be compatible with Federal grant programs. Counties and local governments are also important players in operating, managing, and financing transportation infrastructure, particularly roads and airports. Finally, quasi-public, independent, regional authorities operate many major ports and airports.

With so many different entities responsible for different aspects of transportation infrastructure, it is understandable that the transport system does not always function smoothly. This chapter outlines the issues and problems that characterize the present national transportation system and describes the status of management and technologies specific to each transportation mode. It also identifies changes to Federal programs and other approaches that could make the system work more efficiently and productively.

Transportation Issues

Fast, convenient travel for passengers and cargo depends on a well-maintained, smoothly functioning intermodal system with the capacity to handle most of the demands placed on it. Yet, historically, Federal planning, funding, regulation, and policy support in the United States have fostered competitive, modal systems. Modal interdependence, inequalities in maintenance practices, and traffic bottlenecks (capacity problems) that affect total system performance are not addressed in Federal grant programs. Intermodal data collection, planning, and coordination are largely ignored, and successful efforts to integrate land-use planning and transportation requirements are rare.

Because institutional frameworks and funding policies vary for each mode, substantially different

[1] Lucius J. Riccia, New York City transportation commissioner, ss quoted in Andrew L. Yarrow, "Late Repairs Increase Traffic Jams in Region," New *York Times,* Sept. 24, 1990, p. A-1.

[2] U.S. Department of Transportation Economic Studies Division, *Federal, State and Local Transportation Financial Statistics, Fiscal Years 1978-1988* (Washington, DC: March 1990), p. 24.

Table 3-l—Transportation System Characteristics

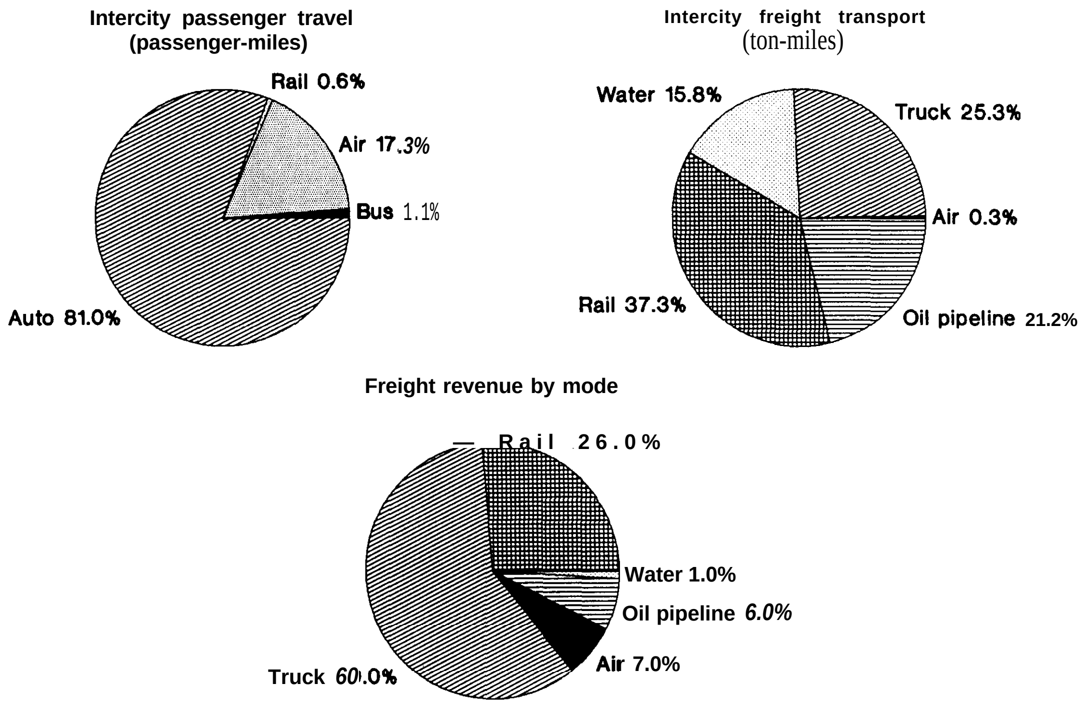
Mode	Major components	Facilities	Vehicles	Traffic volume: Passengers (billions of passenger-miles)	Traffic volume: InterCity freight (billions of ton-miles)
Highways	InterStates	43,000 miles	144,375,000 cars and taxis	1,445	712
	Principle arterials	138,000 miles	42,524,338 trucks		
	Total public roads	3,874,000 miles	615,669 buses		
Airports and airways	Public airports	5,680 airports	5,028 commercial aircraft	351	9
	Private airports	11,647 airports	209,500 private aircraft		
	Airways	384,691 miles			
Mass transit systems	Motor bus	2,671 systems	60,388 buses	41	N/A
	Rapid and light rail	27 systems	11,370 railcars		
	Commuter rail	12 systems	4,649 raiicars		
	Demand response	2,582 systems	16,100 vans, minibuses, etc.		
Railroads	class I	141,000 miles	Freight:	13	1,048
	Regional	16,000 miles	1,239,000 freight cars		
	Local	15,000 miles	19,647 locomotives		
	Switching/terminal lines	4,000 miies	Amtrak:		
	Amtrak	700 miies[a]	1,742 passenger cars		
			312 locomotives		
Waterborne	Ports	177 deepwater ports	754 U.S. flag vessels	N/A	438[b]
		175 shallow ports	5,188 tows and tugs		
	Harbors	757 commercial harbors	31,089 barges		
	Inland waterways	178 loals			
		25,777 miles			

[a]Amtrak also includes 23,000 miles of leased track.

[b]Domestic ton-miles only; about 2 billion tons of cargo transfer through U.S. ports.

SOURCE: Office of Technology Assessment, 1991, based on a variety of data summaries.

Figure 3-I-Passenger and Freight Travel, by Mode



SOURCE: Office of Technology Assessment, 1991, baaed on information provided by the U.S. Department of Transportation and the Eno Foundation.

infrastructure problems characterize each model portion of the transportation system (see table 3-2). Details relating to these difficulties are provided later in this chapter in the appropriate modal sections. However, a number of issues are applicable to the system as a whole.

Intermodal Transport

Efficient intermodal operations have become critical to shippers, many of whom rely on 'just-in-time" deliveries made possible by speedier and more consistent door-to-door service. Freight transfers between ship, truck, rail, and barge involve physical challenges, such as loading, unloading, and storage of cargo, as well as complex intercompany, interjurisdictional, and even international agreements. Industry has addressed many of these challenges through innovations. Containers permit cargo transfer between modes without repackaging, and automatic equipment identification, electronic data interchange, electronic fund transfers, and computer-aided operations all speed freight movements.

Intercity travelers and urban commuters also use multiple modes for daily commutes, business trips, and vacations. Because passengers and freight moving through airports, marine ports, and rail stations rely on trucks and automobiles for most connections, traffic jams on local roads are often key sources of delay.

Congestion problems increase personal trip times, hurt productivity, and add to industry and individual costs. However, the fractured transportation management framework makes successful programs to combat congestion extremely difficult to develop and implement. To a large extent, surface traffic congestion problems are products of decisions made by governments and individuals and are outside the control of a single industry or level of government. During the 5-year period from 1982 to 1987, traffic congestion in our major cities, as measured by volume of traffic per lane of travel, increased by an average of 17 percent.[3]

More effective, comprehensive regional transportation and land-use planning spanning modes and jurisdictions is essential to efficient intermodal

[3]OTA calculation based on Texas Transportation Institute, "Roadway Congestion in Major Urban Areas 1982 to 1987," Research Report 1131-2, 1989.

Table 3-2—Major Issues and Problems in Transportation Public Works

Transport mode	Condition	Capacity	Environment	Management and investment
Highways and bridges	10 percent of roads and 42 percent of bridges rated deficient.	Congestion and delays increasing in many urban and suburban areas; excess capacity in rural areas.	Air quality; land use; noise.	Life-cycie management needed; large capital investment would be required to expand urban roadways to meet demand-a temporary solution, at best.
Mass transit	Structural deterioration of rail systems in older urban areas.	Excess capacity available in most rail and bus systems.	Bus emissions.	Roadway management enhancement needed to improve bus transit; life-cycle management and financing for rail transit; little recent R&D investment.
Rail	Generally good for large railroads, problems due to deferred maintenance on some regional and shortline railroads.	Excess capacity on most lines.	Waste disposal on Arntrak trains; noise and land use for high-speed trains.	Federal operating subsidies for Amtrak; Amtrak capital equipment needs.
Ports and waterways	With a few exceptions, locks, dams, protective works, and channels are generally in good rendition.	Locks are the bottlenecks on the iniand waterways; delays can exceed 2 days at a few locks.	Dredging and dredged material disposal; noise, land use, and surface traffic problems at ports.	Transportation users, especially on the inland waterways, require much greater General Fund subsidy than other transport modes; no cost sharing by nontransportation beneficiaries of navigation projects.
Airports and airways	The condition of airport and airway facilities rarely impedes traffic.	The number of available runways at the busiest airports is the greatest capacity constraint. The staffing levels and technological capabilites of certain airway sectors can be sources of delay.	Aircraft noise in communities surrounding airports; surface traffic congestion due to airports.	Constructing new airports or physically expanding existing airports will be difficult for most immunities. Technology advances could effectively expand existing capacity by up to 20 percent.

SOURCE: Office of Technology Assessment, 1991.

Photo credit: American Consulting Engineers Council

Intermodal operations of all kinds have long characterized ports. Increased international trade and just-in-time delivery have made intermodal transport essential for many shippers and air, land, and water carriers.

travel. Using double-deck railcars or increasing vehicle frequency to expand mass transit capacity is useless unless intermodal connections, such as bus feeder lines and suburban park-and-ride lots, are provided. The program described inbox 3-A typifies the kinds of major improvements needed to facilitate intermodal transportation.

Physical Condition

The condition of any part of transportation infrastructure reflects management and investment decisions-planning, design, construction, operations, maintenance, and rehabilitation--that span a system's lifetime, or "life cycle. " The waterway and airway systems are generally in good condition because the Federal Government has primary responsibility for them and manages and maintains the systems as investments. Systems for which a number of separate governmental or private entities share responsibility, such as highways, bridges, and railroads, are much more likely to have major segments in poor condition, usually because of neglect due to fiscal constraints felt by one or more of the owners.

Capacity

The present transportation system in the United States has plenty of excess capacity-but it is **not** available on the busiest routes and at terminals at the times most people want to travel. Transportation demand fluctuates across time and location, and periods of heavy demand create what are called "peaking" problems. To ensure adequate capacity, infrastructure must be designed and built to accommodate traffic volumes somewhat greater than average, However, since facilities can rarely be built to be both cost-effective and large enough to handle smoothly the greatest "peaks,' designs reflect a trade-off between costs of delay and congestion and costs to build, operate, and maintain the infrstructure.

Most infrastructure for transportation is supplied and managed by the public sector. When demand exceeds supply, delays and safety problems occur

Box 3-A—Intermodal Transportation Improvements in Southern California

The proposed Alameda Corridor Transportation Authority (ACTA) project in southern California is a $500-million program[1] of highway and railroad improvements that will facilitate freight movement between the Ports of long Beach and Los Angeles and downtown Los Angeles, where rail yards of three major carriers--the Union Pacific, Southern Pacific, and Santa Fe Railroads-are located TIM project is intended to improve port access and mitigate the impacts of port-related traffic on highway congestion, air pollution, grade crossing delays, and train noise in residential areas. It will involve construction of double tracks for the main rail line between the ports and downtown, grade separations, and street widening along a route running parallel to the rail line. On-dock, ship-to-rail container loading facilities will be expanded to reduce truck traffic out of the ports. ACTA officials estimate that the rerouting of trains of all three carriers onto a single double-track corridor and the elimination of grade crossings will bring a 90-percent reduction in train-related traffic delays, or a total of about 6,300 vehicle-hours per day.

The improvements will be carried out under ACTA, a joint powers authority that consists of representatives of some 13 local, regional, and State agencies. Over $300 million of the total cost will be sought from Federal highway funds. State contributions, totaling $80 million in bond issues, and funds from the Los Angeles County Transportation Commission, the railroads, and the ports will cover the balance of the cost of the project.[2]

The Port of Long Beach's $80-million Intermodal Container Transfer Facility (ICTF), whose sole operator is the Southern Pacific Railroad, provides a fine example of technology's role in making freight transport more efficient. The ICTF brings together elements of electronic data interchange and computer control of rail yards to expedite the movement of containers and the makeup of stack trains, and nearly every facet of the facility's operations is overseen by computers. Computers in the control tower are linked with those of ocean vessels, so that the yard's computer receives information about each container before it arrives at the Long Beach or Los Angeles Ports. As containers are trucked into the yard from the ports, drivers are directed to the proper areas for container inspection and parking. Yard tractors are equipped with mobile computer units to allow location and status updates for containers and ensure that time-sensitive stack trains are efficiently assembled and dispatched.

[1]Much of the information on the Alameda Corridor Transportation Authority program is derived from "Southern California Consolidated Transportation Corridor" informational document, May 1990.

[2]Leland R. Hill, managing director, Planning & Engineering, Port of Long Beach, personal communication Nov. 16, 1990.

and congestion (especially on highways) is likely to create air quality problems. If the delays worsen and persist, officials look for a way to expand capacity. Building new structures to meet growing demand has been an attractive cost-effective option, in terms of direct costs for land, materials, and labor. However, this is no longer true in many of the country's largest urban areas, where congestion is most severe. For a variety of reasons-large upfront capital expenses, insufficient land where the need is greatest, and community opposition to the expected impacts on the environment and quality of life—States and localities plan to build few new highways, airports, or waterways.

About 20 percent more traffic capacity could be squeezed out of the existing roadways, airports, and waterways[4] by implementing near-term technology developments, discussed later in this chapter. However, traffic demand at many busy airports and highways is expected to outpace the capacity gains possible through technology.

Managing Demand

Better management is another way to increase the capacity of the existing system. Reducing peak-hour trips, minimizing the inefficient mixing of vehicle types; and carrying more passengers or cargo per trip by increasing the average vehicle capacity are all possibilities. These changes could be encouraged by enhancing alternative networks to draw traffic away from busy facilities, by rationing access to overcrowded facilities during peaks, and by charging differential prices to reflect more closely the full costs of congestion and delay.

Shifting demand away from peaks to underused times, locations, or other transport modes is a first step toward reducing delays due to overcrowding; in congested areas, where the network is close to

[4]The Army Corps of Engineers estimates a range of capacity increases of 5 to 10 percent for small-scale improvements to 30 percent or more. See U.S. Army Corps of Engineers, Institute for Water Resources, "The U.S. Waterway System: A Review," unpublished report, April 1989, p. 26.

Table 3-3-Federal Transportation Trust Fund Summary

Trust fund	Date established	Revenue sources
Highway Trust Fund:		
Highway account	1956	Taxes on gas and diesel fuels and tire sales.
Transit account	1982	A share of the Highway Trust Fund gas tax.
Airport and Airways Trust Fund	1971	Taxes on airline tickets, way bills, aviation fuels, and international departures.
Inland Waterway Trust Fund	1978	Taxes on marine fuels.
Harbor Maintenance Trust Fund	1986	Taxes on the value of vessel cargo.

SOURCE: Office of Technology Assessment, 1991.

saturation, small reductions or shifts in demand can prevent many delays. Financial demand management mechanisms, such as quotas or differential pricing, raise costs to users and create issues of social and economic equity that are hard to resolve. These forms of demand management often generate heated protests when they are introduced, because travel patterns are closely coupled to home and work sites, normal working and sleeping hours, and established and familiar costs, such as parking fees.

Providing alternatives to conventional travel is another possible way to change demand. New technology possibilities include a system of tiltrotor aircraft that would not compete for conventional airport infrastructure, and high-speed rail or magnetic levitation rail, which could match airline service at distances up to approximately 500 miles. However, with the exception of high-speed rail, which is now operating successfully in several foreign countries, alternative transportation technologies are still under development. Even if shown to be cost-effective, new technologies will not be ready for public use for at least another decade.

Environmental Issues

The environmental impacts of transportation systems, such as some forms of air pollution and aircraft noise, freely cross political boundaries. Consequently, decisions about financing and managing infrastructure projects, usually made by individual jurisdictions, often do not adequately address environmental concerns. Issues such as alternative fuels for reduced emissions, higher occupancy vehicles, and land-use planning conducive to environmentally sound transportation must be jointly debated and discussed by all the affected jurisdictions.

The financial trade-offs of improvements to transportation systems required for environmental protection are not easy to calculate, yet such understanding is essential for long-term planning. Public transportation officials must soon make decisions about alternative fuels for transit buses, because of the U.S. Environmental Protection Agency (EPA) emission standards for diesel-powered, heavy duty buses. Concerns over the environmental effects of dredging and dredged material disposal already limit channel maintenance and expansion options, especially for harbors and ports in metropolitan areas. Noise is a problem for transport operators across all modes, but is especially serious for airports and airlines. Community groups fighting to curb the noise of airport operations have restricted present operations and blocked growth in some instances, limiting airport development across the country.

System Management and Financing

Transportation networks provide enormous benefits to the national economy. However, Federal fisca1 policies-general fired subsidies, grant matching requirements, trust fund spending restrictions, and other revenue options-are developed and applied by mode and often work against economical system investment and management. Much of the Federal capital spending for transportation infrastructure is managed through trust fired accounts established by Congress for highways, transit, airways, harbors, and inland waterways (see table 3-3). To ensure that federally financed transportation programs are user supported, trust funds are credited with revenues from dedicated user fees and excise taxes, and the balances serve as the basis for Federal spending authority. For example, in 1989 the Highway Trust Fund was credited with $13.6 billion, raised primarily from gas taxes, and $14.3 billion was spent on capital projects. Unlike mandatory entitlement trust funds, such as social security, transportation fired balances cannot be spent without being budgeted and appropriated.[5] Thus the annual transportation spending agendas must compete with other Federal priorities. Over the last decade, the highway, transit, and airways accounts have built up substantial balances, which transportation supporters claim should be appropriated now to address the Nation's large backlog of needs. However, despite recent increases in Federal fuel taxes and other transportation user fees, expenditures from these trust accounts, which are part of the unified Federal budget, will be limited by the domestic spending ceilings imposed in the 1990 deficit reduction package.

Federal program management does little to promote efficient use of transportation systems. In its almost quarter century of existence, DOT has never successfully transcended the autonomy of its separate modal divisions (see figure 3-2) to establish a leadership or coordinating role for multimodal, system-based programs. System-based, State and local investment and management policies and institutions are lacking too. As one example of the types of problems that result, ports both contribute to and suffer from surface traffic congestion, air pollution, and disputes caused by oversize and overweight container shipments. But ports are often independent authorities, and their shipments usually involve interstate commerce, making it hard for State or local governments to affect them. Few examples of successful intergovernmental mechanisms for setting policies or developing and funding programs to address such problems can be found.

Technology and Management Tools

A number of technologies are available for managing infrastructure maintenance and rehabilitation, alleviating traffic congestion and increasing capacity, and prolonging structure life. Many of these technologies are described in chapter 5. Those with the most promise for transportation include computerized inventory management and decision support tools, sensors for condition assessment and transponders for communication and flow control, and a variety of materials for construction and rehabilitation and construction techniques. Despite their availability, however, new technologies are not in widespread use in public works, and technical advances in equipment and software far outstrip the skills and financial resources available to most State and local public works operators.

Surface Transportation Networks: Highways and Bridges

Roads and bridges are key to moving people and goods; indeed every traveler and freight item travels by highway for at least part of almost every trip. Motor vehicles account for roughly 10 times as many person-miles of travel as all other transportation modes combined, and trucking accounts for over 80 percent of all domestic freight revenues and 25 percent of all the ton-miles of domestic freight.[6]

Management and Financing: Who Owns, Pays for, and Operates What

Counties and local jurisdictions own and manage the lion's share of roads and bridges, while States own and administer Interstates, most arterial roads, and one-third of collector roads. The few Federal roads are almost exclusively on Federal property, such as national parks and forests.[7] About one-half of total national spending for roads (about $69 billion in 1988)[8] is provided by States and about one-quarter by local governments. More than three-quarters of the almost 3.9 million miles of public roads that now lace the country had been built by 1920, although less than 15 percent were paved. Even today, 1.7 million miles of road remain unpaved.

All Interstate miles and 97 percent of other arterial route-miles are considered part of the Federal-aid system and are eligible for Federal funding aid for development and maintenance. See figure 3-3 and table 3-4 for further information about funding and road characteristics. Federal-aid funding from the Highway Trust Fund, about $14 billion annually, represents around one-quarter of total road spending. Of the nearly 577,000 bridges in the United States,

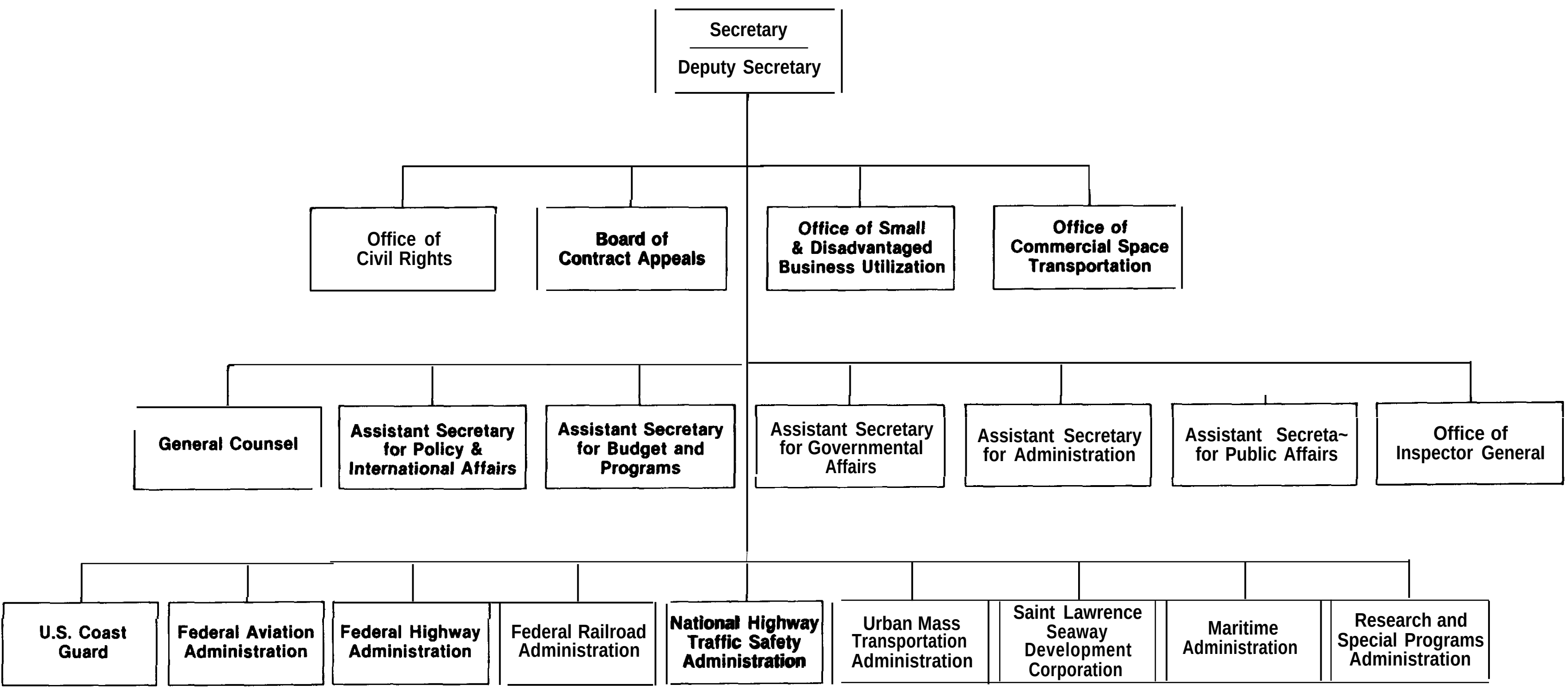
[5] John Hornbeck, *Transportation Trust Funds: Economic and Policy Issues* (Washington, DC: Congressional Research Service, September 1990), p. 2.

[6] National Council on Public Works Improvement, *Highways, Streets, Roads and Bridges* (Washington, DC: May 1987), p. 55.

[7] U.S. Department of Transportation, Federal Highway Administration, *Highway Functional Classification-Concepts, Criteria, and Procedures* (Washington, DC: March 1989).

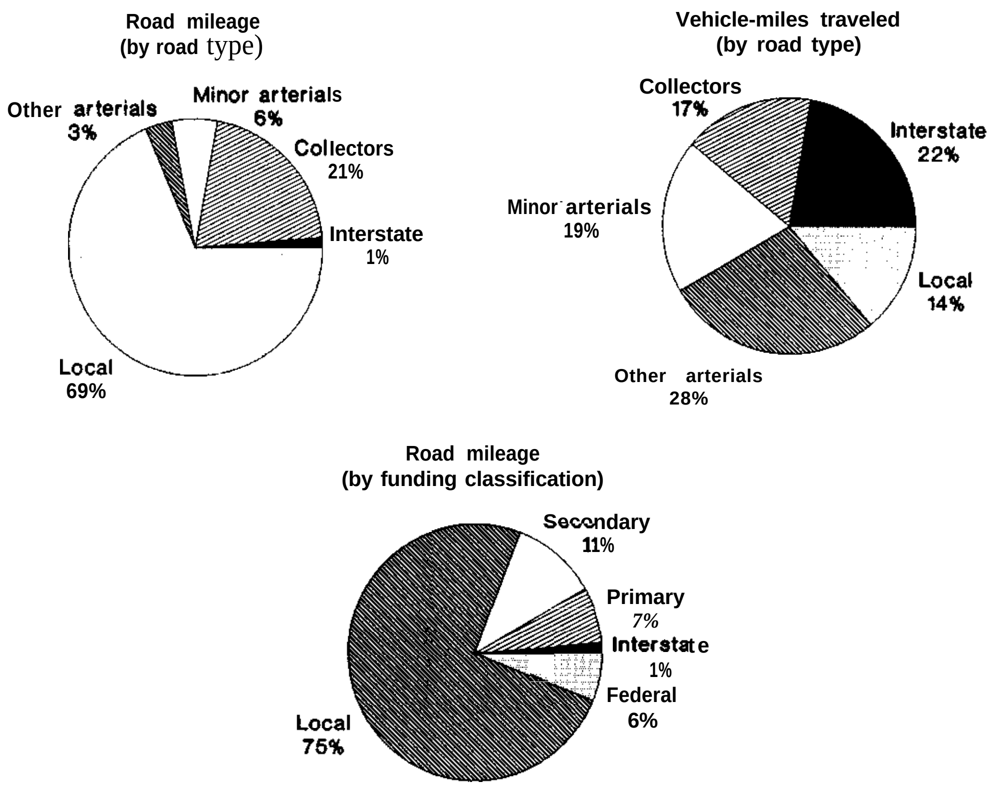
[8] U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics 1988* (Washington, DC: 1989), p. 38.

Figure 3-2—US. Department of Transportation



SOURCE: U.S. Department of Transportation, 1990.

Figure 3-3-Characteristics of the Nation's Road System



SOURCE: Office of Technology Assessment, 1991, based on information from the U.S. Department of Transportation,

almost 275,000 are on Federal-aid roads, with the remainder on off-system roads.[9]

State highway officials administer a wide variety of State-funded programs and, with the Federal Highway Administration (FHWA), the Federal-Aid Highway Program. States allocate about 60 percent of all highway outlays, construct and maintain about 22 percent of the Nation's highway mileage and 43 percent of the bridges,[10] disperse Federal and State funds to local jurisdictions, and enforce construction standards and grant conditions. All States levy motor fuel taxes; in 1990, the average gas tax was 16 cents per gallon. During the 1980s, 47 States increased their levies—some more than once. Most, but not all, States dedicate this revenue to transportation purposes, and their officials view the large balances in the Federal Highway Trust Fund with anger, believing the Federal Government is withholding these dedicated highway user fees for general budget balancing purposes.

Issues

Local governments design, construct, and maintain the vast majority of the Nation's roads and bridges,[11] and virtually every jurisdiction has a large backlog of road and bridge maintenance and repair needs. These are particularly acute in large, older cities where infrastructure is heavily used and many structures have long since reached the end of their design lives; in New York City, for example, more traffic lanes will be closed for repairs than will be reopening under a rehabilitation program that will

[9] Ibid., p. 134.

[10] National Association of Counties, *Linking America* (Washington, DC: 1989), P. 8.

[11] U.S. Department of Transportation, Federal Highway Administration, *Our Nation's Highways—Selected Facts and Figures* (Washington, DC: 1987), p. 4.

Table 3-4-Highway Mileage and Funding Statistics

Road classification	Miles	Jurisdiction	Capital funding	Maintenance funding
Interstate System[a]	44,000	State	90% Federal 10% State	100% State
Federal-Aid Primary System[b] (excluding Interstate)	260,000	State	75% Federal 25% State	100% State
Federal-Aid Secondary System[c] . .	400,000	State	75% Federal 25% State	100?40 State
Federal-Aid Urban System[d]	125,000	State	75% Federal 25940 State	100% State
Local roads[e]	2,751,000	Counties, municipalities, and townships	Not eligible for Federal aid	Local and State
Federal roads[f]	226,000	Federal	100% Federal	100% Federal

a Routes that connect principal metropolitan areas, serve the national defense, or connect with routes of continental importance in Mexico *or* Canada (subsystem of the Federal-Aid Primary System).
b Interconnecting roads important to interstate, statewide, and regional travel.
c Major rural collectors that assemble traffic and feed to the arterials.
d Urban arterial and collectors routes, excluding the urban extensions of the major primary arterials.
e Residential and local streets.
f Roads in national forests and parks; roads on military and Indian reservations.

SOURCE: U.S. Department of Transportation, Federal Highway Administration, Highway Statistics *1988* (Washington, DC: 1989); and U.S. Department of Transportation, Federal Highway Administration, Our Nation's *Highways: Selected Facts and Figures* (Washington, DC: 1987)

Photo credit: American Society of Civil Engineers

Road and bridge maintenance needs are particularly acute in large, older cities such as New York where infrastructure is heavily used and many structures have passed the end of their design lives.

take 10 years to complete.[12] However, extensive physical rehabilitation is needed on the entire highway system—rural and urban segments alike. Over 10 percent of the Nation's roads have enough potholes, cracks, ragged shoulders, ruts, and washboard ridges to be classified as deficient; heavy axle weights, such as those of large trucks, and the stresses caused by freezing and thawing of harsh weather are the major causes of pavement damage.[13] Nearly 42 percent of the Nation's bridges are rated as unable to handle traffic demand or structurally deficient (see figure 3-4); costs for repairing and replacing these are estimated at $67.6 billion.[14]

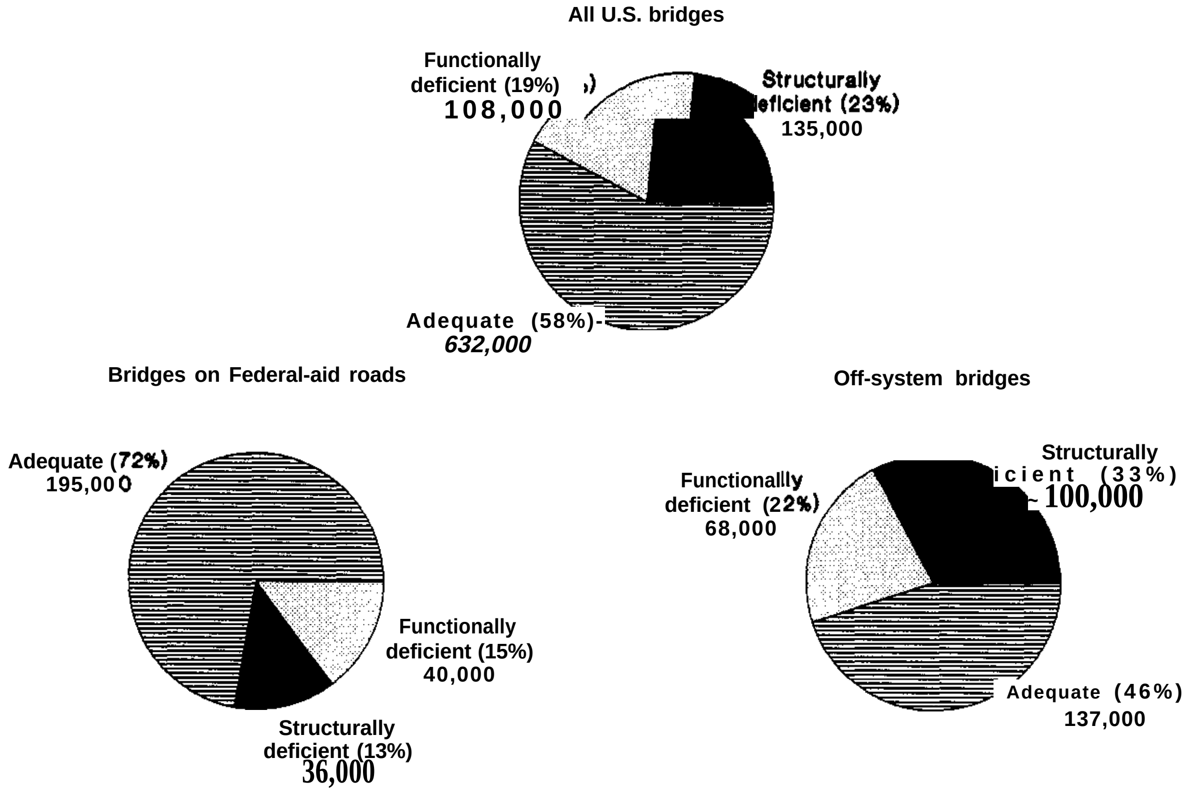
Maintenance is an easy budget item to defer in every jurisdiction when resources are low. However, if maintenance is put off for too long, simple procedures are no longer adequate, and more extensive and costly work becomes necessary. FHWA administers five major highway grant programs (interstate, interstate 4R, primary, and urban and secondary), which can provide up to 75 percent of the funds for construction/reconstruction and rehabilitation of Federal-aid highways. Despite this availability, less than 25 percent of Federal highway obligations have been used for these purposes (see

[12] Yarrow, op. cit., footnote 1.

[13] Transportation Research Board, *Truck Weight Limits: Issues and Options, Special* Report 225 (Washington, DC: 1990), p. 27.

[14] U.S. Congress, House Committee on Public Works *and* Transportation, *The Status of the Nation's Highways and Bridges: Conditions and Performance and Bridge Replacement and Rehabilitation Program,* Report of the Secretary of Transportation to the United States Congress (Washington, DC: U.S. Government Printing Office, June 1989), p. 121.

Figure 3-4-Physical Condition of U.S. Bridges



SOURCE: U.S. Department of Transportation, The Status of fhe Nation's Highways *and Bridges* (Washington, DC: June 1989).

figure 3-5) over most of the past decade.[15] In fact, of all the money all levels of government spend on highways annually, only about one-quarter goes to maintenance and repair.[16]

Costs for rehabilitation and maintenance fall most heavily on large, rural States because of their extensive mileage and low populations. They must maintain miles of lightly traveled roads and numerous bridges to standards that accommodate heavy agriculture loads, although such heavy vehicles may use the system only a few weeks a year.

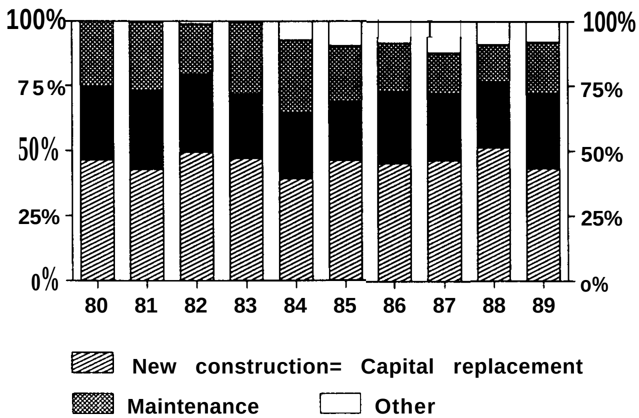
To be eligible for Federal aid, local street and bridge projects must conform to categorical grant requirements. With a few exceptions, Federal funds focus on capital projects, precluding their use to fund preventive maintenance and traffic management improvements, such as upgraded signals, ramp metering, and real-time traffic monitoring, that could reduce congestion. Because Federal funds contribute substantially to State and local highway budgets, it is not unusual for project priorities to be tailored to fit Federal-aid categories or for reconstruction and maintenance to be deferred because money is short or Federal aid is not available.

Hard pressed to finance road improvements, local governments have turned to dedicated portions of State gasoline and sales taxes, seeking greater State and Federal support, and in some cases, private sector partners. Denver's limited access, circumferential highway, E-470, now under construction, provides an example of the potential for nontraditional means of highway financing, such as right-of-way dedication, tolls, and earmarked vehicle registration fees. Such broad-based financing concepts and public-private partnerships are likely to be tried more often in the future, because of the keen competition among government programs for funds.

[15] John Hornbeck, *Maintaining Highway and Bridge* Investments: *What Role for Federal Grant Programs?* CRS Report 90-227 *E* (Washington, DC: *Congressional* Research Service, May *31,* 1990), pp. *4-8.*

[16] OTA calculations based on Federal Highway Administration, op. cit., footnote 8, pp. 40, 165-168.

Figure 3-5-Federal Obligations for Interstate, 4R, Primary, Secondary, and Urban Programs, by Improvement Type



SOURCE: Congressional Research Service from Federal Highway Administration. See Congressional Research Service, *Maintaining Highway and Bridge Investments: What Role for Fe&al Grant Programs?* (Washington, DC: 1989.)

Loca1 roads serving regional needs frequently fall victim to differing local, State, or **Federal manage**ment goals and responsibilities, or their planning and financing become stalled by interjurisdictional squabbles.[17] Furthermore, because Federal and State grants are allocated by mode, communities have little incentive to seek intermodal solutions to areawide transportation problems. Weak land-use planning and development controls further compound congestion problems. While new technology can bring some short-term solutions, changes in land-use management and development patterns, lifestyles, and institutional arrangements are likely to be required for long-term solutions in regions where congestion problems are severe.

Technologies for Highways and Bridges

Technologies can make substantial contributions to addressing congestion and capacity problems and to bringing the physical condition of the highway system to a satisfactory level. If money is available to purchase equipment, and personnel are trained to operate and maintain them, the technologies described below can bring major benefits.

Keeping the System in Good Condition

Keeping pavements and bridges in good condition requires collecting information, careful management, investment in appropriate and durable equipment and materials, and adequately trained personnel. Management and information systems are essential planning and resource allocation tools. Decisions about materials and construction are also key to maintaining a healthy road system.

Pavement and Bridge Management Systems-The essential components of any pavement or bridge management system include data collection and processing, techniques or models for pavement performance prediction, and setting priorities for resource allocation. Most current State pavement management systems resemble that used in North Carolina and its municipalities. This includes visual pavement inspection by trained professional evaluators of the entire paved street system, from a vehicle traveling at about 10 miles per hour. **Both State and** local evaluators record pavement condition according to the same, well-defined levels of distress.[18] Municipalities use the results to set priorities for engineering investigation, testing, maintenance, and resurfacing. The system helps to set priorities for limited funds and facilitates exchange of technology, information, and training programs.

A somewhat more automated pavement management system, developed by the Army Corps of Engineers, has the capability to store inventory and inspection data, analyze pavement condition, predict future pavement condition, compare costs of maintenance and repair, and plan budgets. It is available for use by public works officials.[19]

Advances in electronic sensors and system management software permit automated data collection and analysis, and these technologies have great potential to speed up and standardize the condition assessment process and help set priorities for repair. Several States have programs utilizing them (see box 3-B). However, when more data are collected, more powerful data management tools and special-

[17] John Gunyou, city finance officer, Minneapolis, *MN, personal* communication, June 21, IWO.

[18] James B. Martin, ''Pavement Management for North Carolina Municipalities,'' *Transportation Research Record 1200 (Washington DC:* National Research Council, 1988).

[19] U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, *"Micro* Paver Pavement Management System," informational document, May 1989.

Box 3-B—Video Technology and Pavement Management

Since the early 1980s, the Connecticut Department of Transportation has used a pavement survey van equipped with a movie camera to record images at regular distance intervals (100 pictures per mile) on all 7,600 miles of State-maintained road. This process, known as photologging, produces a film of the entire road network which is then developed, producing some 760,000 images, and transferred to videotape. Images from the videotape are then transferred onto 15 double-sided laser videodiscs. Connecticut has developed an image retrieval system that allows any desired stretch of road to be examined on a video monitor to determine pavement distress. When correlated with road geometry and roughness data which is collected simultaneously with the same pavement survey van, this information provides highway engineers with a complete database to use in setting priorities for road maintenance.

Connecticut's surveys are conducted annually and take about 4 months to complete. The State has found that photologging saves gas, makes more efficient use of labor, eliminates much of the need for field inspections, and provides better pavement ratings than its previous method, which consisted of 4'. . . two people riding in a seal@ at 40 miles per hour jotting down general impressions. . ." of pavement quality.[1] Other States pursuing videodisc technology for pavement data acquisition and retrieval include Minnesota, Iowa, Utah, Texas, and Wisconsin. Future efforts will focus on eliminating the need to use movie cameras or video cameras and writing data directly onto disc.

[1]John Hudson, photolog supervisor, and Richard Hanky, transportation senior engineer, Connecticut Department of Transportation, personal communications, Nov. 8, 1990.

ized personnel and expertise become necessary,[20] and these are beyond the resources of many State DOTS.

Bridge Inventories—Investigations into the collapse in 1967 of the Silver Bridge between West Virginia and Ohio, which killed 46 people, revealed a lack of uniform reporting standards for bridges and a need for a national inventory of bridges, improved inspection standards, and inspection training procedures. While a national bridge inventory that includes condition ratings is now in place, recent bridge failures have demonstrated that significant inspection, maintenance, and repair issues must still be addressed (see box 3-C).

Computerized bridge inventory systems can coordinate bridge condition analyses, set priorities, and budget for maintenance and repair. For example, the bridge inventory for Texas is a database that includes 140 different entries for each bridge. The data help the engineers determine a sufficiency rating for every bridge in the State, and those that are classified as deficient are eligible for FHWA funds.[21]

Thermal Mapping—An extension of pavement management for deicing and ice prediction applications, thermal mapping requires mounting infrared thermometers on vehicles to measure pavement temperatures along stretches of road. Thermal mapping can be used to position permanent sensors in the road, to determine how many sensors are needed to provide adequate temperature profiles, and to redesign salting routes. Thermal mapping trials have been carried out in several counties in England.[22]

Paving Materials-Composites, ceramics, plastics, and higher strength cements, are gradually being used more frequently in bridges and highways. They can provide faster curing, weight, and durability advantages over steel and concrete when properly used and in the right conditions. Quick-curing concrete can produce a road ready for vehicle traffic inside of 24 hours, minimizing the need for rerouting traffic, an inconvenience that can last for weeks under traditional paving operations. Though fast-track construction adds $1 to $2 per square yard to the pavement costs, the increase is offset by reductions in traffic rerouting and liability .23 Extensive tests performed on U.S. 71 in Iowa showed promise

[20]Haris Koutsopoulos, "Automated Interpretation of Pavement Distress Data,'' *Construction*, newsletter of the Center for Construction Research and Education, Massachusetts Institute of Technology, winter 1989, p 10.

[21]Jane Mills Smith, ''Middle Age Crisis, *Windows*, Texas A&M University, summer 1988.

[22]Thermal Mapping International, Ltd., Birmingham, England, informational brochure, n.d.

[23]Marlin Knutson and Randell Riley,' 'Driving in the Fast Track, ' *Civil Engineering*, vol. **58, No. 9,** September 1988, p. 56.

Box 3-C—Bridge Inspections

The 1989 failure of the Hatchie River Bridge in Tennessee highlights some of the inadequacies of present bridge management practices. Four passenger cars and one tractor-semitrailer fell into the river when the bridge collapsed during a flood. The National Transportation Safety Board (NTSB) identified several contributing factors, including migration of the main river channel beneath the bridge and the failure of authorities to evaluate and correct the resulting problems. A lack of redundancy in the bridge design also contributed to the severity of the accident, Channel migration and scour, or wear, exposed the bridge piles to as much as 10 feet of water, reducing their ability to support the bridge. Although a 1987 onsite inspection identified the piles' vulnerability to water, no settlement or leaning was noticed in the supports, and the bridge was given a "poor" rather than "critical" rating, thus not making it a priority for repair. NTSB determined that State officials did not recognize the potential for scour from the inspection report, and that overweight vehicles were frequently permitted to cross the bridge, further weakening the structure.[1]

After its investigation, NTSB issued 19 recommendations for improved inspection and maintenance procedures for the Nation's bridges, stressing the need for dealing with the effects of channel migration and river course changes, overweight traffic loads, and scour on the integrity of the bridge support structures. The recommendations also highlight the need for raising qualification standards for evaluators of bridge inspection reports and for the creation of a system to set priorities for bridge repairs.[2]

[1] National Transportation Safety Board, "Safety Information," informational document, June 5, 1990.

[2] Ibid.

for quick-curing concrete technology. The Strategic Highway Research program (SHRP) has sponsored fast-track. concrete pavement overlay experiments in Missouri on Route 67 with a pavement mixture designed to harden in 12 hours.[24] (See chapter 5 for further discussion of advanced materials.)

Pavement additives for deicing, developed in Europe and tested in the United States, include particles of ground rubber or calcium chloride particles covered with linseed oil. These are mixed into the material used for the road surface. These additives can double or triple paving material costs and are not effective in all climates or under all highway conditions.[25] Salt, currently the cheapest and most available deicer, has been widely used in this country, although it causes extensive corrosion to unprotected pavement. (See chapter 5 for further details.) Laboratory and field tests have shown calcium magnesium acetate to be comparable to rock salt as a deicer, while lacking many of the adverse side effects. However, its price, 15 to 20 times that of rock salt, prevents extensive use.

Design and Construct ion—bad ***and resistance factor** design* (LRFD) is a promising alternative to standard allowable stress design, which treats all loads and member strengths as if they were known with roughly equal certainty, rarely the case. LRFD recognizes that some loads (the bridge's own weight, for instance) and material strengths can be calculated with a fair amount of certainty, while others (the wind load from a hurricane, for example) can only be guessed. LRFD takes uncertainty into account by multiplying each load by a load factor and each member strength by a resistance factor, with both reflecting the probability that each particular number is wrong. In many structures, LRFD allows the use of smaller members or lower strength steels, reducing the cost of the structure. Load factor design (LFD) was adopted by the American Association of State Highway and Transportation Officials (AASHTO) in 1969 as an alternative method for both steel and concrete bridges. Most States now recognize LFD as an acceptable design method,[26] and by 1992, AASHTO bridge design and construction specifications will be revised in the LRFD format. However, LRFD takes time to learn and requires educating staff and converting or replacing computer programs that use conventional design formulas.

Primarily because they can be constructed quickly, ***segmental bridges*** minimize traffic disrup-

[24] Strategic Highway Research Program, "Focus," newsletter, August 1990, p. 3

[25] Kevin Stewart, pavement Research Division, Federal Highway Administration, personal communication, Apr 24, 1990.

[26] "Steel Design's Reluctant Revolution," *Engineering News Record,* vol 223, No 19, Nov. 9, 1989, pp. 54-60

tion, since contractors can place precast or cast-in-place segments from above or below.[27] The behavior of the joints between the precast segments involves complex interactions, however, and great care must be taken to ensure that shear forces are transferred across the joints.

Two promising technologies for strengthening existing bridges are the *reinforcing arch* for truss bridges and the *post-tensioning* system for steel girder bridges. If critical truss bridge members are reinforced with superimposed steel arches, chord supports, and additional floor beams, the carrying capacity and service life of the bridge can be increased at a significant savings compared with the cost of a new bridge. High-strength steel tendons bolted to the ends of the girders and tightened reduce the stress on the bottom of the girders. This process enables the bridge to carry heavier weights, minimizes traffic disruption because work is done above the roadway, and is significantly less costly then replacing single-span steel girder bridges.

Increasing Capacity and Managing Traffic: Smart Cars and Highways

Present strategies for overcoming congestion include building *new* roads, adding lanes to existing highways, creating high-occupancy vehicle (HOV) lanes, and promoting car pooling and public transportation. However, no city, even those using all of these techniques, has achieved more than modest success in solving its congestion problems. Intelligent Vehicle/Highway System (IVHS) technologies can help reduce congestion and improve highway safety, and two of these-advanced traffic management (ATM) and automatic vehicle identification (AVI) and billing-are particularly applicable for public works and are available now for wider use. More advanced IVHS technologies—collision warning and avoidance, driver information and route guidance, and automatic vehicle control-both steering and headway-are under development.[28]

Advanced Traffic Management—ATM systems include urban traffic control systems, incident detection systems, and freeway and corridor control systems. Hardware consists of sensors, traffic signals, ramp meters, changeable message signs, and communication and control devices integrated into a single *system.* Urban traffic control systems coordinate traffic signal operations throughout a given area, based on traffic patterns as measured by detectors in the roadway. Freeway control systems include sensors of all types to monitor congestion and transmit the data to driver-information signs and ramp meters to control access. In the United States, freeway systems are almost always separate from urban traffic control systems. Although several are planned, only a few integrated systems are in place. One of these, Information for Motorists (INFORM), is a traffic monitoring and control system, sponsored by FHWA, along a 35-mile east-west corridor on Long Island.[29]

Because current traffic detectors, usually embedded in the roadway, are susceptible to frequent failure, more reliable methods of measuring traffic are being investigated, including infrared sensors and machine vision systems (video cameras linked to a computer that analyzes the images to generate traffic flow and congestion information).[30]

The Automated Traffic Surveillance and Control system (ATSAC) in Los Angeles (see box 3-D) is one of the most advanced ATM systems presently in use in this country. Pathfinder, an in-vehicle driver information and route guidance demonstration in the Los Angeles area, recently began preliminary testing, and TravTek, an Orlando-based project using similar technology, will begin operation during 1991-93.

Only about 6 percent of urban freeway mileage is covered by ATM systems. While most large, urban areas have arterial traffic signal control systems, many are old and inadequate for current needs, cover too small an area, and do not respond well to

[27] "Controversial Bridges Scrutinized at Conference," *Civil Engineering,* vol. 60, No. 2, February 1990, p. 20.

[28] For further details, see U.S. Congress, Office of Technology Assessment, "Advanced Vehicle/Highway Systems and Urban Traffic Problems," staff paper of the Science, Education, and Transportation Program, September 1989.

[29] Lyle Saxton, assistant for advanced technical systems, Federal Highway Administration, personal communication, July 24, 1989.

[30] Panos Michalopoulos, professor, Department of Civil and Mineral Engineering, University of Minnesota, and Robert Behnke, Research Administration and Development, Minnesota Department of Transportation "Testing and Field Implementation of the Minnesota Video Detection System," unpublished document, n.d.

Box 3-13-The Automated Traffic Surveillance and Control (ATSAC) System

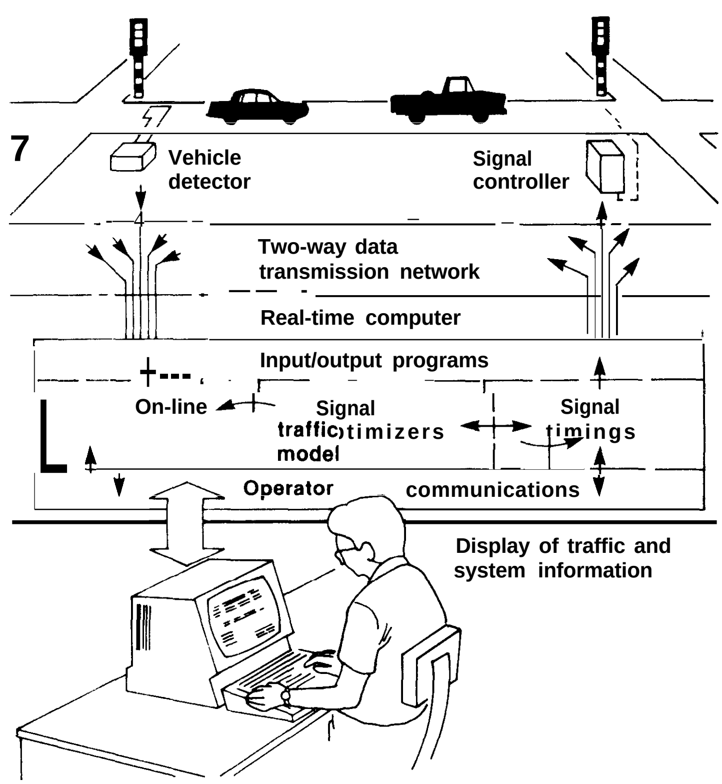
One of the more advanced urban traffic control systems in place in this country is the ATSAC system, a computerized traffic signal control system installed in Los Angeles. It is based on the Urban Traffic Control System (UTCS) software package developed by the Federal Highway Administration (FHWA) and was put into operation several weeks prior to the 1984 Olympic Games. Initial installation included 118 intersections and 3% detectors in a 4-square-mile area centered at the University of Southern California and the Los Angeles Coliseum. It has since expanded to include areas of the San Fernando Valley and central business district for a total of 371 intersections. The airport and Westwood areas are targeted for later implementation, and in 1991, the system is planned to include 1,600 intersections. ATSAC is funded by a combination of FHWA monies, a traffic mitigation fired financed by developer fees, and distributions from the Petroleum Violation Escrow Account fund[1]

From their workstations, ATSAC operators can monitor any portion of the surveillance area at any desired level of resolution, from traffic flow data at intersections to traffic behavior over a region. ATSAC gives the current status of any traffic signal in the network and gives traffic flow data for any loop detector in the network. Since it was first installed, ATSAC has evolved into a signal timing system that automatically selects (and switches) timing plans by matching current traffic patterns against historical data Signal timing can be fine-tuned by manual override or automated control to relieve local congestion. Figure D-1 depicts a typical system.

Closed-circuit television cameras, installed at important intersections assist in incident management and confirm incidents. ATSAC has improved traffic flow and economic benefits: travel time (-13 percent), number of stops (-35 percent), average speed (+15 percent), fuel consumption (–12 percent), and vehicle emissions (–10 percent). Computerized signal control also provides rapid detection of faulty sensors and unusual traffic patterns due to incidents. Estimated cost savings to motorists (business and truck trips only) as a result of lower operating costs and time saved recovered the $5.6-million construction cost of ATSAC after only 9 months of operation. The annual operating costs are recovered within the first week of operation every year.[2]

However, ATSAC relieves street congestion only, not freeway congestion, since freeway traffic falls under the authority of CALTRANS. Recognizing this limitation, the major transportation agencies in the Los Angeles area have begun the Smart Corridor demonstration project, which integrates selected city-operated surface streets and State-operated freeways in a single traffic management system.

Figure D-l—Typical Automated Traffic Management System



SOURCE: Ferranti Computer Systems, GEC Traffic Automation Ltd., and Plessey Controls Ltd., "Dynamic Urban Traffic Control," SCOOT *brochure, 1985.*

[1] Edwin Rowe, general manager, Department of Transportation% City of Los Angeles, personal communications, Aug. 19 and 30, 1989.

[2] Edwin Rowe et al., *ATSAC Evaluation Study* (Los Angeles, CA: City of Los Angeles, Department of Transportation, July 1987).

nonrecurring congestion.[31] Over one-half of all vehicle-hours of delay are caused by nonrecurring congestion or incidents (vehicle accidents and breakdowns that tie up traffic). Incident management programs use a variety of ATM tools to detect incidents, including conventional traffic surveillance, service patrols, closed-circuit television, roadside and mobile telephones, and citizens-band radio.

Automatic Vehicle identification—AVI systems are a promising option for automatic billing on toll roads and bridges.[32] Radio or microwave transponders on a vehicle can be "read' by equipment placed along a route or at a point where information exchange or billing needs to occur, such as toll facilities, weigh stations, and ports of entry. Additional AVI technologies include optical and infrared systems, inductive loop systems, and surface acoustic wave systems.

Because AVI-equipped vehicles need not stop for data transfer, widespread use would substantially reduce delay at these normal congestion points. AVI could also be used to control access to facilities and to provide traffic data for travel flow and congestion monitoring. Such systems are operating at the Coronado Bridge in San Diego, the Mississippi Bridge into New Orleans, the Lincoln and Holland Tunnels in New York City (for buses), the Grosse Ile Bridge in Michigan, and the Dallas North Tollway. The Dallas (see box 3-E) and New Orleans systems are the most heavily used, with 20,000 and 13,000 subscribers, respectively .33

AVI also makes possible congestion pricing, or charging automobile drivers for driving in congested areas during peak hours. Congestion pricing provides more funds for system improvements, and may cause some motorists to shift to public transit, make fewer trips, or plan their trips during nonpeak hours, thus reducing delays.

Weigh-in-Motion —WIM systems use road-mounted sensors to determine the weight of moving vehicles by taking into account axle weights, vehicle length, and vehicle speed. By also calculating axle spacing, WIM devices can classify vehicles and determine their compliance with weight standards. Technologies used for WIM include piezo-electric sensors, load cell systems, shallow weighscale systems, bending plate systems, and bridge systems. The most accurate WIM systems currently have accuracies within 10 percent of true vehicle weight, limiting their usefulness for enforcement purposes,[34] although the information they provide about truck weights has proven useful for highway research and pavement design.

Box 3-E—Fast Toll Collection in Dal!as

The Dallas North Tollway is one of the largest automatic vehicle identification (AVI toll roads in the Nation, Since August 1989, all of its toll lanes have been equipped with reading equipment capable of interrogating transponders (toll tags) attached to the inside of the windshields of subscribers' vehicles. The credit card-sized toll tags can be purchased in $40 increments bymail or at a tag store located near the tollway. Tag users pay an extra 5 cents per transaction over the usual toll as well as a $2 service charge for use of the transponder. After a successful transaction, a "valid tag-go" sign is flashed to the driver. If the toll tag credit is used up, a' 'call tag store" sign is flashed and the driver must pay the toll in cash. Before the system began operation, an average of 350 vehicles per hour passed through a toll plaza lane during rush hour. Now, 800 vehicles per hour pass through lanes for drivers with toll tags or with exact change, and AVI-only lanes, which will be implemented in late 1990, are expected to process 1,200 vehicles per hour, based on a vehicle speed of 10 miles per hour. At present, the tollway has some 30,000 AVI subscribers, accounting for over 1 miIlion AVI transactions monthly.[1]

[1]Ken Tucker, director of toil collection, Dallas North Tollway, personal communication, Nov. 7, 1990.

[31]Gary Euler et al., ''Final Report of the Mobility 2000 Working Group on Advanced Traffic Management Systems (ATMS),' unpublished report, March 1990, p. 2.

[32]Automatic vehicle identification technology is also sometimes referred to as electronic toll and traffic management.

[33]Maureen Gallagher, director of research and member services, International Bridge, Tunnel and Turnpike Association personal communication, May 31, 1990.

[34]Neil Emmott, engineer, Castle Rock Consultants, personal communication Apr 28,1989.

Automatic Vehicle Location—AVL systems currently have their primary application in commercial fleet operations, since they typically identify vehicle location and transmit it to a central facility for monitoring or dispatch purposes. An AVL system consists of equipment to locate the vehicle-usually based on dead reckoning, map matching, proximity to roadside beacons, or radio determination—and mobile communications equipment, which relays this information to the central location. **AVL can** provide real-time information on shipment status and eliminates the need for time-consuming driver-to-control-center communication.

Surface Transportation Networks: Mass Transit

Mass transit refers to regional and municipal passenger transportation systems, such as buses, light rail, commuter rail, trolleys, and subways (see table 3-5). Early mass transit service was provided by private horsecar in the mid-1800s, and cable cars and electric streetcars served numerous urban riders between 1880 and 1920. The versatility brought by buses and automobiles caused rail transit ridership to decline slightly during the 1930s. During the immediate postwar years, transit patronage and revenues fell again, and local governments began to takeover the systems from private operators. The establishment of a Federal grant program for transit in 1964 and substantial increases in Federal support in 1970 (see chapter 2 for further details) brought a large increase in public takeovers of transit agencies.

Transit Management and Financing

Today, most cities and towns with populations over 20,000 have bus systems, usually operated by a municipal transit authority; over one-half (58 percent) of all systems are located in towns with populations of less than 50,000. Local governments manage transit systems as operating departments or through a public transit authority. Transit buses, operating on established routes on set schedules, account for over one-half of all public transit vehicles, passenger trips, and vehicle-miles operated.[35] Seattle, Philadelphia, Boston, Dayton, and San Francisco transit agencies still operate some electric trolleys. Rail transit, rapid rail, light rail, and commuter rail systems are usually owned by municipal transit agencies, although some commuter rail services are run by State governments or operated by Amtrak.

Paratransit operators maybe municipalities, special purpose agencies, or private entities. Services include dial-a-ride, van pools, subsidized taxis, and shared rides in minibuses or vans; paratransit can provide more direct origin-to-destination service, and operates on demand rather than on a fixed schedule. The primary residential users of paratransit are the elderly, handicapped, and children; airport shuttles are heavily used by business people and travelers.

Of total transit revenues in 1988,36 percent came from passenger fares, 53 percent from State and local assistance, and 6 percent from Federal capital and operating assistance, which totaled $3.3 billion (in current dollars) in 1988,[36] down about 40 percent from 1980 (see chapter 2, table 2-2). Quadrupling from about $1 billion in 1980 to almost $4 billion in 1988, State aid to local and regional transit now surpasses Federal aid.[37] At least 40 States provide local mass transit with some funds from general revenues, a dedicated portion of the general sales tax, or motor fuels and vehicle taxes. States support transit because it is one of the few options available for relieving auto congestion and air pollution in urbanized regions, and seven heavily urbanized States contribute 80 percent of total State aid.

Federal capital grants may be used to finance bus and subway car purchases, rail construction, and other capital improvements, but these programs have been criticized for not meeting community needs. Some cities receive more capital funds than they can use, encouraging large construction budgets, which may cause them to shortchange maintenance. Others, often those with older rail ***systems, are*** substantially underfunded[38] and in desperate need of capital equipment and track rehabilitation. About 70 percent of transit operating costs are labor expenses,“[39] these are not eligible for Federal assist-

[35] American Public Transit Association, *1989 Transit Fact Book (W-~ DC:* 1989), pp. 10-13.

[36] Ibid., *pp. 24-27,74-75.*

[37] U.S. Department of Transportation op. cit., footnote 2, p. 24.

[38] U.S. Congress, Congressional Budget Office, *New Directions for t& Nation's Public Works* (Washington, DC: November 1989), p. 37.

[39] American Public Transit Association op. cit., footnote 35, P. 33.

Table 3-5-Characteristics of Mass Transit

Type	Right-of-way	Fare collection	Maximum speed	Power source	Places in use	Funding
Bus	City streets and dedicated bus lanes	In vehicle or station	35 mph on city streets, 55 mph on highways	internal combustion engine	Virtually all urban areas	UMTA discretionary grants (sec. 3), formula grants for operating and capital expenses (sec. 9), and operating and capital assistance for rural areas (sec. 18)
Heavy rail	Dedicated underground, surface, or elevated	in station	75 mph	Third rail	New York; Chicago; Boston; Philadelphia; Atlanta; Washington, DC; San Francisco; Los Angeles (under construction)	UMTA formula and discretionary grants (sees. 3 and 9)
Light rail	City streets and/ or fully grade-separated tracks	In vehicle or station	55 mph	Overhead catenary	New Orleans; San Francisco; Philadelphia; San Jose; Portland, OR; Boston; Sacramento; Buffalo; Cleveland; San Diego; los Angeles; Long Beach	UMTA formula and discretionary grants (sees. 3 and 9)
Commuter rail	Railroads	In vehicle	100 mph	Diesel/electric locomotive	San Francisco Bay area; New York-New Jersey; Boston; Philadelphia; Chicago; Washington, DC-Baltimore; Miami-West Palm Beach	UMTA formula and discretionary grants (sees. 3 and 9)

SOURCE: Office of Technology Assessment, 1991, based on Urban Mass Transportation Administration (UMTA) information.

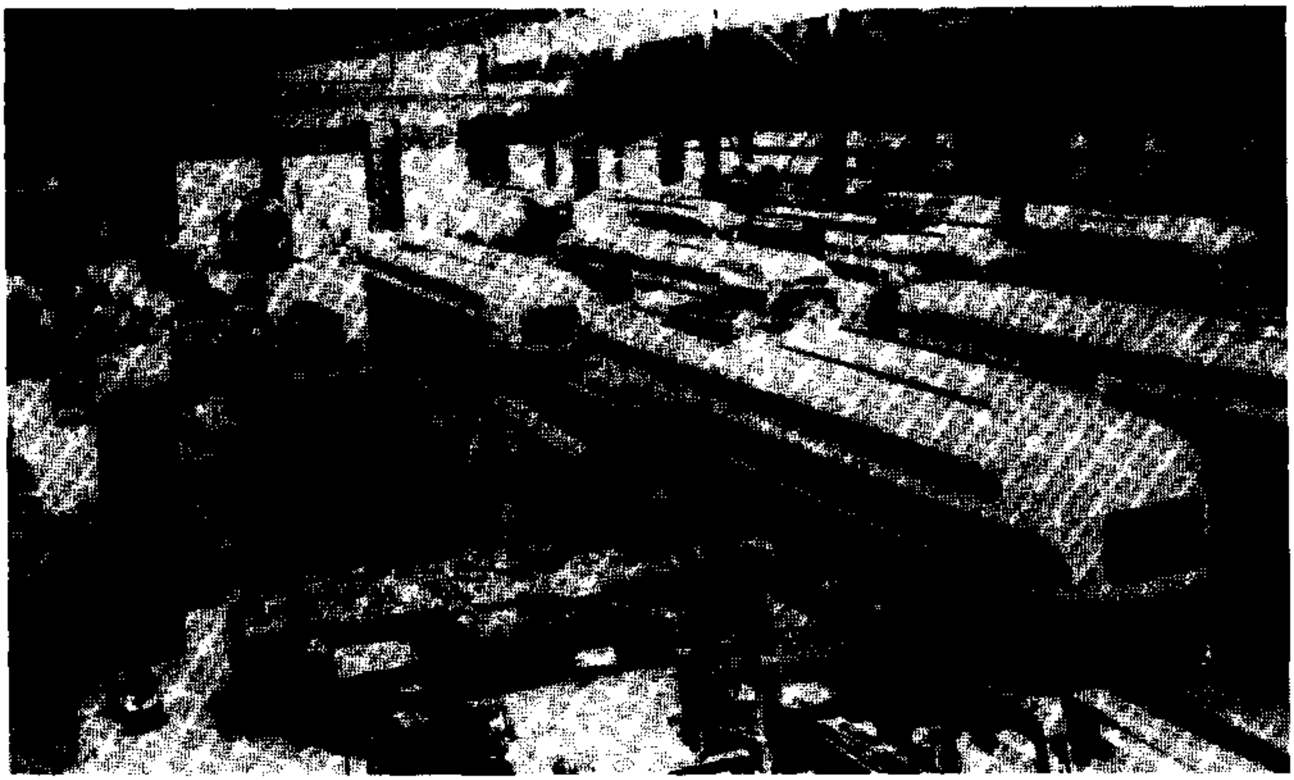


Photo credit: American Consulting Engineers Council

Rail transit systems need to rehabilitate and maintain vital system components. Costs for modernizing these systems are estimated to total $17.9 billion nationwide.

ance. Critical to urban movement, public mass transit is not a profitmaking venture anywhere in the world. In the United States, farebox revenues cover less than 40 percent of operating costs on average, and service is usually subsidized locally from **State or** local general funds and earmarked taxes. Buses receive substantially higher subsidies than rail transit systems.

Issues

Transit agencies are not typically an integral part of local and regional transportation and land-use decisionmaking which undermines transit's potential role in solving local and regional transportation problems. While transit is subsidized in most communities, its competitive position as a transportation alternative is reduced by municipally subsidized parking and by Federal policies that do not tax employees for parking benefits, but do tax most **transit allowances.** Furthermore, the costs of alternative capital improvements (a new highway lane, for example) are often underestimated.

Transit systems are important alternatives for increasing surface transportation capacity in congested urban corridors. However, transit must complement strong growth management programs, such as those applied in Oregon (see box 3-F), if transit is to be more effective at alleviating congestion.

Bus transit systems have made major efforts to upgrade their maintenance programs, because vehicles in poor condition break down frequently, making schedules hard to keep. However, many operators of smaller buses, such as those used in small communities or in paratransit, encounter problems with brake wear, corrosion, electrical and air conditioning systems, wheelchair lifts, and vehicle handling.[40] Maintenance costs are thus high for these small operators.

[40] Charles Dickson, director of training, Community Transportation Association of America, personal Communication, May 31, 1990.

Box 3-F-Oregon's Growth Management Program

Oregon is using growth management to control urban sprawl and cut public works costs. All Oregon cities must incorporate urban growth limits and public facilities plans into their State-mandated comprehensive plans and adopt consistent zoning ordinances. State legislation, adopted in 1973 to protect prime agricultural land from haphazard urban development, requires that comprehensive plans show an urban growth boundary, which defines the extent of urban expansion permissible over a 20-year period. The boundary is based on forecasted land-use needs, physical characteristics of the land and local growth policies.[1] Although it took over a decade to achieve, all cities and counties now have State-approved comprehensive plans. State actions, including those of the Highway Department, must be compatible with local plans.

In addition to comprehensive planning requirements and urban growth boundaries, State housing policy is an important growth management tool, because it requires cities to zone for high-density development as a means of stimulating construction of affordable housing. To a greater extent than in most other States, development in Oregon in recent years has followed high-density patterns; in 1989 Portland had the highest percentage increase in multifamily construction in the country and from 1985 to 1989,54 percent of all residential construction in the State was multifamily.[2] Developers generally support the high-density zoning policy because it reduces per-unit construction costs and because the mandated consistency between zoning ordinances and comprehensive plans eliminates lengthy and unpredictable rezoning proceedings. Local officials find compact, highdensity development provides the market needed for mass transit, reduces other municipal service construction and operating costs, and increases affordable housing. Heightened interest in light rail transit, instead of more highways, is another benefit of this policy.[3]

While State officials are optimistic about the long-term effectiveness of growth management to reduce transportation and other facility costs, pockets of existing development outside the urban boundary undercut the effectiveness of growth limits. These low-density unincorporated areas, largely exempt from the strict limits on development in effect elsewhere, continue to grow. In the Portland region, they have absorbed only 5 percent of residential growth, but in other fast growing areas one-quarter to over one-half of residential development occurs in these unregulated places, complicating regional planning and financing for highways and public utilities, Even within urban growth boundaries, new development is not necessarily contiguous to old and gaps occur, which increase public works costs and inefficiency. The Oregon Department of Land Conservation and Development is conducting a major study to evaluate the impact of current growth management programs and how to improve them.[4]

1Land Conservation and Development Commission, *Oregon's Statewide Planning Goals, 1990* (Salem, OR: 1990), p. 14.

2John Kelly, project manager, Oregon Department of Land Conservation and Development Commission, personal communication, Nov. 1, 1990.

3Ibid.

4Ibid.

For r-ail transit systems the components most in need of rehabilitation or replacement are railcars, power substations, overhead power wires, maintemince facility buildings and storage yards, and bridges. All also require high degrees of ongoing maintenance. Facilities and equipment in the poorest condition are usually the oldest, such as those in New York City, Chicago, and Philadelphia, some of which are more than 50 years old. Rehabilitation and modernization costs to bring the Nation's existing rail transit systems to a level ''. . . consistent with current standards of safety, reliability, and aesthetics for new rail systems . . ." have been estimated at $17.9 billion.[41]

Technologies for Transit

Fleet and facility management and regular maintenance are of primary importance in extending the lives of mass transit vehicles, in controlling costs, and minimizing environmental effects.

41Gannett Fleming Transportation Engineers, Inc. et al., *Rail Modernization Study*, Report No. UMTA-PA 06-0099-86-1 (Washington, DC: U.S. Department of Transportation, Urban Mass Transportation Administration, April 1987), p. 2.

Buses

Busways-One traffic management strategy implemented by many cities is the creation of exclusive bus lanes on which only buses and commuter vans may travel. Busways have reduced travel times significantly and cost far less than new rail lines. They can be grade-separated, created from widening existing roads, or by simply dedicating existing lanes to bus traffic.

Automatic Vehicle Monitoring—AVM systems can locate transit buses and communicate information to drivers, dispatchers, central traffic control computers, and passengers. Methods for locating buses include LORAN C, dead reckoning, satellite referencing, and roadside beacons and detectors. (See chapter 5 for further discussion of location technologies.) Radio channels can provide voice communication or data transmission links between the bus and the central control. To speed travel, buses with communication links to the municipal traffic control system (as in some French and Dutch cities) can be given signal priority at intersections. AVM technologies are used by transit authorities for automated bus-to-dispatcher communication, as well as for collection of data on bus travel times, stops, and adherence to schedules, and thus can bean important source of data for planning and management.[42]

Communications technologies, such as cable television, videotex, telephone, video screens, and speaker phones, can provide schedule and status information to passengers on the bus, at bus stops, or at home. Speaker phones and automatic telephone information systems can supply patrons with bus arrival information specific to each bus stop. Cable television enables bus passengers to view map displays of routes and bus locations, while video screens at bus stops give passengers bus schedule and arrival information. Onboard systems display upcoming stops and connections with other modes of transportation.

Electronic Control Systems-Such systems can reduce emissions, smooth shifting, increase acceleration, and quiet operations for engines and transmissions and electronically controlled power and drive trains. The ability to diagnose engine and transmission problems electronically should reduce maintenance costs and allow vehicles to stay in service longer.[43]

Bus systems in cities with serious air pollution problems must comply with new emissions standards by 1994. Emission control equipment and reformulated (''clean' diesel fuel or alternate fuels are among the alternatives, and agencies must weigh the trade-offs between capital costs, fuel costs, maintenance, and relative reduction in emissions in making decisions. Regardless of the ultimate choice, different equipment and/or fuels will bring new maintenance concerns.

Particulate **Traps-These** consist of a metal-clad ceramic falter, which captures particulate from the exhaust stream of a diesel engine. Tests conducted in California demonstrated that particulate traps can remove some 70 percent of smoke and soot emissions from the engine with no sacrifice in performance. However, the reliability and durability of the traps over the life of a bus remains in question. Tests of diesel particulate trap oxidizer systems are in progress or planned in nine North American cities.[44]

Methanol—This is the alternative cleaner burning fuel that has been tested most thoroughly for bus use. It is producible in the United States from natural gas, coal, and biomass. It has one-half the energy content of gasoline, meaning that 1 gallon of M100 (pure methanol) gives about one-half the mileage of 1 gallon of gasoline. However methanol is toxic, corrosive, and highly flammable, so different handling procedures and redesigned fuel and exhaust systems are necessary. Lastly, a distribution system comparable to the existing system for gasoline and diesel fuel will be needed before methanol can be available for nationwide use.

Natural Gas-Used in motor vehicles since World War II, natural gas now fuels primarily light-duty van and truck fleets. The largest current program for buses is in Vienna, Austria, where 400 buses run on liquefied natural gas. Compressed

[42]Canadian Urban Transit Association, *Proceedings: The International Conference on Automatic Vehicle Location in Urban Transit Systems* (Toronto, Ontario, Canada: September 1988).

[43]George Izumi, program manager, Office of Engineering Evaluations, Urban Mass Transportation Administration, personal communication, May 31, 1990; and "NJ Transit Gains Advantage With Electronic Engine and Transmission Control Systems," *Bus Ride, vol. 26, No.* 1, March 1990, pp. *48-49.*

[44]Manufacturers of Emission Controls Association, ''Trap Oxidizer Control Status Report,'' unpublished document, November 1989, pp. 8-10.

natural gas (CNG) is the most common form considered for bus use in this country, however. In contrast to methanol, CNG is not corrosive, causes less engine wear, and gives longer engine durability, although as for methanol, larger onboard fuel tanks and new distribution facilities would be needed. CNG vehicles can require substantially more time to refuel than methanol or diesel fuel vehicles, a particular concern for bus fleets, which can afford little down time.[45]

Rail Transit

Track Inspection Technologies—These include automated track measurement systems, which operate either as dedicated vehicles or measuring devices fitted to passenger cars. The equipment uses electro-optical or electromagnetic methods to give dynamic measurements of track geometry under loaded conditions. It measures and records track location, gage, profile, and alignment in a fraction of the time required by a track walking crew. However, the automated track geometry measurement system does not detect other track characteristics such as rail fatigue, tie fastener problems, or concrete cracks. Newer track geometry cars can be equipped with video or other equipment to record information such as overhead clearance, third rail alignment, foliage clearance, and tie condition. Dedicated rail flaw detection cars are used to test rails ultrasonically for defects, which usually result from fatigue. Track data of all kinds can be stored in computerized data management systems to help in setting priorities for further inspection and maintenance.

New **Rail Propulsion** Technologies—Such technologies as alternating current (AC) traction motors can save substantial energy costs. AC traction motors are operating successfully on rail vehicles in Europe and Japan and have been introduced in New York City and Philadelphia; trolley buses and light rail already use them. AC motors can reduce energy consumed in starting, braking, and heating; reduce maintenance and repair expenditures because they have fewer moving parts; and reduce slipping, skidding, and wheel and rail wear.

Offsetting these benefits is the greater weight of the line filter, which must be added to smooth line current and reduce signal interference. The cost of converting existing cars to run on AC is substantial-about $200 million for one regional agency.[46]

Control Systems—Most modem train control systems now use pulsed currents through the track circuit to communicate allowable speed information and employ cab signaling, rather than wayside signaling, which allows quick response to changing traffic information. While older, wayside signaling conveys information only at block entrances, cab signaling gives signal displays within the cab of the train, and displays are updated continuously in response to the condition of the track ahead. This enables trains to run with a higher level of safety than with wayside signaling (see box 3-D again).

Automated Guideway Transit—AGT typically provides slow-speed continuous service along dedicated, isolated guideways; cars are controlled by microprocessors. They function automatically and do not require onboard operators, but they do require exclusive right-of-way and security systems, such as anti-intrusion devices at stations and on the right-of-way. They can use steel wheels on rails, rubber tires on concrete guideways, or even magnetic levitation. Fare collection takes place in the stations. Examples of AGT include people mover systems in Detroit, Miami, Jacksonville, Tampa, Morgantown (West Virginia), VAL in France, SkyTrain in Vancouver, British Columbia, the M-Bahn in West Germany, and numerous shuttle systems in airports, and amusement parks.

Personal Rapid Transit—Concepts for PRT systems include new configurations of existing technology and feature:

- small, fully automated vehicles (without human operators or attendants), available for exclusive use by an individual or a small group traveling together; and
- vehicles captive **to a** small, dedicated guideway, located above ground, **at or near ground** level, or underground, which provide direct origin to destination service on demand without stops or transfers.

PRT systems face difficult environmental hurdles in the form of objections to above-ground guideways and stations, which duplicate the road network to some extent. Security concerns center on the driver-

[45] L.R. Davis, director, Equipment Maintenance, Southern California Rapid Transit District, personal communication, Mar. 22, 1990.

[46] Officials from the Washington Metropolitan Area Transit Authority, personal communication, Jan. 22, 1990.

less cars and unattended stations, while safety issues include whether many small, closely spaced vehicles can run safely on a single-lane guideway.

Surface Transportation Networks: Railroads

Rail service in the United States is provided by a mix of public and private entities. The quasi-public National Rail Passenger Corporation (Amtrak), created in 1971, is the primary intercity passenger rail company (see figure 3-6). Because of the importance of public sector support to the continuation of passenger service, discussion in this section will emphasize passenger service and the Federal role. However, hundreds of private freight railroads play an equally critical part in the national transportation system, carrying bulk materials, such as coal and agricultural products, and about 50 percent of the market for long-haul transportation of manufactured commodities.[47] Freight railroads compete with barge lines for shipments of large bulk commodities and with tractor-trailer trucks for smaller bulk shipments. To counter the faster, more flexible service trucks can provide, rail companies have concentrated traffic and investment on fewer, high-density lines[48] and introduced double stack and rail-highway vehicle services. The largest, or Class 1, freight railroads, account for over 90 percent of railroad traffic and employ over 90 percent of the rail work force.[49]

Regional railroads are usually defined as those with between 250 and 1,000 miles of track, while those with less than 250 miles of track are classified as *shortline or local railroads.* Most of these 32 regional lines are privately owned. However, 1 of them, and 31 of the over 400 shortline or local lines are owned and operated by State and local governments (although they operate on privately owned track). Since the Staggers Act (see chapter 2), the number of shortline and regional railroads has grown significantly, providing continued service for many localities.[50]

Railroad Management and Financing

The private sector owns and operates most rail infrastructure, including 97 percent of the total track mileage, as well as most bridges, control systems, communications systems, yards, service buildings, vehicles, and support equipment.[51] Amtrak owns much of the track along the Northeast corridor between Washington and Boston (its busiest routes) and some along the Chicago-Detroit corridor, a total of 600 miles. The Corporation contracts with 15 private freight railroads to provide train dispatch and track maintenance services outside these corridors. Its operating fleet includes some 300 locomotives and 1,900 passenger cars, most of which it owns. Of its almost 39 million passengers in 1989, about 44 percent rode on commuter rail systems operated by Amtrak on a contract basis; the rest were intercity passengers.[52] In 1989, Amtrak trains carried more travelers between Washington and New York than any airline.[53]

Each year, Amtrak receives a Federal operating subsidy of about $500 million, which it splits equally between its intercity long-distance routes and its shorter distance Northeast corridor operations. In fiscal year 1989, the Corporation earned $1.27 billion in revenues, enabling it to cover 72 percent of its operating costs from its own sources. About one-half of Amtrak's yearly capital expenses come from internal sources, and the rest come from Federal aid.[54]

States play a relatively minor role in financing, operating, or regulating railroads. Nonetheless, at least 20 States provide assistance to local rail service from earmarked taxes and general appropriations, and most maintain a State Rail Plan that includes an

[47] Informational material prepared for OTA by the Association of American Railroads, Jan. 31, 1990.

[48] Federal Railroad Administration, briefing document prepared for OTA, 1989.

[49] U.S. General Accounting Office, *Information on Regulatory Reform Under the Staggers Rail Act of 1980* (Washington, DC: Aug. 17, 1983), p. 1.

[50] Federal Railroad Administration and Interstate Commerce Commission *A Survey of Shipper Satisfaction With Service and Rates of Shoreline and Regional Railroads,* joint staff study (Washington, DC: August 1989), p. 1; and Association of American Railroads, *Profiles of U.S. Railroads,* supplement No. 1 (Washington, DC: 1990).

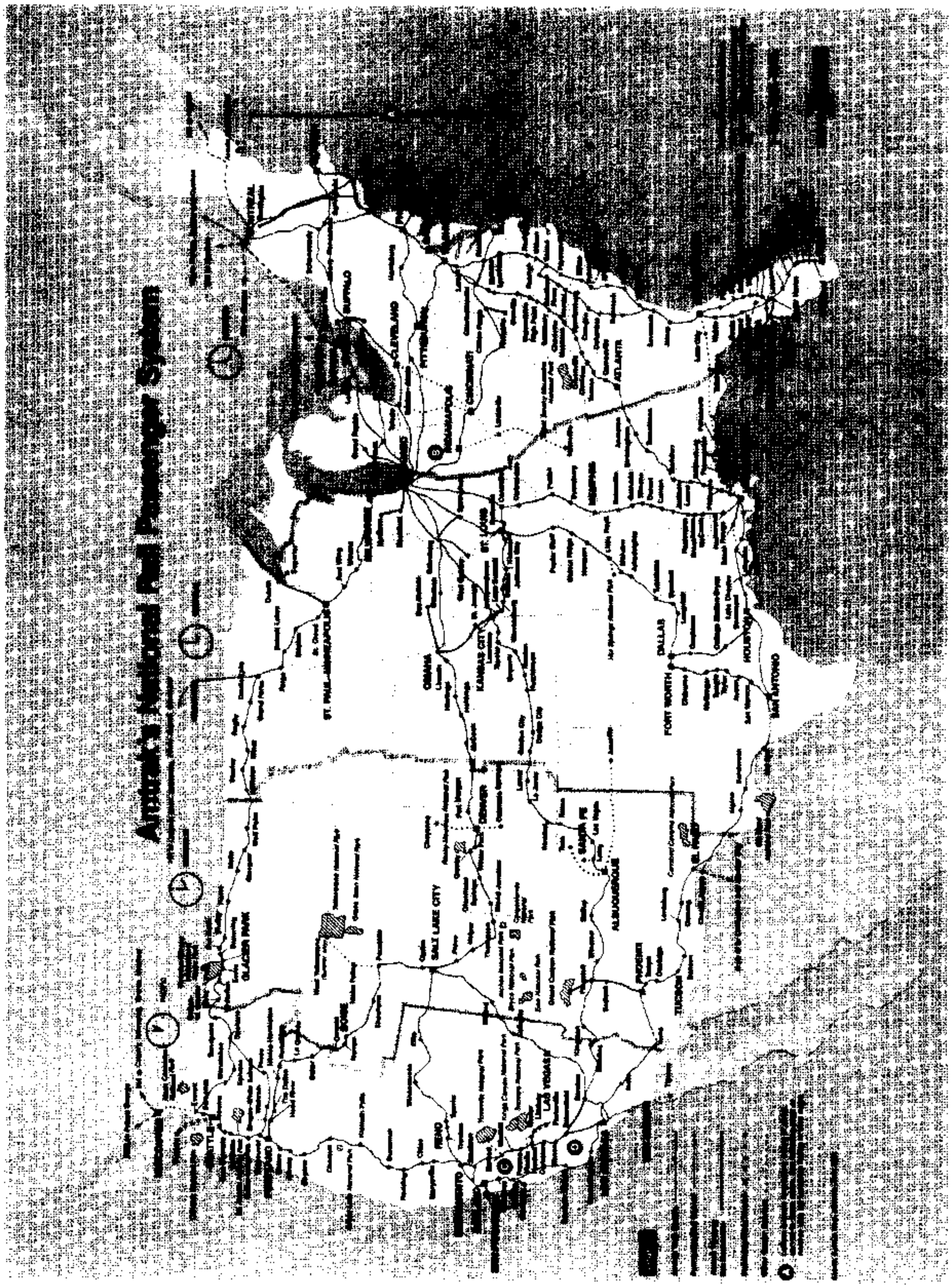
[51] Federal Railroad Administration, op. cit., footnote 48.

[52] Commuter services operated by Amtrak include the Massachusetts Bay Transit Authority (MBTA) and the Maryland Rail Commuter Service (MARC).

[53] National Railroad Passenger Corp., *Annual Report 1989* (Washington, DC: 1990).

[54] National Railroad Passenger Corp., "1990 Legislative Report," unpublished document, Feb. 15, 1990, pp. 5-9.

Figure 3-6—Amtrak's National Rail Passenger System



SOURCE: Amtrak, 1989.

inventory of facilities and a ranking of proposed projects. A few large, urbanized States, California and Pennsylvania, for example, subsidize or supply intercity passenger train service. Other State aid is distributed as grants or loans to small, shortline freight carriers. Local governments have few direct responsibilities for railroads, although commuter railroads are major highway traffic relievers in congested metropolitan areas.

Rail Issues

Amtrak hopes to achieve full operating self-sufficiency by the year 2000, but needs to replace its aging fleet of cars and upgrade track along several corridors to maintain and expand current levels of service. It could operate far more efficiently with new locomotives and by using double-deck passenger cars on heavily traveled lines. To meet demand on sold-out long-distance routes, Amtrak plans to purchase at least 75 two-level sleeping and food service cars. On several routes, these cars will replace single-level cars, which can be used on other routes to expand capacity.

Although Amtrak must purchase a good deal of new equipment to sustain revenue growth, doing so requires large amounts of capital, which the railroad has few means of accumulating. Yield management, higher fares, and efficient utilization of equipment,[55] its current sources of increased revenue, are unlikely to generate the dollars needed. Improved track, maintenance facilities, locomotives, and passenger cars are expected to cost the Corporation about $300 million annually during the 1990s and require sums far greater than the current Federal capital grants of about $30 million annually.

Rail facilities are strategically located in most cities and offer often underutilized capacity, which, under the right circumstances, could bean economical option for moving people and goods within and between metropolitan areas. However, funding constraints often prevent railroads from making the investments necessary to keep customers. Shortline and regional railroads that have formed from railroad lines where maintenance was deferred and neglected face rehabilitation needs far exceeding their ability to pay. A Federal Railroad Admfinistration survey of small railroads found the one-time costs of track and roadbed rehabilitation-replacing ties and ballast and improving track surfaces-to be higher than annual revenues for many lines, about $428 million in total. Modal subsidies, embedded in Federal programs for other types of transportation assistance, provide support for other modes in ways that would benefit railroads.

Labor issues are a final management concern for railroads. Federal regulations requiring a supplemental retirement system for railroad employees, raihoad-funded benefits for employees made jobless by a consolidation, line sale, or abandonment,[56] and railroad workers' compensation statutes are particularly hard on shortline and regional railroads because of their small size and scale of operations.

Rail Technologies

Railroad technology in the United States **is not** characterized by rapid change; for instance, the air brake system is the same conceptually as when it was introduced, and standard track still **consists of steel rails, spikes, and wood ties mounted on ballast** of crushed stone.[57] (For **a potential exception, see box 3-G.)** However, new technologies for railroad operations have developed rapidly in recent years. Electronic data information systems, radio communications, advanced train control systems, and other propulsion innovations have enabled many railroads to operate more efficiently and productively.

Keeping the System in Good Shape

Track condition has benefited **from a new** emphasis on longer wear rail metallurgy, **continuous welded rail, profile grinding to extend rail life, concrete cross ties, new fastening systems for both concrete and wood ties, track geometry measurement systems, track maintenance planning tools, new inspection technologies,** and more mechanized and automated maintenance equipment.[58]

Track Maintenance Management Systems- Such systems function as decision support tools for

[55] W. Graham Claytor, Jr., president and chairman of the board, National Railroad Passenger Corp., testimony at hearings before the House Subcommittee on Transportation and Related Agencies, Committee on Appropriations, Mar. 22, 1989, pp. 2-3.

[56] The Interstate Commerce Commission which has the authority to exempt line sale from labor protection has granted exemptions to most of the newest regional railroads.

[57] Federal Railroad Administration op. cit., footnote 48.

[58] Ibid.

Box 3-G-Magnetic Levitation Research

The High Speed Ground Transportation (HSGT) Act, passed in 1965, established the Office of High speed Ground Transportation in the Department of Commerce whose objectives were to explore advanced intercity ground transportation technologies. Most early work on magnetic levitation (maglev) occured around the time of the act's - at Brookhaven National Laboratory the Massachusetts Institute of Technology (MIT), and a number of private industry research facilities. However, other than feasibility studies and technical assessments, U.S. maglev work essentially ended in 1975, with the expiration of the HSGT Act.

The Department of Energy, Department of Transportation, and the Army Corps of Engineers *have recently begun* anew effort, the National Maglev Initiative, to assess the engineering, economic, and environmental aspects of maglev and determine its feasibility for the transportation system. The budget appropriation for fiscal year 1991 include $10 million for the Federal Railroad Administration and $2 million for the Army Crops of Engineers to begin work. A major program report planned for March 1991 will include technical and economic assessments, plans for developing U.S. capability to surpass existing foreign technologies, and recommendations on whether to pursue further development.

Currently, maglev research is most active in Germany and Japan whose efforts have been underway way since the late 1960s. Research in Germany, sponsored by the Federal Ministy of Research and Technology has focused on electromagnetic suspension designs, while the Japanese are investigating both electromagnetic and electrodynamic designs.

One of the Japanese systems, an electrodynamic"c suspension design was originally developed by the Japanese National Railways (JNR). Work began in 1967, and research and development (R&D) costs through mid-1988 were $416 million. Since the priva tization of JNR in 1987, development of this system has come under the responsibility of the Railway Technical Research Institute (RTRI) one of 12 offshoots of JNR. RTRI receives funds from the Japan Railways Group, a Consortium including six passenger railway companies the Japan Freight Railway Company, and the Japanese govermnent (Ministry of Transportation).[1] The vehicle has a top speed of over 300 miles per hour, but has been tested only over short distances at a test facility in Miyazaki. This system is the only maglev technology that uses superconductivity. This Japanese technology require less sensitive tolerances between track and train than the German system and thus maybe less costly to construct and maintain Although recent advances in developing high-ttemperature superconducting materials are not likely to affect the overall feasibility of this maglev technology, using high-temperaturee superconductors for mshlrb could bring modest gains in energy efficiency cfficiency and reliability.

[1] Richard A. Uher, director, High Speed Ground Transportation Center, Carnegie Mellon Research Institute, testimony at hearings before the Senate Subcommittee on Surface Transportation, Committee on Commerce, Science, and Transportation, Oct. 17, 1989.

railroad engineers, technicians, and planners for identifying physical track assets, inspecting and evaluating track, identifying work needs, and planning and priority setting. Information is collected and stored in large databases and includes installation information; track segment inventory; inspections, traffic levels, maintenance records, and repair costs; and work crew history. These systems can also handle information about operations and store data on planned and completed maintenance and repair work for each track segment.

AC induction Motors-AC motors can be adapted to passenger rail and could extend the mean time between motor failures from 11/2 years to more than 5 years.[59] Amtrak has acquired two AC traction locomotives, which it is now evaluating in revenue service. The motors have fewer parts than DC motors, require less maintenance, and are smaller, lighter, and less noisy. Amtrak has not yet determined whether its future locomotives will use AC or DC traction.[60]

Concrete Cross Ties-Concrete ties provide track with greater stiffness and stability than wood ties and may be more durable, if track and vehicle are well maintained. However, concrete ties are susceptible to cracking or fracture from impact loads, such as those caused by irregularities in track or wheels. Widespread use of concrete ties has therefore been primarily on modem systems that are maintained to high tolerances, such as the TGV in France, and in

[59] K.M. Watkins, director, Motive Power, Amtrak, personal communication, May 25, 1990.

[60] Terry Brunner, general superintendent of Iocomotives, Amtrak, personal communication Nov. 6, 1990.

A *27-mile* test facility is under development in Yamanashi prefecture, and an extensive 4-year test of the system is expected to commence in 1993. About $3 billion will be invested over the next 7 years for construction and testing, and the Yamanashi" test track may become part of a possible revenue line between Tokyo and Osaka.

The other major Japanese system is the High Speed Surface Transportation (HSST) system, an electromagnetic suspension design with a top speed of 180 miles per hour. Development of this system began in 1975 by Japan Airlines, but in 1985, the technology was transferred to the HSST Corporation. Since 1981, the HSST system has received no government funding; this system is still under development with no estimated completion date. HSST maglev has been demonstrated extensively but has never realized its top speed during these demonstrations because test track length has always been less than 1 mile. Because of its relatively low maximum speed in relation to other maglev designs the HSST system will probably not compete with the RTRI system over longer routes. However, the technology is more mature, and applications could begin much sooner.

Modem maglev technology in Germany began in 1969, when the Federal Ministry for Transport commissioned a study on high-speed, track-bound, ground transportation. In 1977, the Ministry of Research and Technology decided to concentrate development work on electromagnetic suspension designs, and between 1970 and 1980, provided funding in support to the Transrapid consortium As of mid-1988, over $800 million had been spent on the Transrapid R&D program. The TRANSRAPID 07 vehicle has achieved a top test speed of 280 miles per hour and accommodates about 200 seated passengers. The Emsland test facility has a 19.5-mile track which has been in operation since 1983; more than 15,000 miles of tests have been accumulated on the system. Although German Transrapid technology is currently the most advanced of the prototype systems many feel its precise tolerance requirements could lead to high maintenance costs. The Transrapid is estimated to cost $20 million per double-track-mile, not including right-of-way acquisition and station costs.[2]

In December of 1989, the German government approved a 33-mile revenue route between the airports of Cologne/Bonn and Dusseldorf, later to be extended to Essen for a total of 51 miles. However, the government has stipulated that the DM 3.6 billion in capital costs must be shared by private industry, the airports and airlines, and the state of Northrine-Westphalia and it is unclear whether this condition can be fulfilled.3 Recognizing the bleak outlook for maglev in Europe because of the likely dominance of conventional high-speed rail systems-the French TGV and German ICE, for examp--Transrapid is pursuing corridors and feeder routes in foreign markets, such as the USSR, Saudi Arabia, Canada and the United States, to showcase its technology. A 13-mile route from the Orlando, Florida, airport to the Disneyworld vicinity maybe the first high-speed revenue maglev system.

[2]Ibid.

[3]*Spektrum der Wissenschaft*, February 1990, p. 32.

this country, Amtrak's Northeast corridor and heavy-duty "height lines with extensive curvature.[61]

Rail Head Lubrication—This can increase fuel efficiency and reduce track and vehicle wear. Trains traveling over straight sections of lubricated track consume between 3 and 10 percent[62] less fuel than trains traveling over unlubricated sections, and lubrication may save costs for car and locomotive wheel replacements as well.[63]

Passenger Waste Disposal—Criticism for releasing untreated human waste from trains en route led Amtrak in August 1989 to initiate a research program to identify technologies capable of retaining up to 72 hours of waste. Prototype systems have been installed on Amtrak trains, and their durability and the costs associated with providing and operating equipment on existing trains are being assessed.

Increasing Capacity

High-speed train technology alternatives can increase capacity and efficiency without requiring major acquisition of new right-of-way (see box 3-H) in crowded intercity corridors. In the Northeast corridor, electrifying the entire line and utilizing tilt trains could reduce travel time between New York

[61]Ibid.

[62]Douglas B. Tharp, Consolidated Rail Corp., "Examination of Methods to Achieve Rail Lubrication," *Transportation Research Record 1174* (Washington, DC: National Research Council, 1988).

[63]Luther S. Miller, "Rail Greasing: Big New Savings Identified," *Railway Age*, vol. 190, No. 9, September 1989, pp. 49-60.

Box 3-H--High-Speed Rail

With substantial government assistance, high-speed rail has become both successful and efficient in Prance, Japan, and Spain over the past several decades. The TGV France's high-speed rail system, began operations in the early 1980s. Construction on the newest line of the TGV, the Atlantique, began in 1985. The Y-shaped line consists of a main trunk between Paris and Courtalain and two auxiliary branches. The Western Paris-Le Mans branch was completed in 1989, and the southwestern Paris-Tours line was completed in 1990. Total estimated cost is 16 billion francs ($3 billion) for construction of 163 miles of track and rolling stock. The line includes 13 miles of tunnels, 2 miles of viaducts, and seven flyovers to keep trains from crossing existing tracks. Maximum design speed is 300 kilometers per hour (km/hr) (186 miles per hour (mph)), with turnout crossing speed of 160 and 220 km/hr (100 and 136 mph).[1]

Land belonging to the SNCF (the French national railway company), the government, or alongside existing rail or highway right-of-way was used for 60 percent of the Paris-Courtalain stretch. To avoid level crossings, there are more than 310 structures along the line, including 164 road bridges and 139 rail bridges. Continuous welded rail and reinforced concrete crOSS ties are used throughout. The line is electrified and uses five power Substations. A control center at Paris-Montparnasse has telemetry and remote control equipment for the crossovers, spaced at approximately 14-mile intervals, between the two tracks. It also controls electric power feed and can interven via radio Iinks with all trains on the line. Fifteen satellite stations house safety equipment for each crossover site. The track-to-locomotive transmission system sends signaling information to the cab, where the driver reads it on the control panel.[2]

The TGV's power and adhesion, and dedicating the high-speed corridor to passenger service with its light loads, made possible a line with gradients of up to 3.5 percent (on the Paris-Sud Est Iine--the maximum grade on the Atlantique line is 2.5 percent), instead of the usual 0.5 to 0.8 percent gradients. As a result, the line could be routed over plateaus where large-radius curves could be easily laid out, and thus avoid valleys, which are often sinuous, densely populated, and furrowed by waterways and roadways--all of which increase construction costs. The TGV lines are compatible with existing track, so that the trains can penetrate city centers and serve all major station on the way.[3]

The Japanese Shinkansen (Bullet Train) long-distance high-speed railways include two groups, the Tokaido and Sanyo Shinkansen, which run Southwest from Tokyo, and the Tohoku and Joetsu Shinkansen, which serve the regions to the northeast. The Tokaido line began service in October 1964, while the Sanyo Shinkansen began

[1] SNCF, Direction de la communication, 'The TC3V Atlantique: Construction of the New Line," June 1986.

[2] Tbid.

[3] SNCF, Direction de la communication, "The Railways of France," brochure, n.d.

and Boston to under 3 hours from the present 41/a hours. Equipment and right-of-way upgrades could lower the time between Washington and New York to under 2 hours 15 minutes. While requiring substantial public investment, these improvements are important in the short term, because they could relieve traffic congestion in air and highway corridors.

Advanced Train Control Systems-ATCS are computer based and give precise data on train position, condition, and speed. Location and speed are determined by coupling locomotive odometers with either in-track transponders or a satellite-based Global Positioning System (GPS). Information is transmitted between the central dispatch computer and the locomotive through a UHF or VHF radio data communications link. Display screens in each locomotive cab show train location and speed, upcoming route profile, speed limits, and other authorities from the dispatch center. The dispatcher can send instructions directly to the locomotive engineer and receive precise information on train location and speed. Efficiency is improved by better coordination of train movements, precise meet and pass planning, and more efficient use of crews and equipment. Sensors mounted on the engine, electrical and air systems, and fuel tanks can collect data and monitor locomotive performance in real time. Transmitted to dispatchers and maintenance facilities, these data can reduce troubleshooting times and maintenance costs. Safety is improved, because if the engineer does not follow speed instructions or operating in March 1972. The Tohoku Shinkansen which runs north from Tokyo, began operation in June 1982; its east-west connecting line, the Joetsu Shinkansen began service in November of the same year. Maximum speed for the line is now 150 mph.

When the Japanese National Railways was privatized in 1987, these lines became the property of the new Shinkansen Holding Corporation, which leases them to three passenger railway companies: the East, Central, and West Japan Railway Companies. A total of 2.7 billion passengers have been carried on the Shinkansen without injury. The Shinkansen's ability to take passengers directly from city center to city center makes it competitive with airline and expressway transportation, and five additional routes are scheduled for future construction.[4]

Shinkansen tracks are equipped with snow-melting facilities to prevent railway switch points from freezing in cold weather. Additional steps, such as covering the lower parts of the cars and using centrifugal snow separators,, which remove snow from the intake air,[5] are taken for the lines that pass through areas with heavy snowfall. Trains operating in areas prone to earthquakes are protected by a combination of earthquake detection and control systems, including seismometers installed every 20 to 80 km along the line. If land cables are damaged by large earthquakes, a communications satellite system will be used to transmit information.[6]

Tilt train technology is based on car bodies capable of tilting when moving through curves to reduce passenger discomfort. Development of one tilting train, the Spanish TALGO, began in the 1940s. The latest TALG0 model is designed for a maximum speed cm straight track of 125 mph and for rounding curves safely at speeds 25 percent faster than conventional trains.[7] The TALGO trainset is made up of a succession of rigid cars articulated so as to permit the train to negotiate curves without vertical or transversal displacement between cars. Acceleration felt by the passenger due to displacement when the train rounds a curve depends on the tilt of the car and is significantly reduced if the car is tilted in toward the center of the curve. The suspension system in TALGO cars is above the center of gravity; the air springs of the main suspension behave elastically, allowing the car to tilt naturally around curves as a result of centrifugal force. The TALGO trains also have an automatic gage changing mechanism to accommodate different track gages.[8] Other tilting train configurations are manufactured by Bombardier of Canada and Asea Brown Boveri, a Swedish-Swiss consortium. These are active tilt systems, which employ powered actuators to cause the desired roll.

[4] East Japan Railway Co., Shinkansen brochure, n.d.

[5] Ibid.

[6] Ibid.

[7] RENFE, "TALGO: An Up-to-Date Train; A Long History," informational document, n.d.

[8] RENFE, "TALGO Pendular," informational brochure, n.d.

conditions along the route require emergency control,[64] speed can be remotely controlled.[65]

Perhaps the most dramatic recent development in increasing the efficiency of rail freight transport has been the introduction of *double* **stack service.** Double stack cars consist of skeleton car spines, each capable of carrying two containers. This reduces weight and aerodynamic drag and cuts by roughly one-half the amount of power needed to move trains at market-competitive speeds; that is, 100 containers on double stack cars require 4 locomotives, the same number needed to haul 50 containers on conventional cars. Double stack has been a major competitive success; long-haul truck traffic in major double stack lanes fell 25 percent between 1985 and 1988, even though long-haul trucking in the rest of the country grew 33 percent during the same period.[66]

Fuel Efficiency Measures-Approaches include automatic devices to prevent or reduce fuel spillage, recovering and recycling spilled fuel for heating and air conditioning railroad sheds and buildings, improved aerodynamic designs of railroad equipment, and calculating the optimal mix of power, weight, and speed for maximum fuel efficiency under various operating conditions. Other technologies under study for increasing fuel efficiency include

[64] Steven R. Ditmeyer, "A Railroad Command, Control, and Communications System for the 21st Century," paper presented at the International Conference on Technology and Technology Exchange, New York, NY, June 30, 1989.

[65] Association of American Railroads, op. cit., foonote 47.

[66] Ibid.

Photo credit: Port of Long Beach

Double stack cars carry almost twice as many containers, but use only slightly more energy than a conventional freight train.

Photo credit: Port of Long Beach

Many operations at the Intermodal Container Transfer Facility in Long Beach, CA, are computerized for speed and efficiency. Computers in the control tower are linked with those of ocean vessels, and the yard receives information about each container before it reaches port.

alternative fuels, such as mixtures of diesel fuel distillate with lower grade fuels, and the burning of coal in diesel engines. Rail electrification is another energy alternative, but the high initial cost of converting to electrification might be a barrier, considering the current cost and availability of diesel fuel.[67]

Data Management and Transfer—These are key to efficient operations, and Amtrak has in place a management information system that serves the railroad well. (See chapter 5 for further details on such systems.) Freight railroads have found many benefits in electronic data interchange, the electronic transmission of administrative data, such as tracking materials and supplies, revenue, car accounting records, and freight loss and damage claims. Freight railroads plan to shift to electronic data exchange rather than paper, when cars are interchanged, and some railroads already allow shippers direct access to their information systems.

Federally Managed Infrastructure: Waterways and Airways

In the two transportation areas where the Federal role in operations and maintenance is large-waterways and airways-the infrastructure has generally been kept in good physical shape and provides convenient transport except at periods of peak demand. With proper maintenance and rehabilitation, locks and dams can remain operable indefinitely,[68] and safety requirements help ensure the reliability of air traffic facilities. When facilities, such as a major lock or a runway at a busy airport, must be removed from service for rehabilitation, the Federal managers work with all concerned parties to develop ways to minimize delays.

Ports and Waterways

Historically, communities and industries developed near ocean and riverfront ports, which handled raw materials or finished goods primarily for local consumption or from local suppliers. Today, the United States has the world's largest port[69] system, with about 200 major ports, each handling at least 250,000 tons of cargo annually or having channels

[67] Association of American Railroads, "When It Comes to Fuel-Efficiency, Railroads Lead the Transportation Pack," background Paper, September 1988.

[68] U.S. Army Corps of Engineers, Institute for Water Resources, "The U.S. Waterway Transportation System: A Review," unpublished report, April 1989, p. 24.

[69] In this section, "port" means land-baaed facilities as opposed to offshore, midstream, or other nontraditional transfer locations for cargo or passengers. Commercial ports are links in a transportation network serving passengers, freight, and bulk cargo, and do not include facilities used solely for recreation or fishing.

deeper than 20 feet.[70] Critical junctures in the national transportation network, ports often combine truck, rail, pipeline, barge, and ship operations for transferring most of the 2 billion tons of cargo moving into or out of the United States every year. Less than 2 percent is handled directly by offshore facilities and pipelines.

Fifteen percent of total U.S. freight ton-miles are produced by commercial barges and tows carrying bulk commodities, such as petroleum, grain, and coal, on the Nation's shallow draft (less than 14 feet) inland and intracoastal waterway system.[71] The Mississippi River, its tributaries, and connecting waterways are the Nation's major inland water transportation network. (See figure 3-7 for a map of the inland waterway system.) Waterway transport offers the lowest ton-mile costs to shippers.

After a decline during the recession in the early part of the decade, total waterborne commerce in the United States grew at about 3 percent per year during the 1980s. Continued growth at that rate would place heavy demand on certain landside facilities,[72] although adequate port capacity exists to meet U.S. commerce needs.[73] The waterways can also handle more freight shipments, and limited traffic demand makes system expansion unlikely.

Management and Financing

Waterside facilities are constructed, maintained, and operated primarily by the Federal Government, through the U.S. Army Corps of Engineers (the Corps), which supports virtually all U.S. ports of national significance.[74] The U.S. Coast Guard furnishes communication and navigation safety facilities. Until the late 1980s, virtually all navigation infrastructure costs were paid out of the Federal General Fund. Port project location and size were established on a project specific basis, rather than as part of a national system. Thus, the practical effect of many harbor deepening projects has been to maintain competition among ports rather than to meet transportation system needs.

To support economic development, the majority of States with navigable waterways provide grants for construction of landside port facilities and water cargo terminals. Currently these grants, which total about $500 million annually, are administered through State DOTS, economic development agencies, or State port authorities, which coordinate the public works components of major improvement projects. Most States are reluctant to take over responsibility for inland waterways from the Federal Government.

The largest ocean and freshwater port facilities are owned and managed by a municipality or public or quasi-public agencies, such as the Port of Seattle or the Port Authority of New York and New Jersey. These ports consist of bulk facilities, often privately owned, and general cargo facilities, many of which are leased to private operators.[75] Inland waterway terminals are usually privately owned.

Ports raise operating funds locally from user fees and capital from revenue bonds and State appropriations. Since 1986, port operators have been required to share dredging costs with the Corps, through an ad valorem tax paid by shippers into the Harbor Maintenance Trust Fund on all cargo loaded or unloaded at U.S. commercial harbors. Anon-Federal sponsor, often a local government or port authority, must share up to 60 percent of the costs of constructing new or deeper channels. The non-Federal sponsor must finance at least 50 percent of the maintenance dredging costs for new channels deeper than 45 feet.[76] The tax, which finances a portion of harbor maintenance costs, was more than tripled in the 1990 budget agreement, from 4 cents per $100 of cargo to 12-1/2 cents per $100. Since trust fund outlays are limited to 40 percent of the total Federal expenditures attributed to commercial navi-

[70] U.S. Army Corps of Engineers, op. cit., footnote 68, p. 2.

[71] U.S. Army Corns of Engineers, Institute for Water Resources, *The 1988 Inland Waterway Review*, IWR Report *88-R-7* (Ft. Belvoir, VA: November *1988), p. 26.*

[72] U.S. Army Corps of Engineers, Institute for WaterResources, "The U.S. Port and Harbor System: A Review," unpublished report, September 1989, p. 6. Port demand depends largely on cargo volume; deepwater harbor requirements are determined by ship size.

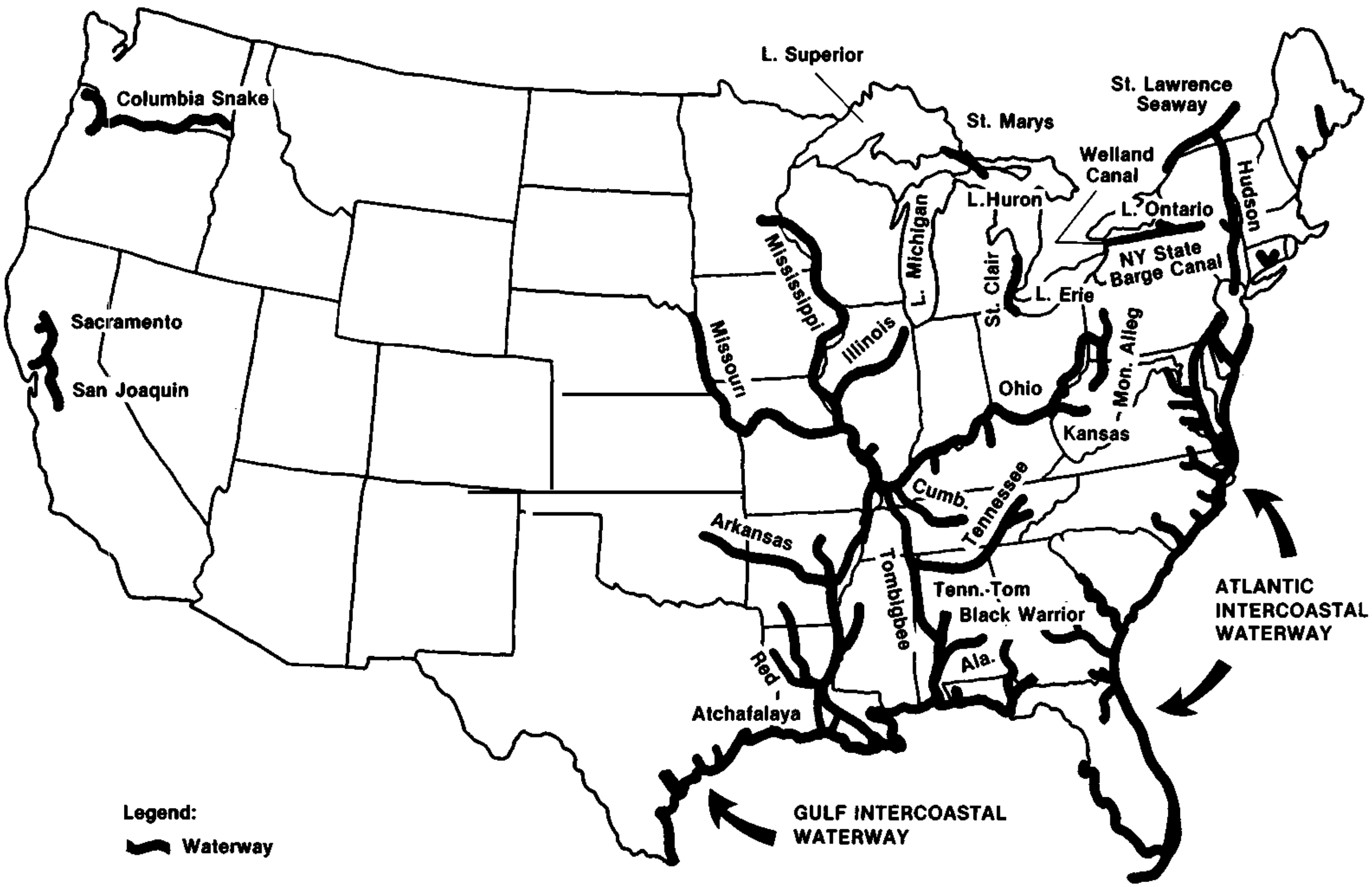
[73] 1bid., p. 13.

[74] Ibid., p. 5.

[75] John M. Pisani, "Port Development in the United States: Status, Issues and Outlook," paper presented at the Sixteenth International Association of Ports and Harbors World Ports Conference, Miami Beach, FL, Apr. 22-28, 1989, p. 13.

[76] The Water Resources Development Act of 1986 (Public Law 99-662).

Figure 3-7—The Navigation Systems of the Continental United States



SOURCE: U.S. Army Corps of Engineers, 88 gation in harbors, annual increases in surplus trust funds are likely.

Because of the tax, users are funding gradually increasing portions of deepwater channel operations, maintenance, and new construction. Requests for expansion projects are fewer and scaled back since the cost-sharing requirements became effective; the Corps estimates that project size has been reduced by two-thirds from the levels initially requested or authorized.[77]

Waterways-The Corps has modified all commercial waterways with locks, dams, bank protection, and dredging to allow passage of 9-foot draft vessels. The number and size of lock chambers determine the maximum through speed for vessels on segments of the waterway. The Corps has standardized lock chamber sizes, and barges have been designed to make the most efficient use of this capacity.

Perhaps because the Federal Government has always supported maintenance for water-related facilities, waterway maintenance costs have not compounded as locks and dams have aged.[78] Site-specific conditions, such as geology, climate, water quality, and usage, affect maintenance and replacement needs more than age. Most locks have been replaced because traffic growth has overtaken their capacity and long backups occur at peak periods, not because they have physically deteriorated.[79]

Barge operators pay a fuel tax that feeds the Inland Waterway Trust Fund (IWTF), which finances 50 percent of construction costs, and applies on the 11,000 or so miles[80] of waterways that account for over 90 percent of inland waterborne commerce. The Inland Waterway Users Board, a federally established body that advises on waterway priorities, has emphasized replacement projects on the Mississippi and Ohio systems and has specifically discouraged spending user fees for new waterways or rehabilitation.[81]

Issues

With limited fiscal resources available to maintain and physically expand the system, Federal investment decisions pose important questions for water transportation. In addition, Federal environmental requirements for protecting wetlands have created difficult and costly construction and dredged-material disposal problems. Thus, fiscal and environmental issues frame the biggest challenges for decisionmakers concerned about ports and waterways.

Fiscal Concerns-Congress has chosen to appropriate more water-related project monies from the General Fund than for any other transportation mode. Presently, 60 percent of harbor maintenance costs and 100 percent of inland waterway operations and maintenance expenses are paid for from the General Fund. In addition, the General Fund pays for roughly 50 percent of all capital costs for both waterways and harbors. In comparison, less than 5 percent of Federal highway expenditures come from the General Fund. In contrast to other public transportation networks in the country, waterway user fees cover no operations or maintenance expenditures.

Projections of future IWTF revenues indicate that they will support approximately five lock and dam replacement projects per decade.[82] Although scheduled increases will raise the industry contribution,[83] the annual fuel tax revenue is now less than 10 percent of the total annual costs (for construction, operations, and maintenance) for the portion of the inland waterway system subject to the tax. Certain segments of the inland and deepwater system generate disproportionate costs relative to the amount of traffic carried (see tables 3-6 and 3-7). Traffic levels on the Tennessee-Tombigbee Waterway, completed in 1985, are far below the projec-

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[77] U.S. Army Corps of Engineers, Op. Cit., footnote 72, p. 14.

[78] U.S. Army Corps Of Engineers, op. cit., footnote68, p. 24.

[79] Ibid., p. 24.

[80] Over 25,000 miles of navigable waterways exist in the United States.

[81] Inland Waterway Users Board, "The Second Annual Report to the Secretary of the Army and the United States Congress," unpublished report, December 1988.

[82] L. George Antle, Institute for Water Resources, U.S. Army Corps of Engineers, remarks at "Managing the Investment Process fOr Deep Draft Channels and Inland Waterways,' the 1990 Transportation Research Board Annual Meeting, Washington DC, Jan. 9, 1990.

[83] Congressional Budget Office, op. cit., footnote 38, p. *3.

Table 3-6-Traffic and Operations and Maintenance (O&M) Costs on Inland Waterways, 1986

Waterways	Ton-miles (millions)	O&M costs (millions of dollars)	O&M costs per ton-mile (dollars)
1 Upper Mississippi	12,871.9	53.5	0.0042
2 Middle Mississippi	17,504.7	16.9	0,0010
3 Lower Mississippi	100,058.3	84.2	0.0008
4 Illinois	8,505.9	12.6	0.0015
5 Ohio	61,603.6	87.2	0.0014
6 Gulf Intracoastal Waterway	19,119.6	37.8	0.0020
7 Mobile	5,746.2	23.3	0.0041
8 Atlantic Intracoastal Waterway	367.1	15.8	0.0430
9 Columbia-Snake-Willamette	1,228.2	9.0	0.0073
Total	227,005.6	340.2	0.0015

NOTE: Segments of each waterway have a wider range of operations and maintenance costs per ton-mile.

SOURCE: U.S. Army Corps of Engineers, institute for Water Resources, The 1988 */n/and* Waterway Rewiew, iWR Report 88-R-7 (Ft. Beivoir, VA: November 1988).

tions used to justify its construction.[84] These discrepancies raise a number of difficult equity and access issues.

Despite the importance of ports to local economic development, few cities have integrated transportation systems that link ports to pipeline, rail, and truck services. Paradoxically, a port's success and its contribution to the local economy increasingly depend on its intermodal transfer capabilities rather than solely on the local demand for its waterside services.[85]

Environmental Concerns-Few U.S. channels and harbors have natural depths greater than 20 feet, and ship dimensions set the demand for waterway depth. Bulk carriers and tankers often load to depths of 50 feet, while freighters, including modern containerships, can normally use 40-foot deep channels. However, no minimum standards have been established for ship maneuverability to guide those who must decide how to modify channels. The creation of navigation channels and structures, such as breakwaters and jetties, changes preexisting

Table 3-7-Federal Port Operations and Maintenance Outlays per Ton of Cargo, 1974-84 (In 1985 dollars)

Ports	Average	Minimum	Maximum
All ports	0.22	0.001	270.25”
Large ports (more than 10 million tons per year)	0.17	0.001	0.99
Medium ports (100,000 to 10 million tons per year)	0.50	0.001	23.30
Small ports (less than 100,000 tons per year	11.68	0.050	270.25

[a] High operations and maintenance (O&M) costs usually apply to federally maintained harbors with little commercial service. The beneficiaries are often fishing vessels and recreational users, neither of whom pay fees for O&M.

SOURCE: Congressional Budget Office calculations using data from U.S. Army Corps of Engineers.

currents and sedimentation. The design and siting of channels and their protective works are thus crucial factors that determine dredging and maintenance requirements and environmental effects.

In the past, dredged material was often placed within a mile of the dredging site, since transportation to upland or ocean disposal sites added substantially to total costs. However, population growth in coastal areas and wetlands protection requirements now limit land disposal possibilities, and about one-third of dredged material is disposed of in the open ocean.[86] ‘‘The most prevalent single environmental issue facing ports in the U.S. is the proper disposal of dredged material, without which channel improvements would simply come to a halt. ”[87] Although only a fraction of harbor bottom sediments meet the contamination criteria under which disposal in costly containment areas is required,[88] gaining approval for dredging projects from a long list of government and environmental groups can take years. In some cases (Gary, Indiana, harbor, for example), maintenance restrictions have caused waterways to become shallower and narrower, severely limiting the types of vessels they can accommodate.

‘Ibid., p. 87.

[85] U.S. Army Corps of Engineers, op. cit., footnote 68, p. 16.

[86] U.S. Congress, Office of Technology Assessment, *Wastes in Marine Environments, OTA-O-334 (’Washington DC:* U.S. Government Printing office, A@ 1987), p. 237,

[87] Erik Stromberg, president, American Association of Port Authorities, quoted in John M. Pisani, *Port Development in the United States: Status, Issues and Outlook*, prepared for the Sixteenth International Association of Porta and Harbors World Ports Conference, Miami Beach, FL, Apr. 22-28, 1989 (Tokyo, Japan: The Iaph Foundation, 1989), p. 27.

[88] U.S. Army Corps of Engineers, *Op.* cit., footnote 72, p. 31.

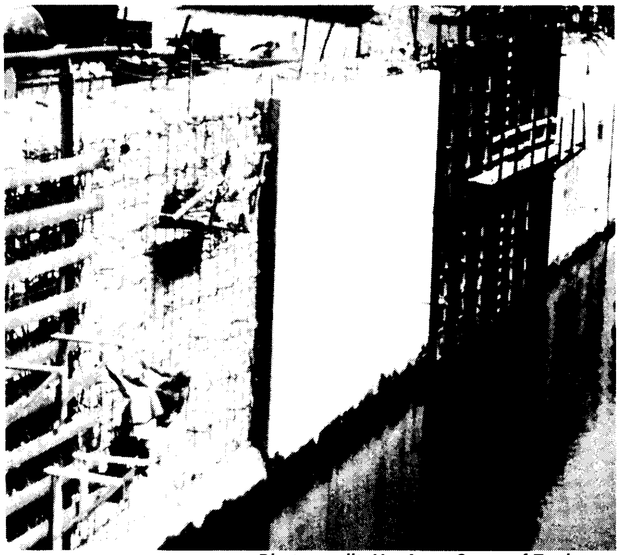

Photo credit: Us. Army Corps of Engineers

Maintenance technologies advanocs developed by the Army Corps of Engineers' laboratories have helped the Corps double the lives of many of the Nation's dams.

The lengthy process from authorization to completion for channel and harbor construction (which averages 22 years, according to the Marine Board) has weakened the effectiveness of port and waterway planning and design. In many cases, fleet demand and market economies change drastically before a channel can open for business, making the design inappropriate for current use.

Technologies

The Corps has research, development, and evaluation projects for maintenance, construction, and rehabilitation technologies and methods ongoing at each of its laboratories and has established an effective technology transfer system through its many offices. Addressing structural problems in locks, dams, jetties, and breakwaters, setting priorities among competing needs, and determining when and where modification is economically appropriate are all water system activities that can benefit from recent technology advances. Decisionmaking[90] tools can help industry and government alike to operate more efficiently.

Corps Technology ***Aids-Nondestructive evaluation*** technologies (examination methods used where visual inspection is impractical) can give managers more extensive information about structural conditions and maintenance and repair needs. Although visual inspections followed by core sampling are the most common ways for lock and dam technicians to find structural problems, visible defects are often indicative of a chronic problem that is costly to repair. Sonar is used to find defects on underwater surfaces and electromagnetic sensors and pulse/echo ultrasound devices are used to probe inside solid structures. (See chapter 5 for further details.)

Models and simulations of the physical and economic characteristics are valuable tools throughout the life cycle of a system, and can aid in planning, design, and making investment decisions for infrastructure. For example, techniques for observing and modeling local circulation and sedimentation can help design engineers locate and orient piers, wharves, and other pile-supported structures, so that a structure does not cause accelerated shoaling.[89] The Corps has good modeling capabilities at the Waterways Experimental Station. (For further details see chapter 6.)

Two Corps' programs to coordinate infrastructure-related work at the laboratories and in the private sector are the Repair, Evaluation, Maintenance, and Rehabilitation Research Program and the Construction Productivity Advancement Research Program (see chapter 6). Field-tested projects include *in situ* repair of deteriorated concrete, precast concrete for lock wall rehabilitation, and roller-compacted concrete for dams. (See chapter 5 for details on these technologies.)

Structural **Technologies-During icy winter** conditions or prolonged drought, vessel operators must carry lighter loads, use higher power (which increases operating costs), or find an alternative route. The natural channels of most inland rivers vary with seasonal rainfalls, and controlled releases by the Corps from water reservoirs help maintain suitable river stages throughout the year. However, some dredging is necessary to clear silted and shoaling channels.

Dredging-Dredging's two major components are extracting material and disposing of it. Extract-

[89] National Research Council, *Marine Board, Dredging Coastal Ports: An Assessment of the Issues* (Washington, DC: National Academy Press, 1985), p. 103.

[90] Ibid., p. 101.

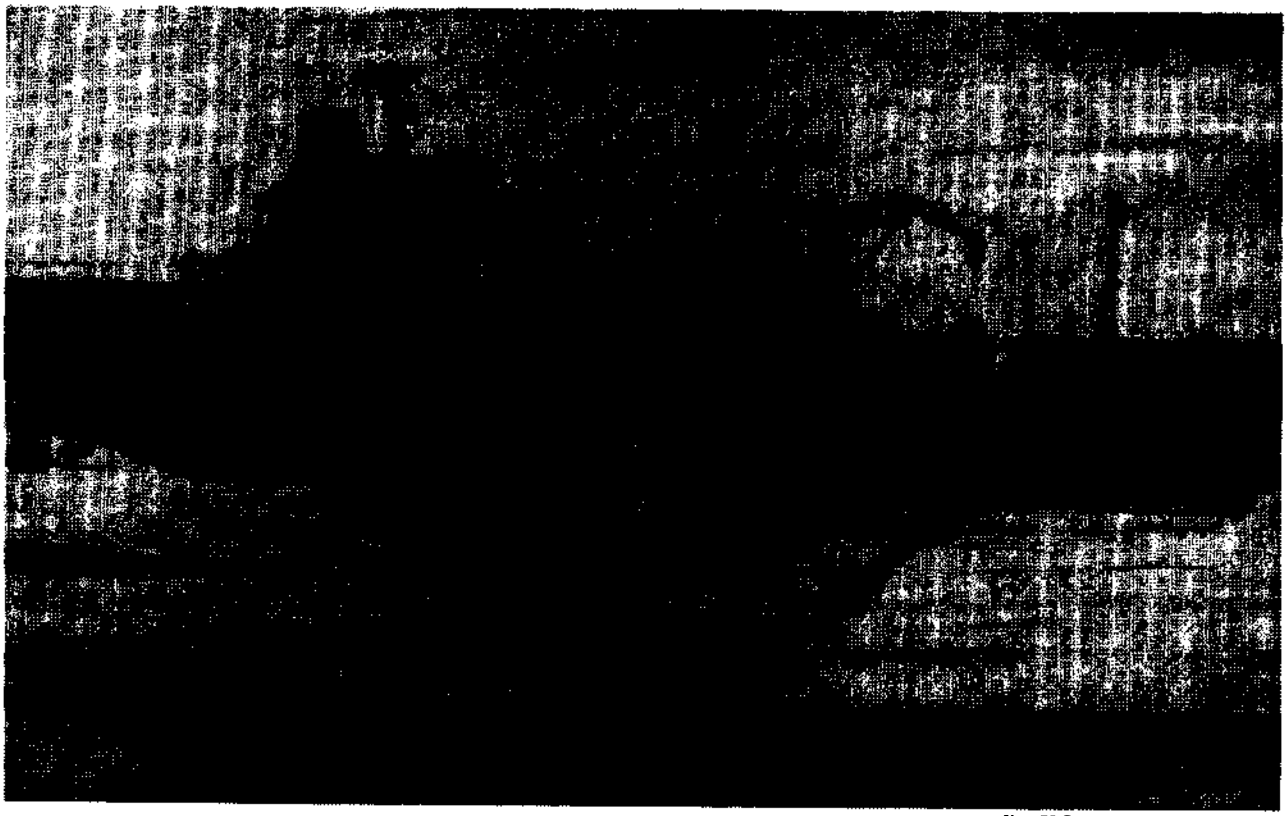

Photo credit: U.S. Army Corps of Engineers

Although dredges are now more efficient, environmental concerns about the proper disposal of dredged material have slowed channel dredging projects

ing techniques and technologies have benefited from automation, sensing, and positioning advances (see chapter 5). The same dredging equipment is employed generally for both maintenance and construction.[91]

Bank Protection--Articulated concrete slabs and gravel prevent channel migration and permit self dredging channel designs. Dikes and other structures deflect or stabilize currents within a channel.[92]

Lock and Dam-Slackwater systems are used where dredging, river embankments, and flow regulation are insufficient for commercial navigation.[93] Several dams are usually required to make a long waterway navigable. The higher that dams are built, the fewer are necessary, but a dam's cost increases exponentially with height.[94] The number and size of lock chambers, fock filling and emptying rates, and the ***types*** of tows and other vessels determine the traffic flow through a waterway. A typical lock can transfer vessels between pools in a 20- to 30-minute operation. Tows too large for a lock chamber must be split and the two groups of barges passed through separately and then reassembled. Such double lockages take about 11/2 hours.[95]

The capacity of the lock system can be increased by adding locks, rehabilitating structures, or replacing existing locks with larger ones. Since funds for new construction are very limited, smaller, affordable projects with immediate benefits must be considered. Alternative, lower cost, vessel lift technologies

[91]The specific type of dredging equipment used depends on geologic and environmental conditions.

[92]U.S. Army Corps of Engineers, Institute for Water Resources, *National Waterways Study—A Framework for Decision Making: Final Report*, NWS-83-1 (Ft. Belvoir, VA: January 1983), p. B-152.

[93]Open channels are generally less costly to construct and operate and support much greater traffic levels than lock and dam system

[94]U.S. Army Corps of Engineers, op. cit., footnote 92, p. B-153.

[95]Ibid,

and methods have been developed, but are not economically feasible for the locations analyzed by the Corps.[96] Lock-based tow haulage equipment could increase the capacity of some locks by 30 percent by pulling unpowered barge cuts (from double lockages) through the chamber.[97]

Other relatively minor structural improvements include extended guidewalls to permit recombining double lockage tows outside the chamber.[98] New coupling equipment (fixed rigging and permanent winches for tows and barges) to permit faster double lockages and tow work is a cost-effective option for smaller navigation locks.[99] Structural changes that modify river currents, as well as protect locks from tow collision damage, can improve lock approaches and allow tows to position more quickly and safely for lockages.

Traffic Management Options—Although no safety reasons require Federal control of waterway traffic, the low cost and wide availability of communications and surveillance technologies make systemwide traffic management a technical option. Scheduling access to congested facilities would allow better planning by industry and could reduce operating costs, since vessels often operate at inefficient fuel consumption speeds (too fast) given that delay at the next lock is likely. Tow breakage delays could be reduced by a "ready-to-serve" policy; vessel operators would need an extra towboat in each tow, or they could combine resources and station helper boats near each lock. Another traffic management option at locations with single locks is to give commercial traffic priority when traffic is heavy. Recreational vessels could be allowed transit only at scheduled times or on a space-available basis. Safety precautions prohibit mixed lockages of tows and recreational craft.

Locks operate more efficiently when traffic moves in a single direction, because the next tow can be positioned while the lock is cycled. For two-way traffic, the next tow must remain a safe distance away and wait for the departing tow to clear the chamber and approach area. Orderly one-way operation alternates a fixed number of lock cycles (commonly three to five) in each direction, increasing lock flow through by up to 15 percent over a random first come-first served policy[100] and reducing average delays. This method is similar to traffic management on one-lane bridges or during road construction.

While total system capacity will not change with better traffic management and scheduling, industry operating costs will be lower. Industry initiatives, such as new coupling equipment, system scheduling, and better fuel monitoring equipment,[101] can achieve substantial economic benefits.

Technologies for Industry Efficiency-System monitoring and performance data, such as traffic measurement, are essential for decision analysis, leading a number of ports to setup electronic service centers. Shipping documents transmitted by computers route and track cargo, and release import freight. The United Nations has developed EDIFACT (Electronic Data Interchange for Administration, Commerce and Transport) as a standard for the current disparate computer/data management systems.

Other alternatives for economic marine transportation are vessel operating changes, new forms and locations for ports, and vessel design modifications. Short-term alternatives include some of the operating practices already in use today-calling at shallow ports with less than a maximum load, timing movements with tides (or other conditions), and midstream cargo/fuel transfers. These measures are more expensive for carriers than larger vessels operating fully loaded without delays for the tide or lightering.[102]

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[96] Noel Bilbrough, U.S. Army Corps of Engineers, "Middle Columbia River Study: Ship Lift Alternatives," *Transportation Research Circular Number 350: Ports, Waterways, Intermodal Terminals, and International Trade Transportation Issues* (Washington, DC: Transportation Research Board, May 1989), pp. 66-72.

[97] U.S. Army Corps of Engineers, op. cit., footnote 68, p, 26.

[98] Leeper, Cambridge & Campbell, "Upper Mississippi River Transportation Economics Study: FinaReport," study sponsored by the U.S. Department of Agriculture et al., April 1989, p. 25.

[99] Ibid., p. 3.

[100] U.S. Army Corps of Engineers, op. cit., footnote 68, p. 26.

[101] Leeper, Cambridge & Campbell, op. cit., footnote 98.

[102] L. George Antle, chief, Navigation Division, Institute for Water Resources, U.S. Army Corps of Engineers, personal communication, July 10,1990.

Loading additional cargo or fuel after the vessel passes restrictive channels is considered the most cost-effective option,[103] and at present coal colliers can load in midchannel below New Orleans, while tankers can load and unload in the Gulf offshore from Louisiana.[104] Alternative vessel designs include a proposed jumbo barge carrier three times the size of the largest ship today. Cargo from the main carrier would be offloaded to barges, which could serve ports that would not need deep-draft channels or large load center facilities.[105]

Building a large "island" offshore in 80 feet of water in the Delaware Bay has been proposed. However, the operational feasibility of such a major offshore terminal would depend on multi-State agreements and substantial new investment in landside infrastructure, and its economic success would depend on diverting much of the traffic from other ports. The potential environmental impacts of construction and operation have already led to strong opposition.[106]

Intermodal Advances—The major recent changes in maritime-related, intermodal operations have occurred in the private sector—in containers and technologies that support fast vessel turnaround, including ship design, cranes, truck chassis, double stack railcars, and electronic information management. The Shipping Act of 1984, which permitted single bills of lading for intermodal cargoes, spurred demand for these technologies. Containers eliminate the handling of individual cargo, improving loading and unloading efficiency and transfer to railcars or truck chassis. New container vessels called "post panamax" ships, because they are too large to pass through the Panama Canal, carry up to one-third more containers than the previous generation. Since these huge vessels have high operating expenses and are designed for transferring cargo efficiently, they must use ports that can provide fast turnarounds if they are to operate economically.

Federal Infrastructure: Aviation

Air transportation is truly a national system in the United States; the effects of a thunderstorm in an air traffic control (ATC) sector near Chicago or a closed runway in Denver ripple across the country in delays, missed connections, and rerouted aircraft. Airlines and the military operate under a uniform set of Federal regulations and fly in a relatively centralized public airspace and ATC system.[107] Each element of the system—pilots, controllers, and other aviation personnel, aircraft, and airports-must meet Federal safety standards and be certified by the Federal Aviation Administration (FAA). Airports and airways are the public works portions of the system.

Management and Financing

Although the routes and airspace or airways linking airports are defined electronically and procedurally, they are nonetheless public works. The federally operated ATC system, established principally for flight safety, coordinates and directs all flights to and from U.S. airports, and comprises one of the most complex transportation operations in the world.

For ATC purposes, the airspace above the United States is partitioned according to airport locations and the amount of traffic into three broad categories: terminal, en route, and oceanic airspace. Terminal airspace surrounds airports, and is characterized by aircraft changing speed, direction, and altitude, as they maneuver after taking off or prior to landing. The airways connecting airports make up the en route airspace, while oceanic airspace begins over international waters, with much of it lying beyond sight of land. Costs for the system, managed and operated by FAA, are paid out of the Federal Airport and Airways Trust Fund and the General Fund.

The National Airspace System (NAS) P!an— First published in 1981, the NAS Plan is FAA's comprehensive program for modernizing air traffic facilities and equipment, and consists of more than 90 separate projects. Relying on advances in automation that are part of the NAS Plan, FAA expects

[103] National Research Council, op. cit., footnote 89, p. 5.

[104] Antle, op. cit., footnote 102.

[105] Lester A. Heel, "Marine and Intermodal Transportation: Issues and Challenges," *TR News, No.* 144, September-October 1989, pp. 15-19.

[106] Antle, op. cit., footnote 102.

[107] There are large sectors of uncontrolled airspace across the United States, generally below 12,000 feet, often used by general aviation.

Table 3-8-Passenger Enplanements at 25 U.S. Airports, 1988

Airport	Rank	Total enplanements[a] (in thousands)	Percentage[b]	Cumulative percentage
Chicago O'Hare	1	28,850	5.8	5.8
Atlanta Hartsfield	2	23,573	4.8	10.6
Dallas-Fort Worth	3	23,029	4.7	15.3
Los Angeles International	4	22,179	4.5	19.8
New York JFK	5	19,415	3.9	23.7
Denver Stapleton	6	15,015	3.0	26.7
San Francisco International	7	14,683	3.0	29.7
Miami	8	14,316	2.9	32.6
Boston Logan	9	11,802	2.4	35.0
New York LaGuardia	10	11,790	2.4	37.4
Newark International	11	11,580	2.3	39.7
Honolulu International	12	11,081	2.2	41.9
St. Louis International	13	10,139	2.1	44.0
Detroit Metro	14	10,044	2.0	46.0
Phoenix Sky Harbor	15	9,559	1.9	47.9
Pittsburgh International	16	8,971	1.8	49.7
Minneapolis-St. Paul	17	8,939	1.8	51.5
Houston Intercontinental	18	8,142	1.7	53.2
Orlando	19	8,122	1.6	54.8
Washington National	20	7,888	1.6	56.4
Philadelphia	21	7,789	1.6	58.0
Seattle-Tacoma	22	7,659	1.6	59.6
Las Vegas	23	7,658	1.6	61.2
Charlotte	24	7,613	1.5	62.7
Baltimore	25	5,363	1.1	63.8

[a]Includes us. certificated route air carriers, foreign flag carriers, supplemental, air commuter, and air taxis.
[b]Based on 493.8 million passenger enplanements.
[c]Cumulative percentage is a running sum: e.g., the top five airports have 23.7 percent of total U.S. enplanements.
SOURCE: U.S. Department of Transportation, Federal Aviation Administration, *FAA Aviation Forecasts: Fiscal Years 1990-2001*, FAA-AP090-1 (Washington, DC: March 1990).

to address current constraints due to controller workload, computer processing capacity, hazardous weather detection, and communications.

When it was first presented to Congress, costs for the NAS Plan were projected to be $9 billion over 8 years, but adding new projects and changing existing ones may raise total costs to $25 billion by the year 2000.[108] Complexities of implementing technology changes in a large operating system have caused the major projects within the NAS Plan to fall behind their original schedules by 1 to 5 years.[109] FAA also maintains a plan for research, development, and engineering to examine technologies outside the NAS Plan.[110]

Airports—Airports, most of which are not federally owned, provide landing and takeoff areas for aircraft and facilities for transferring passengers and cargo to other transportation modes. The large and small *commercial airports,* which offer cargo and passenger airline service, are owned primarily by municipalities or special authorities and by 13 States. A relative handful of these facilities handle most commercial airline passengers—almost one-quarter of total passengers board flights at just five airports (see table 3-8). Of the over 17,000 airports[111] in the United States, most are public-use *general aviation (GA) airports* owned by municipalities, counties, or private groups and used primarily by personal and business aircraft.

[108]U.S. General Accounting Office, *Continued Improvements Needed in FAA's Management of the NAS Plan,* GAO/RCED-89-7 (Washington, DC: November 1988), p. 3.

[109]Ibid., p. 3.

[110]U.S. Department of Transportation, Federal Aviation Administration, "Federal Aviation Administration Plan for Research, Engineering, and Development,'' vol. I, draft manuscript, September 1989.

[111]U.S. Department of Transportation Federal Aviation Administration, *FAA Statistical Handbook of Aviation for Calendar Year 1987* (Springfield, VA: National Technical Information Service, 1987); included in the "airport" count are heliports and seaplane bases.

The concentration of commercial passengers at major airports permits them to be largely self-supporting from landing fees, airline rents, and revenues from parking and concessions. Management and oversight of groundside facilities differs drastically from airport to airport. Airlines typically lease terminals and gates[112] from the airport operator, obtaining exclusive-use rights, and the major lessors often gain a strong voice in decisions on whether and how to expand ground facilities. Under the 1990 budget agreement, airports are permitted to levy up to $3 per passenger charge, providing anew source of revenue, for use solely on airport improvements.

Medium and small airports rely on Federal or State help in meeting their funding needs. Almost all States have airport aid programs, usually targeted to smaller, nonmetropolitan airports, and most maintain statewide airport development plans. Funds come from State aviation fuel taxes and general appropriations.

Issues

Land-use, financial, and environmental concerns frame many governmental decisions about aviation. System capacity has become a major issue. Because technological advances allow capacity increases without a decline in safety, airspace capacity is limited by Federal investment decisions and technology.[113]

Environmental Concerns—Aircraft noise is a serious problem for airport operators and airlines, leading to measures that permit Federal funds to be used to soundproof homes and schools, and in some cases, purchase real estate in high noise areas. Community groups fighting to restrict airport operations because of noise concerns have limited airport development across the country.

While the intensity of sounds can be measured precisely, determiningg what constitutes objectionable noise is more subjective. Currently, individual aircraft must meet FAA noise standards, based on a 24-hour average of noise energy,[114] commonly referred to as Stage 1, 2, and 3 rules.[115] While differences in local conditions and jurisdictional factors have made establishing a more definitive Federal standard for airport noise difficult, Stage 1 aircraft are already banned, and all Stage 2 aircraft are prohibited after December 31, 2000.[116] Newer aircraft must meet Stage 3 requirements, the strictest ones.

In each successive jetliner generation, new technology has lowered noise levels, but additional reduction through technology may be limited, posing contentious issues. For example, 50 percent of the noise from a Boeing 757 on landing approach is aerodynamically produced, a type of noise that experts believe cannot be reduced much more. Nonetheless, a working group of the International Civil Aviation Organization (ICAO) is studying the feasibility of Stage 4 noise limits.[117]

The 1990 deficit reduction agreement requires that the Secretary of Transportation establish, by July 1, 1991, a national noise policy that considers the economic impact on air carriers and makes recommendations related to aircraft noise to Congress for changes in State and local government authority and other standards, procedures, and programs. No airport will be allowed to restrict Stage 3 aircraft operations without forfeiting all Federal aviation grants or the right to impose passenger facility charges, unless the program was in place before October 1,1990, or the Secretary of Transportation approves the restrictions.

The current level of aviation operations has a small, but significant effect on air quality. In the Los Angeles basin, aircraft exhaust and fueling emissions contribute about 1 percent of the total volatile organic compounds. FAA and EPA are addressing these air quality issues by requiring that new jet engines reduce organic compounds emissions by 60 to 90 percent. EPA is considering regulations

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112 Airlines sometimes lease ground space and build their own facilities.

113 Based on current air traffic control separation standards, the usable airspace above the continental United States could accommodate, theoretically, well over 1 million aircraft at once.

114 14 CFR 150, app. A.

115 14 CFR 36.

116 *Congressional* Record, Oct. 16, 1990, P. 12535.

117 Michael Zywokarte, project manager, Engineering, Federal Aviation Administration, personal communication, July 1989.

118 Nicholas P. Krull, Office of Environment and Energy, Federal Aviation Administration, personal communication, July 31, 1990.

Table 3-9-Congested Airport Rankings and Expansion Plans

Airport (1987 rank)	Airport rank by total hours of air carrier delay in 1987	Ranked by total air carrier operations in 1987	Planned construction that will increase IFR capacity
Chicago O'Hare	I[a]	2	
Atlanta Hartsfield	S[b]	1	X
Dallas-Fort Worth	3[b]	4	X
Los Angeles International	4[c]	3	
Denver Stapleton		5	x
Newark International		19	
San Francisco International	7[d]	6	
New York LaGuardia	8[d]	21	
New York JFK	9[d]	26	
Boston Logan	10[d]	10	
St. Louis Lambert	11[d]	11	
Miami International	12[d]	22	
Phoenix Sky Harbor	13[d]	9	
Washington Dunes	14[d]	28	X
Detroit Metro	15[d]	12	X
Philadelphia	16[d]	13	
Washington National	17[d]	25	
Minneapolis-St. Paul	18[d]	18	
Honolulu International	19[d]	16	
Pittsburgh International	2o[d]	20	
Houston International	2 1[d]	27	X

KEY: IFR = instrument flight rules.

a Total air carrier delay exceeds 100,000 hours.

b Total air carrier delay is between 75,000 and 100,000 hours.

c Total air earner delay is between 50,000 and 75,000 hours.

d Total air carrier delay is between 20,000 and 50,000 hours.

SOURCE: U.S. Department of Transportation, Federal Aviation Administration, Airport *Capacity* Enhancement *Plan*, DOT/FAA/CP189-4 (Washington, DC: May 1989).

requiring vapor recovery systems for aircraft fueling.[118]

Capacity—According to recent estimates, delays cost scheduled air carriers almost $2 billion in extra operating expenses and passengers $3 billion in lost time, excluding commuter and general aviation data, which are not available.[119] About two-thirds of all delays are caused by bad weather-restricted visibility, thunderstorms, or snow or ice on runways—which affects airports less than 10 percent of the time on average. Too much traffic for airports and ATC to handle during normal conditions accounts for roughly 25 percent of delays, while pavement construction and ATC equipment problems each account for less than 5 percent.[120]

Annual airline travel demand depends on the strength of the economy and generally follows trends in the GNP. Current forecasts indicate that increasing numbers of U.S. and foreign airports will have traffic demand exceeding their capacity for longer periods of time each day. Average annual growth of 4.2 percent in passengers enplaned on U.S. airlines and 2.1 percent in total aircraft operations is projected.[121] The annual delay problems that plague 25 commercial airports are shown in table 3-9. If no capacity improvements are made, estimates are that by 1997,[122] 17 airports will be in the same delay category as Chicago O'Hare, Atlanta Hartsfield, and Los Angeles International are today.[123]

[119] U.S. Department of Transportation, Federal Aviation Administration, *Airport Capacity Enhancement Plan*, DOT/FAA/CP/88-4 (Washington, DC: April *1988), p.* 1-11.

[120] U.S. Department of Transportation, Federal Aviation Administration, *Airport Capacity Enhancement Plan*, DOT/FAA/CP/89-4 (Washington, DC: May *1989), p.* 1-10.

[121] U.S. Department of Transportation, Federal Aviation Administration, *FM Aviation Forecasts, Fiscal Years 1990-2001*, FM-APO 90-1 (Washington, DC: March 1990), pp. 5,7.

[122] Federal Aviation Administration op. cit., footnote 120, p. 2-1.

[123] Ibid., table 2-2, p. 2-4.

Airline hub-and-spoke operations can place as severe a burden on ground capabilities as on the airside, and ground access to and from airports depends entirely on local planning and transportation management. Moreover, no single agency or organization is responsible for research or planning for enhancing the capacity of ground facilities; FAA's authority over landside development and management is limited.[124]

Building more runways and airports, which would provide the greatest increase in aviation system capacity, requires high capital investment, and more important, overcoming community opposition based on land use and noise and air pollution concerns. These are such difficult obstacles that just six of the most congested airports are planning new runways (see table 3-9 again).

Access and Equity Concerns—When traffic demand exceeds runway capacity, as happens regularly during peak periods at busy airports, each single occupant aircraft imposes roughly the same amount of system delay as an airliner with 300 passengers. However, smaller aircraft almost always pay much less in landing fees and Federal taxes for using the system, a policy that embodies difficult and contentious equity and access issues. Major airlines have altered schedules and purchased larger aircraft, so they can carry more passengers and cargo under these circumstances.[125]

Underutilized Airports-Modifying lightly used airports close to busy facilities to make them more attractive to commercial or GA users is generally more feasible than new construction. FAA has sponsored reliever or satellite airport development for GA traffic by earmarking funds especially for developing and upgrading these airports,[126] to reduce delays at nearby, busy, commercial airports by removing the small, slow GA aircraft. However, reliever and other GA airports face some of the same noise and competing land-use problems as commercial airports. Furthermore, any policy to divert traffic also diverts revenue from the major airport.

Restricting Airport Access-Restricting access, at least to certain runways, for small, low-performance aircraft is one way to increase runway availability for large jets. However, unless suitable alternative facilities, such as reliever airports, are found for excluded aircraft, such a policy could be considered discriminatory and a restriction of interstate commerce.[127] Moreover, while quotas and restrictions may be acceptable temporary measures, actions to change basic underlying demand will also be necessary if capacity cannot be increased.

Quota systems for all aircraft are used at several airports where demand exceeds physical or noise-related capacity regularly for much of the day. Four major airports-Chicago O'Hare, La Guardia and JFK in New York, and Washington National-are covered by FAA's high-density rule, established in 1973, which legally caps the number of flights that can be scheduled for these airports. Landing and takeoff slot quotas are established for three user classes: air carriers, commuters, and GA. While GA slots are distributed by call-in reservations, air carrier and commuter slots are allocated by airline scheduling committees, which are granted antitrust immunity to negotiate the assignments. FAA reserves the right to distribute the slots if negotiators fail to reach agreement.[128] During good weather, high-density airports can usually handle aircraft without assigned slots.

Current quota systems favor incumbent airlines, since slots are granted based on prior use, a complaint raised frequently by airlines formed after deregulation and currently by airlines wishing to establish a market at the four airports. Established carriers counter that since they invested in the airport and its market over many years, they should be able to keep their slots, now worth millions of dollars apiece to the holders at several airports.

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[124] Transportation Research Board, *Measuring Airport Landside Capacity*, Special Report 215 (Washington, DC: National Research Council, 1987), p. 57.

[125] After virtually no change since 1983, commercial aircraft seating capacity is projected to grow by three seats per aircraft, on average, in each of the next 12 years. From U.S. Department of Transportation, Federal Aviation Administration, *FAA Aviation Forecasts, Fiscal Years 1990-2001*, FAA-APO 90-1 (Washington, DC: March 1990), p. 53.

[126] U.S. Congress, Office of Technology Assessment, *Airport System Development*, OTA-STI-231 (Washington, DC: U.S. Government Printing Office, August 1984), p. 110.

[127] Ibid., p. 114.

[128] Ibid., p. 114.

Market Concerns-Market pricing of positions at congested airports raises other access and equity issues. Selling (or leasing) airport landing slots through the open market is viewed by many economists as the most effective way to determine the value of airport access and allocate these scarce resources.[129] However, competition among airlines could potentially be limited if slots are hoarded, and small aircraft could be effectively excluded from the airport.

The appropriate use of the proceeds from slot transactions is a contentious issue. Although airlines have been allowed to treat slots as private goods, the slots are created and provided by public agencies, the airport proprietor, and FAA. A strong case can be made that slot payments belong to the agencies providing the services and should be used for public purposes.

Differential/ Pricing-At present, ATC services and public airspace are available at no charge to all properly equipped and operated aircraft. Access to public airports, except where quotas are in effect, is generally open to anyone willing to pay the landing fee, usually less than 2 or 3 percent of the aircraft's operating costs.[130] Landing fees offset the capital, maintenance, and operating costs for runways and other airport facilities. Fees do not generally vary by time of day and are typically based on aircraft weight, which is roughly related to required size of facilities and the amount of wear caused by the aircraft. However, most fees fail to reflect the costs to other users of delay and congestion, and provide no incentive to shift demand to nonpeak periods.

A few airport operators have tried to manage demand by raising landing fees, but small aircraft operators and airlines alike have successfully challenged landing fees in court as unreasonable and discriminatory. In 1986, the Port Authority of New York and New Jersey successfully instituted a surcharge of $100 for GA aircraft landing at its three major airports from 8:00 a.m. to 9:00 p.m., reducing traffic by 30 percent for those times.[131] The Massachusetts Port Authority, reallocated airport costs among all users, charging higher landing fees for GA

Photo credit: Office of ***Technology Assessment***

Taxis and private automobiles carry the vast majority of passengers to and from airports.

and lower ones for airlines. However, the fee structure was challenged as discriminatory, and was overturned by DOT (see box 3-I).

Passenger Surcharges-Direct passenger surcharges for flights during peak periods will probably not be passed on to the passengers affected unless fares are regulated in some form, not a likely prospect. Finally, passenger charges alone do little to divert small aircraft or encourage large aircraft use.

Transportation **to Airports-Getting to and** from the airport, which can represent a sizable portion of total trip time, depends on the capabilities of the regional transportation system surrounding the airport and on the convenience of road circulation, the availability of parking, and mass transit access at the busiest airports. Because origins and destinations are so scattered throughout urban areas, road vehicles, especially private automobiles and taxis, carry over 90 percent of the passengers to and from most airports. Airport employees, who account for about one-third of all access trips, usually must also rely on automobiles. Many major airports have significant air pollution problems stemming primarily from automobiles and surface traffic congestion, although aircraft contribute as well.[132] The growth of

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[129] U.S. Congress, Office of Technology Assessment, *Safe Skies for Tomorrow: Aviation Safety in a Competitive Environment*, OTA-SET-381 (Washington, DC: U.S. Government Printing Office, July 1988), p. 38.

[130] Office of Technology Assessment, op. cit., footnote 126, p. 116.

[131] Jan E. Monroe, "Practical Methods for Shifting General Aviation Traffic From Commerce Service Airports to Reliever Airports," *Transportation Research Record 1218* (Washington, DC: Transportation Research Board, 1989), p. 13.

[132] David W. Davis, executive director, Massport, personal communication, May 2, 1990.

Box 3-I—The Massachusetts Port Authority

On July 1, 1988, the Massachusetts Port Authority (Massport) implemented the first phase of its Program for Airport Capacity Efficiency (PACE), a plan to reduce delays at Logan International Airport by basing landing fees more closely on the actual airport costs for accomrnodat.ing each aircraft. Fees rose for small aircraft (the previous minimum of $25 was increased to $91) and fell for the largest airliners. The fee changes caused general aviation flights to drop by one-third and improved Logan's on-time performance ranking, established by the U.S. Department of Transportation (DOT) for the 30 busiest commercial airports, from roughly 21st to 2nd during the last month of the PACE program.[1] However, small aircraft owners[2] filed complaints with the Federal Aviation Administration soon after the PACE plan was announced and on December 22, 1988, DOT ruled that the new fee structure was ". . . unreasonable and contrary to Federal statute. Faced with the loss of millions of dollars in Federal funds for airport improvements, Massport's Board voted to return temporarily to the previous fee schedule and to develop another, more acceptable, pricing method. Logan's on-time performance ranking plummeted to 29th by April 1990.[4]

PACE landing fees had two components: a weight-based portion to cover runway construction, maintenance, and other costs that vary with aircraft size; and a charge to recover costs linked to each flight (such as lighting, emergency services, and snow plowing), which according to Massport, had been previously subsidized by commercial airline passengers. A second phase of PACE, never implemented, proposed peak-hour pricing and slot sales to shift traffic away from high demand periods. DOT accepted the dual-omponent landing fee concept but disagreed with some of the ways Massport divided the costs between the two components of the fee. For example, Massport divided the costs for maintaining crash, fire, and rescue (CFR) services among all landings regardless of aircraft size, since all flights benefit. However, since the requirements for CFR capabilities are based on the size of the aircraft using an airport, DOT ruled that CFR costs should be assigned on a weight-based scale. Moreover, DOT endorsed peak-hour surcharges as an acceptable pricing option for landing fees,[5] Massport remains committed to winning DOT approval of a landing fee schedule that uses peak-hour pricing to improve airport capacity and is developing alternatives.[6]

[1] David W. Davis, executive director, Massport, personnel communication, May 2, 1990.

[2] National Business Aircraft Association, Regional Airline Association, and Aircraft Owners and Pilots Association.

[3] U.S. Department of Tranaportation, Office of the Secrctary, "Investigation Into Massport's Landing Fees,' ' FAA Docket 13-88-2, Dec. 22, 1988.

[4] Davis, op. cit., footnote 1.

[5] U.S. Court of Appeals for the First Circuit, Massachusetts Port Authority v. U.S. Department of Transportation, "Brief of Petitioner-Appellant, Massachusetts Port Authority," No. 88-2227, Dec. 22, 1988.

[6] Tom Champion, special assistant to the administrator, Massport, personal communication, Nov. 8, 1990.

the rental car industry reflects the lack of suitable alternate forms of transportation from many airports. Procedural and management changes, such as parking restrictions combined with strict enforcement and segregating private autos, taxis, limousines, and buses, are inexpensive and effective options.

About 25 percent of airport trips are to or from the city center,[133] so dedicated surface systems such as rail transit and remote terminals are essential to ground access in major metropolitan areas. Water ferries and helicopters, available for a few large, urban airports, transport relatively few passengers, but are an important alternative in cities like New York and Boston, where surface arteries are very congested.

Funding landside investments involves complex, multijurisdictiona1 arrangements that vary widely from airport to airport. The capital improvements sponsored by FAA are limited to on-airport roadways, guideways, and walkways, including bypass lanes, multiple termina1 entry and exit points, curb frontage, remote park and ride facilities, and pedestrian overpasses or underpasses. For projects to improve ground access off the airport property, jurisdictions must seek FHWA and Urban Mass Transportation Administration grants or find State and local funds.

[133] Office of Technology Assessment, op. cit., footnote 126, p. %.

Technologies for Enhancing System Capacity and Performance

Airports can operate close to peak capacity most of the time. Because airport physical expansion possibilities are constrained and runways already operate close to technologically peak efficiency, the critical long-term limit for air travel is likely to be *runway capacity. Gains in* runway performance will require systemwide air traffic management, such as more efficient aircraft routing, spacing, and sequencing within queues. Technology can contribute by reducing distances necessary for safe separation between aircraft, increasing controller productivity, and enabling flights to continue at the maximum rate in all but the most severe weather conditions.

Analytic tools can help air traffic decisionmakers make rational system choices under such circumstances. FAA already has some computer-based models for quantifying the effects of changes in equipment, procedures, airspace configurations, and user demand on system performance. For example, using its NASPAC simulation model, FAA found that the new airport now under construction in Denver should reduce airline delays nationwide by 4 percent on a moderate winter day and 18 percent on a more snowy day.[134] Plans are under way for a dynamic simulation laboratory to further FAA's system analysis capability, and modeling and simulation technologies are being incorporated into the agency's traffic management facilities.

Some of the options for increasing the capacity of existing airports and runways, their current limitations, and the role of technology are listed in table 3-10. While capacity gains from any option can be quantified, they depend on too wide a range of parameters and conditions[135] to detail in this report.[136] Making runway performance under instrument flight rules (IFR) closer to visual flight rules (VFR) capabilities will have the greatest effect on current delays, and requires technology to reduce the safe spacing between aircraft. Increasing VFR capacity requires reducing the time an aircraft occupies a runway, overcoming wake vortex hazards, and managing arriving traffic to eliminate gaps.

Surveillance-One of the most promising near-term technologies for improving IFR capacity at airports upgrades the secondary surveillance system to give faster radar data updates and larger and clearer controller displays.[137] These radar systems, not a part of the NAS Plan, will permit increased operations on parallel and converging runways. Different systems are currently being tested at Memphis and Raleigh-Durham airports.

Civilian surveillance radars require clear lines-of-sight to monitor traffic. Over oceans or remote areas, or at low altitudes where radar coverage is not practical, satellite technologies are available. The most promising satellite surveillance application is dependent surveillance, under which aircraft-based equipment determines position and relays information via satellite to a ground-based ATC facility. Automatic dependent surveillance (ADS) relies on new applications of established communications and navigation technologies and will likely be used first on the busiest ocean routes. Currently, controllers track oceanic flights through position reports from pilots derived from onboard navigation instruments and relayed by high frequency radio. Once established, ADS will allow closer spacing of oceanic flights, but no satellites yet operate in the aeronautical mobile band, which an operational ADS system must use. ICAO technical standards are stall in the process of being developed, and FAA has not yet established an implementation plan or policy for ADS.[138] FAA is investigating advanced satellite technologies that could have applications for ATC, but the potential reliability of ADS makes the cost-effectiveness of the more expensive independent satellite systems questionable.[139]

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[134] The Mitre *Corp.,* "Analysis of National Delays and Throughput Impacts of a New Denver Airport," unpublished document, April 1990.

[135] Airport capacity depends on how operations are split between departures andarrivalsandamong the mix of aircraft types. Furthermore, IFR capacity is critically dependent on runway configuration. For example, only one runway can be used during IFR at airports with parallel runways that are less than 2,500 feet apart.

[136] A detailed quantitative discussion of ah-field capacity gains resulting from potential operational improvements is presented in John E. Lebron, ***Estimates of Potential Increases in Airport Capacity Through ATC System Improvements in the Airport and Terminal Areas,*** FAA-DL5-87-1 (Washington, DC: U.S. Department of Transportation, Federal Aviation Administration, October 1987).

[137] Ken Byram, project manager, Parallel and Converging Runway Monitoring, Federal Aviation Administration, personnel communication, Dec. 1, 1989.

[138] Zywokarte, op. cit., footnote 117.

[139] Clyde Miller, Research and Development Service, Federal Aviation Administration, personal communication Sept. 11, 1990.

Table 3-10-Enhancing the Performance of Existing Airports and Airways

Potential enhancement	Goals	Current limitations	Potential technological options
Increase the maximum takeoff and landing rate possible for a runway.	Reduce the time an aircraft occupies a runway.	No more than one aircraft allowed on a runway at a time.	High speed exits from runways.
		Fast, moving, heavy aircraft take more time to slowdown than smaller planes.	Improve aircraft deceleration capabilities.
	Reduce wake vortex hazards, allowing closer in-trail aircraft spacing.	Vortices are intrinsically linked to aerodynamic lift and cannot be eliminated.	Make wake vortices visible to pilots; reduce the strength of the vortices.
		Vortices are usually invisible. Aircraft size difference is a large factor in vortex hazards.	
Increase the maximum takeoff and landing rate possible for airports with multiple runways.	Reduce collision avoidance and wake vortex hazards, allowing closer aircraft spacing.	Ground- and airborne-based surveillance, communication, and human reaction time are presently insufficient to safely separate aircraft at the distances necessary for some parallel runways.	Improve surveillance, guidance, communication, and automation.
Increase the average takeoff and landing rate of a runway or airport.	Reduce runway downtime.	Necessary periodic maintenance.	Longer lasting materials; analytical and management tools (e.g., nondestructive evaluation).
		Snow and ice removal.	Snow and ice sensors; selected pavement additives.
	Reduce enroute airspace-related delays.	Human capability to process and transfer information.	Automation, surveillance.
		Oceanic ATC capability far below domestic level.	Better surveillance, communications, and navigation.
	Reduce collision avoidance and wake vortex hazards, allowing closer aircraft spacing, dose the IFR/VFR capacity gap.	ATC radar and cockpit instruments are not as capable as human vision.	Surveillance, navigation, guidance.
	Reduce time-wasting gaps in arrival stream.	Difficult for controllers to position and sequence aircraft at optimal times for runway approaches, especially if traffic is mixed among aircraft with differing sizes and speeds.	Improved strategic and tactical management technologies for air traffic.
	Reduce delays due to inaccurate/Impredse weather information.	Safety margins must be kept large for dangerous thunderstorms and windshear, resulting in delays.	More accurate weather prediction and detection; better information transfer to controllers and fright crews.

KEY: ATC = air traffic control; IFR = instrument flight rules; VFR = visual flight rules.

SOURCE: Office of Technology Assessment, 1991.

Navigation and Guidance-Long-range radionavigation systems, LORAN and OMEGA (see chapter 5), permit navigation in remote locations. As part of the NAS Plan, FAA is providing funds to the Coast Guard to install four additional LORAN stations to allow complete coverage across the continental United States.[140] Combined with an ADS link, LORAN or OMEGA could permit enhanced low-altitude and remote-site traffic control.[141]

[140] U.S. Department of Transportation, Federal Aviation Administration, *National Airspace System Plan: Facilities, Equipment, Associated Development and Other Capital Needs* (Washington, DC: September 1989), p. IV-58.

[141] U.S. Department of Transportation, Federal Aviation Administration, "Federal Aviation Administration Plan for Research, Engineering, and Development" vol. II, draft manuscript, September 1989, p. 258.

Satellite-based systems offer the greatest potential for aviation navigation enhancement. INMARSAT, an international consortium that operates a global satellite system for maritime mobile communications, plans to deploy the first satellite designed to provide civilian aeronautical service. The Department of Defense (DoD) Global Positioning System, which will provide civilian aircraft with location data accurate within 500 feet, is expected to be available for worldwide navigation in late 1993. FAA studied the integration of GPS with LORAN in a single cockpit device and determined that this combination may be suitable as a sole means of navigation, and is currently evaluating avionics.[142]

The NAS Plan includes replacing current instrument landing systems (ILS), which provide course and glideslope guidance for landing aircraft, with microwave landing systems (MLS). MLS allow curved approaches, not possible with ILS, and potential capacity gains in locations where present runway approaches and departures conflict. Although the program has been besieged with controversy and is behind schedule, FAA must comply with ICAO plans to install MLS as the landing aid at international airports by 1998.

Weather Detection and Prediction-Avoiding hazardous weather-windshear,[143] severe turbulence, lightning, inflight icing, or hail-is especially important in terminal areas, where aircraft are close to the ground. Existing radars are able to identify areas of heavy precipitation, often indicative of dangerous flying conditions; however, these radars cannot see clear air turbulence or windshear. Advanced weather radar systems that can measure winds and other automated weather observing systems are being deployed as part of the NAS Plan. Next generation weather radars, funded jointly by DoD, the National Weather Service (NWS), and FAA, will replace existing NWS radars. Because there are no meteorologists at some FAA facilities, the terminal weather radar will employ expert systems to present weather information (such as automatically identifying microbursts) in a usable form directly to controllers.[144]

Communication-Federal aviation communications systems transmit ATC and weather information through voice and digital messages over one-way and two-way radio, landline wire, and fiber optic links. Two communications developments that could support increased airspace capacity are *data link* and *satellite relay* for aircraft. The NAS Plan calls for Mode S digital links to transmit many of the ATC and weather messages sent over voice channels, and to provide new functions such as real-time graphic display of weather and ATC instruction relay and conflation. Digital communications will not replace the current air-ground voice links as the primary system for real-time ATC and weather information until at least late in the decade.

Successful tests using existing satellites for communications have prompted at least five airlines to order airborne systems for their new aircraft.[145] ICAO's Future Air Navigation Systems Committee has stated that". . . satellite-based communications, navigation, and surveillance will be the key to worldwide improvements. ' '[146]

Automation and System Management— Computers are used extensively throughout the ATC system to process flight plans, correlate and display radar returns, and alert controllers to hazardous traffic situations. All traffic control decisions are now made by controllers. However, systems currently being developed will be capable of computing optimal flight paths in real time and relaying instructions directly to cockpits.

ATC Computers-Computers process primary and secondary radar returns, track targets, and provide appropriate data for each aircraft. FAA's Central Flow Control Facility (CFCF) already manages IFR traffic on a national scale. Flight plan information and live radar data from 20 en route centers are relayed to CFCF, where an aircraft situation display presents national traffic data and analyses, updated every 3 minutes, for any portion of

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142 Ibid., p. 256.

143 Windshear is a change, usually sudden, in wind velocity across anaimraft'spath. The most dangerous form owindshear is the microburst, a rapidly descending column of air that maybe impossible for some aircraft to escape from when flying close to the ground.

144 Office of Technology Assessment, op. cit., footnote 129, p. 158.

145 "Tests Demonstrate Potential Benefits of Satellites in Air-Ground Communications," *Aviation Week & Space Technology,* vol. 130, No. 2, July 10, 1989, p. 57.

146 "ICAO's Turn-of-Century Plan Completed," *Interavia*, August 1988, p. 749.

the continental United States. The system automatically alerts the traffic manager when capacity is insufficient. Under the NAS Plan and R&D programs, FAA is working toward using real-time computer analyses to manage runway and airspace configurations and to issue traffic clearances for optimal traffic flows.

The centerpiece of the NAS Plan is the Advanced Automation System (AAS), a $5 billion project to replace and consolidate computer hardware, software, and workstations at airport tower, terminal, and en route ATC facilities. FAA expects better safety, greater system capacity, and lower operational costs, due in large part to new and expanded automated functions. Among the most important of these new capabilities is automated en route air traffic control (AERA).

AERA, to be implemented in three phases, will predict and resolve traffic conflicts in four dimensions and permit more fuel-efficient and direct flight paths. FAA plans to install the first phase in 1997. The objective for AERA 3, on program completion, is automatic monitoring and control of traffic, and removal of the capacity limitations of the current systems to permit controllers to manage airspace regions much larger than present ATC sectors.[147] Many aviation safety experts view increased use of automation with ambivalence. While automated systems increase efficiency and safety in some areas, they require monitoring and accurate data entry. The role of the human in this increasingly automated environment is a critical issue that needs to be studied extensively to establish bases for setting standards.[148]

Technologies for Enhancing Groundside Capacity—An airport's groundside[149] components—aircraft parking aprons and gates, airport terminals, and surface transportation links-are important factors in total trip time for passengers and cargo. Limitations in groundside capabilities can also restrict air service growth.

The number of passengers and the amount of cargo that pass through an airport are the most common economic indicators applied to measuring airport capacity. However, airport operators also must include employees, visitors, and service and ground access vehicles in their calculations, and analytic techniques and data for measuring groundside capacity are less developed than methods for assessing airside capacity.[150]

Gates and Aprons-Airport gates and aprons are the areas where aircraft receive fuel, maintenance, and other servicing. Although fewer gates would be required if airlines shared them, most gates are controlled by individual airlines. Competition between airlines and widely spread facilities at the busiest airports limit the feasibility of jointly using gates. If airport operators had more control over gates, more efficient use would be possible,[151] allowing faster aircraft turnaround and expanding the parking spaces and terminal access available for aircraft.[152] Apron geometry and level of demand also affect aircraft access to gates, and for the next generation B-777, Boeing plans to use folding wings in the design to avoid gate restrictions.

Security Technology and Procedures—To deter aircraft hijacking and sabotage, FAA requires airlines to screen passengers, carry-on articles, and in some cases, checked baggage, and airport operators to control access to the airfield and aircraft. Technology permits much faster processing than manual searches alone would allow, and relatively few significant delays due to screening occur currently in the United States.

147Federal Aviation Administration, op. cit., footnote 140, p. III-38; and Federal Aviation Administration, op. cit., footnote 141, pp. 63-64,

148Office of Technology Assessment, op. cit., footnote 129, p. 125.

149The boundary between "airside" and "groundside" is somewhat arbitrary. The Federal Aviation Administration includes aircraft gates and parking areas in the airside category, as aircraft in these areas are still subject to air traffic control rules and regulations. In this report, however, airside infrastructure are those components whose performance affects airport and airspace capacity. Each gate and parking space is usually controlled by a single airline, and one airline's gate performance generally does not affect other users of the airport. Exceptions are when airlines share gates or gate backups restrict other taxiing aircraft.

An alternate definition of the groundside is the facilities and procedures involved in the passenger's or cargo shipment's journey from the originating point to the aircraft, aircraft-to-aircraft transfers, and from the aircraft to the final destination. (Note: once on board the aircraft, the passenger or cargo is in the airside).

150National Research Council, Transportation Research Board, *Measuring Airport Landside Capacity*, Special Report 215 (Washington, DC: 1987), p. v.

151David W. Davis, executive director, Massport, unpublished remarks, OTA Advisory Panel meeting, Apr. 18, 1990.

152Refers to passenger or cargo trip-time unless otherwise stated.

Table 3-1 l—Traffic Congestion Increases in 15 Major Cities

Cities	Congestion index[a] (1987)	Percent change (1982-87)	Annual total cost[b] (in billions of dollars)	Annual congestion cost per capita (in dollars)
Los Angeles	1.47	20	7.9	730
San Francisco-Oakland	1.31	29	2.4	670
Washington, DC	1.25	31	2.2	740
Phoenix	1.23	6	0.9	510
Houston	1.19	1	1.5	550
Atlanta	1.16	30	1.1	650
Seattle	1.14	20	0.9	580
New York	1.11	4	6.8	430
Chicago	1.11	11	2.5	340
Detroit	1.10	- 2	1.9	460
San Diego	1.08	38	0.6	280
Philadelphia	1.06	17	2.1	520
Dallas	1.03	22	1.0	530
Minneapolis-St, Paul	0.97	24	0.5	240
Milwaukee	0.94	10	0.2	190

[a]The congestion index is a weighted measure of urban mobility levels, and cities with values greater than 1.0 have congestion problems. Roads carrying more than 13,000 vehicles perfreeway lane per day or 5,000 vehicles perarteriailaneperdayareeonsidered congested.
[b]Congestion cost is the estimated cost of travel delay, excess fuel consumed, and higherinsurance premiums paid by residents of large, congested urban areas.

SOURCE: Office of TeehnologyAssessment, based on Texas Transportation Institute, "Roadway Congestion in Major Urban Areas, 1982 to 1987,"' Research Report 1131-2, 1989.

The equipment used today consists of x-ray scanners with moving belts and magnetometers, best suited for detecting metal,[153] and their successful use depends on the skill, alertness, and motivation of the people operating them. These methods are most effective at detecting weapons, and are not very successful at uncovering explosives and volatile substances. Passenger background checks and interviews, as are done by Israel's El Al Airlines, are effective screening methods, but are both labor-intensive, time-consuming) and go beyond traditional limits of privacy, limiting their acceptability in the U.S. system.

New technologies for baggage screening include: x-ray tomography devices; electromagnetic and nuclear-based systems that identify atomic elements, such as nitrogen, a key component of most explosives; and vapor detection techniques that recognize and evaluate trace quantities of organic materials often present in explosives. However, further development to improve speed and reliability will be necessary before these technologies are widely deployed. New security systems may require some redesign of airport interiors to accommodate large screening devices.

Conclusions and Policy Options

Although the U.S. transportation networks provide enormous benefits to the national economy, congestion and structural decay are taking their toll on efficiency and productivity, especially in large metropolitan regions, today's centers of economic activities. The quality of service provided by the transportation infrastructure is a product of government investment decisions made over the system's lifetime, about planning, design, construction, operations, maintenance, and rehabilitation. In the United States, shifts in population and transport patterns and vehicle technology occur much faster than governments change the ways they design, manage, and maintain the transportation infrastructure. The result is overburdened infrastructure in the major urban areas, while many rural States must struggle to provide adequate basic services from their shrinking economic bases. Every year, highway congestion in the Nation's largest cities is estimated to cost motorists over $30 billion (see table 3-1 1), while airport delays take a $5 billion toll on airlines and passengers. **OTA concludes that these problems are due more to investment, land-use, and management policies and practices than to inadequate technologies. While new tech-**

[153]X-ray devices introduced recently are able to distinguish among differing materials—organics, plastics, metal-based on density.

nologies can help improve infrastructure condition and smooth traffic flows in congested areas, the Federal Government must change its infrastructure investment policies and address system management issues, if the most pressing transportation problems are to be resolved.

Financing and Investment

Federal fiscal policies-General Fund subsidies, grant matching requirements, trust fund spending targets, and revenue raising options-vary for each transportation mode. These policies do not always lead to economical system investment and management and have created substantially different infrastructure problems for each mode.

Surface Transportation

Aviation and port and waterway infrastructure (where the Federal Government plays major investment and management roles in operations and maintenance, and the rights-of-way—air and water—require structural systems only indirectly) is in quite good physical condition. Although delays occur, most are amenable to management and technical solutions. In contrast, the Federal Government has always been an important, but minority, investment partner only in surface transportation infrastructure-roads, bridges, mass transit, and railroads-leaving management and operations to the State, local, and private owners. Federal surface transportation funding policies have favored capital investments, without a corresponding commitment to operations and maintenance. The result is that State and local government owners of the far-flung road system have cut back and deferred maintenance and rehabilitation. Most simply have not invested in basic operational improvements, such as advanced traffic signal systems. Private owners, primarily railroads, also neglected maintenance, especially on lightly used track sections, abandoning or selling branch lines as soon as they were able.

Changing Federal fiscal policies for surface transportation to allow Federal trust fund monies to be used throughout the infrastructure life cycle and for operations and maintenance is the top priority. Such spending discretion is of critical importance for rural or other economically constrained areas facing unaffordable infrastructure maintenance and rehabilitation needs. In some regions, local transportation grants may best be used for noncapital investments, such as maintenance management systems, employee training, or advanced traffic control equipment.

State matching requirements range from 10 percent for Interstate construction to 25 percent for primary and secondary programs. However, a primary road in poor condition can create a traffic bottleneck that has a major impact on a connecting Interstate, making rehabilitation of the primary artery crucial to smooth interstate travel. Congress could consider equalizing State matching requirements for all highway grants so that decisions about spending priorities reflect regional priorities, rather than projects tailored to fit grant categories. Expanding State and local options for raising revenue, such as tolls, on facilities built with Federal funds is crucial as well, to help leverage and stretch Federal dollars.

Increased flexibility in the use of Federal highway and transit grant funds-the ability to transfer or combine them—would also help transportation system productivity. Examples include railroad improvements (for Amtrak, too, since over 40 percent of Amtrak passengers travel on trains under contract to jurisdictions), park-and-ride facilities, HOV lanes, and preferential treatment for transit or other high-occupancy vehicles. A funding program for surface transportation condition improvement, which would include passenger rail, mass transit, roads, and bridges, might be such a mechanism. Similarly, a program for surface transportation capacity expansion should include new commuter rail and bus systems, new busways, new lanes, including HOV facilities, and expansion to existing systems and facilities.

Market Pricing

Traffic congestion creates additional operating and maintenance expenses for vehicles and infrastructure, and delay costs for users. Since the price paid for using the transportation system is often below real costs, the demand for frequent transport service to many destinations encourages large fleets of small vehicles to clog the infrastructure. The average passenger and cargo capacity of vehicles is a key factor in efficient system flow. Industry uses large vehicles—widebody jets, long, double trailer trucks, double stack trains, jumbo barges, and new containerships-when economics favor them and regulations allow them. User pricing policies (peak-hour tolls) that reflect vehicle costs to the system could favor higher capacity operations,

Table 3-12—Federal Expenditures and User-Fee Revenue for Transportation, 1989

Transport mode	Federal expenditures (in millions of dollars)	Federal user-fee revenues[a] (in millions of dollars)	Dedicated revenue as percent of expenditures
Highway	13,898[b]	14,270	102
Transit	3,595’	1,357[d]	37
Rail	594’	—	—
Aviation	5,748[f]	3,664	63
Ports and waterways	1,436[g]	223[h]	16

a Does not include interest received on trust fund balances.
b Includes funds outlayed for the Federal Highway Administration, the National Highway Transportation Safety Administration, the Forest Service for forest roads and trails, and the Bureau of Indian Affairs for road construction.
c Includes capital and operating grants and limited research and development (R&D) spending.
d Revenue source is 1 cent per gallon from motor fuel tax (1989).
e Amtrak funding and limited Federal R&D spending.
f Does not include expenditures for National Aeronautics and Space Administration, National Transportation Safety Board, or Department of Transportation Office of the Secretary.
9 Army Corps of Engineers outlays for harbors waterways. Doss not include Maritime Administration, Coast Guard, or Panama Canal Company outlays.
h Includes Inland Waterway Trust Fund, Harbor Maintenance Trust Fund, and St. Lawrence Seaway Tolls.

SOURCE: U.S. Department of Transmutation, *Federal Transportation Financial Statistics. Fiscal Years* 1979-1989 (Washington, DC: May 1990).

such as car pooling and mass transit, and possibly lower total energy use and environmental damage. They could also lower life-cycle costs by matching system characteristics and long-term use patterns. For example, a highway policy basing user fees on the pavement wear imposed by commonly used vehicles (truck axle weights, for example) and using the increased revenue to pay for thicker, more durable pavements could lower long-term total highway costs.

Strict market pricing policies raise issues related to ability to pay and discrimination against certain classes of transportation users. OTA concludes that pricing decisions for demand management may require Federal oversight to ensure affordable transportation options to all users. A share of the revenues generated by those willing and able to pay for premium service could fund alternative transportation systems for other users.

General Fund Subsidies

Tying user charges to system expenditures, especially for operations and maintenance, can encourage realistic infrastructure decisions and provide a long-term revenue stream for system management. While social benefits such as defense, environmental protection, and economic development just@ General Fund support for transportation infrastructure, these tax monies currently subsidize each mode to different degrees (see table 3-12). On both the inland waterways and deepwater channels, the General Fund now pays roughly 50 percent of capital costs, a reasonable amount given the multiple purposes these structures serve, and a marked reduction from historic levels. However, water shippers and operators still pay only a minor share of operations and maintenance costs, in sharp contrast to other transportation modes, where users pay most of these costs. OTA concludes that this preferential treatment for port and waterway users is difficult to justify and that it is time for another look at investment and cost allocation **policies for transportation infrastructure. One option is to equalize General Fund subsidies among transportation modes over a 5- to 10-year period. Another is eliminating the subsidies entirely, using trust fund revenues for Federal programs and looking to new revenue sources, such as higher State and local grant matching requirements.**

Whatever the choice, if General Fund subsidies for transportation are reduced, and budget constraints prevent using trust fund balances, user fees and non-Federal funding must make up the difference, or existing public networks will have to scale back. With the exception of the inland waterway operators, most transport sectors would be capable of generating sufficient revenues to remain at present capacity. Congress could consider a long-term, gradual disinvestment of commercially unproductive waterways, unless regional governments and recreational users are willing to meet substantially more of the costs. For example, hydroelectric power, drinking water, and recreational boating opportunities supplied by these navigation projects, if priced at fair market values, could fund significant amounts of system operating and maintenance costs.

Management Framework

Finding ways to increase system capacity and handle increasing demand without constructing new rights-of-way poses enormous challenges. New technologies can marginally increase the capacity of infrastructure, but they are often expensive and eventually reach structural limits. A systems management approach that encourages carrying the same volume of passengers or cargo on fewer vehicles and makes full use of all modes could address air quality, energy use, and congestion problems.

Intermodal Transportation

While individual intermodal operators—airports, marine ports, terminals, and stations-and transportation companies are investing in advanced equipment and electronics to speed cargo and passenger transfers, problems related to intermodal transport increasingly hamper regional surface transportation links. For example, port operations both contribute to and suffer from surface traffic congestion, air pollution, and problems caused by overweight shipments. Many such issues are international and interstate in scope and beyond the capabilities of State and local governments to resolve.

A host of governmental agencies have regulatory and fiscal authority over separate elements of regional transportation, and no effective mechanism for multimodal coordination has emerged. Federal policy has favored capital investment as support for economic development, a policy that has diminishing application in metropolitan areas, where improved system (regional) management will be the key to future economic success. OTA concludes that Federal incentives for addressing regional transportation issues, intermodal links, surface congestion solutions, and environmental impacts are essential.

Institutional Framework

Neither DOT nor Congress has successfully overcome strong, separate modal interests and achieved an appropriate systems approach to solving transportation problems. In Congress, only the appropriations committees have sufficiently comprehensive jurisdiction, but those committees were never intended to set transportation policy. DOT's recently published National Transportation Policy recognized this and encouraged a multimodal approach toward transportation problems. However, this encouragement is not enough; **OTA concludes that unless steps are taken to institutionalize a multimodal approach within DOT, the traditional modally oriented structure will be perpetuated and the agency will not be able to address today's transportation issues effectively.**

If the Federal Government is to regain a leadership role in transportation, changes in institutional management must be made. In the short run, consolidating several of the water management functions and urban modes makes a great deal of sense. Over the longer term, options include restructuring DOT in divisions by broad mode-aviation, and surface and water transportation-or by function, such as metropolitan passenger and intercity freight transportation. Reforming congressional oversight as well, by developing a mechanism to coordinate or concentrate transportation authorization, will be crucial to the success of a restructured DOT.

An immediate option for Congress to consider is to shift civilian water transportation authority from the Army Corps of Engineers to DOT, as was originally envisioned when DOT was created. This would consolidate all transportation policy and trust funds within a single agency with Cabinet-level attention and facilitate multimodal decisionmaking. Because some of the Corps' traditional missions are waning, over the longer term consideration could be given to making the agency into a National Corps of Engineers with the mission of making its engineering and water resources expertise available to support a number of executive agencies on a reimbursable basis. It could remain loosely associated with DoD and maintain its other current responsibilities, or these could be assigned to other departments as appropriate (flood control could be housed in the Department of the Interior, for example).

Transportation Technologies

Advanced technologies, innovative and alternative multimodal delivery systems, more efficient management and methods, and changes to incentives will be necessary to improve the Nation's transportation system. Yet with few exceptions, data collection and research have been insufficient to identify the best choices among the advanced concepts vying for places in the future transport system. Moreover, much in the current institutional and organizational structure acts to prevent adoption of new technologies and management techniques. Officials, particularly at the local level, are often unaware of suitable new technologies, and even when they do know about new tools, they often cannot afford to buy them or to train employees to use them.

Improving Operations

Technological procedures for mitigating congestion and structural limitations are often expensive to implement, but may be cost-effective when other options are unavailable. New traffic management and control technologies could potentially improve traffic flows on congested roadways, airways, and waterways on the order of 10 to 20 percent, although when new capacity is opened in a congested corridor, it is usually fried quickly by latent demand. Many of these options require significant public investments, and in most cases, users would also need to invest in new equipment, raising issues related to ability to pay.

Roadway technologies that speed traffic flows, inform motorists of congested areas, and detect and respond to traffic incidents promptly are being developed and tested. The backbone of all of these systems is an efficient, traffic-responsive signal control system, a basic technology that can offer immediate congestion improvements. Advanced traffic control signal systems are one of the few highway technologies whose effectiveness depends primarily on actions by public agencies, and they represent a vital first step in the development of other Intelligent Vehicle/Highway Systems. In-vehicle guidance and communications systems will be of limited benefit unless they are linked to the public infrastructure. Federal assistance to local jurisdictions for implementing these highway technologies and ensuring coordination between adjacent municipalities to provide smooth intercity and interstate traffic flow are top priorities.

Managing Demand—Additional reduction in congestion can be attained in urban areas if technology is used in conjunction with full-cost pricing. Longer term Intelligent Vehicle/Highway Systems developments, such as those that control vehicle speed and direction as well as spacing between vehicles, offer greater potential for faster travel and reduced delays, but these technologies are at an early stage of development, and any possible implementation is at least two to three decades away.

The top investment priorities for air are communications, navigation, and surveillance technologies that can improve terminal ATC capabilities and increase effective airport. capacity during inclement weather, the time when most delays occur. Satellite-based systems will be essential for gains in international traffic. However, future gains in ATC capabilities are likely to outpace the ability of airports to handle takeoffs and landings, and some form of demand management is likely to be necessary.

At some congested inland waterway locks, trafffic management and equipment for pulling unpowered tows could increase capacity by over 20 percent. Scheduling access to these facilities would allow better planning by industry and could reduce operating costs. However, the initiative for such system traffic management would best come from the waterway users, since safety issues do not justify precise Federal traffic control on the waterways.

Alternative Modes

Technologies leading to improvement in one transportation mode can benefit the entire system by relieving congestion in other modes. For example, employing high-speed rail in heavily traveled automobile or air corridors, such as those in the Northeast corridor and southern California, could significantly reduce rail travel times and attract passengers away from highways and airports. Improving the attractiveness of bus transit by giving urban buses priority at traffic signals and providing dedicated lanes would similarly help alleviate road traffic in crowded areas. Any gain in roadway performance will likely enhance airport ground access, since most air passengers and cargo depend on road vehicles. See table 3-13 for a summary of the likely effects of various surface transportation measures.

Alternative technologies, such as tiltrotor aircraft or magnetically levitated trains, could play a role in bypassing the parallel problems of limited airport capacity and surface transportation congestion in metropolitan areas. Developing and implementing such radically new technologies will require billions of dollars and is likely to require Federal support. However, since these technologies would serve

Table 3-13-impacts of Surface Transportation Measures

Technology or measure	Impact	Governmental action required
Highways:		
Intelligent Vehicle/Highway Systems	Reduced congestion (10-20%) Improved safety (0-20% fewer accidents) Less driver frustration	Installation of integrated, traffic-responsive signal control systems by local governments ($1 to $20 million/major city) Federal investment in R&D ($10 to $100 million/year)
Timely pavement and bridge construction, maintenance, and rehabilitation .....,. .	Reduced life-cycle cost (50%) Increased life (50%)	Higher annual maintenance expenditures by State and local governments
Rail:		
Timely right-of-way maintenance and rehabilitation	Reduced life-cycle cost (10%) Increased productivity (higher speeds), fewer accidents (50%)	None, private-sector financed
Automatic train control.	Improved service and safety	None, private-sector financed
High-speed passenger rail	Improved service (50-100% quicker travel times than conventional rail) Shift some traffic from airports and highways	Federal support for Amtrak capitalexpenses, Federal support of right-of-way acquisition, construction, and possibly maglev R&D
Mass transit:		
Alternative fuels . . . , ... , ...	Reduced emissions of NOx and particulates (0-20% reduction in ambient air pollution if these fuels are used only on mass transit vehicles)	Increased fuel and equipment expenditures for municipal transit authorities
Automatic vehicle location and passenger information systems	Improved service, increased ridership (10%) leading to congestion relief	Increased equipment expenditures for municipal transit authorities

SOURCE: Office of Technology Assessment, 1991.

overlapping needs, choices may have to be made between them and other technological options, and total *public* costs projected for each system, issues that will need further study. Moreover, Congress will be involved in determining the appropriate sources for funding and how the development program should be managed.

High-speed intercity ground transportation, urgently needed in congested regions such as the Northeast corridor, can ill afford to await the development of maglev or tiltrotor technology. Proven steel-wheel technologies, such as tilt trains and high-speed systems, are available now and can play a key role in speeding passenger travel and relieving congestion from other modes in crowded urban corridors. Tiltrotor aircraft and maglev trains show promise for even faster travel, but require extensive development and are at least a decade away from possible implementation.

CHAPTER 4

Environmental Public Works Management and Technologies

Photo credit: American Consulting Engineers Council

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CHAPTER 4

Environmental Public Works Management and Technologies

In the haste to get new Federal water and related environmental programs in place, consultations and concurrence to ensure equitable and effective results have been neglected if not ignored. [1]

The Federal Government's role in environmental protection includes legislation, policies, and regulations to preserve the quality of the Nation's air and water supplies and to control the disposal of wastes. State and local officials must implement these Federal policies as they supervise, manage, operate, and maintain the public works infrastructure that supplies water, treats wastewater, and collects and disposes of solid wastes.

Ensuring good water quality requires planning, managing, and operating a wide range of public works facilities including reservoirs, locks and dams, flood control structures, and drinking water and wastewater treatment plants. Equal care in managing solid waste and hazardous waste disposal facilities is also necessary because of the potential movement of contaminants through groundwater or overland flow. The U.S. Environmental Protection Agency (EPA) has the Federal lead for environmental protection, setting standards for drinking water quality and surface waters, establishing pollutant limits on the discharge of effluents from municipal wastewater treatment plants and industrial point sources, and addressing issues of disposal of municipal solid and hazardous waste. The agency's responsibilities are established by a set of major environmental laws (see table 4-l).

Meeting EPA standards is not an easy task and places substantial technical, management, and financial demands on States and communities often ill-equipped to meet them. Technologies are essential tools for public works officials in carrying out risk assessments and implementing environmental protection measures. Maintenance, construction, repair, and rehabilitation techniques can improve performance and extend the service lives of existing facilities, and innovative systems, demand management, and improved fiscal and operational methods can reduce inefficiencies and foster more effective operations. The gulf between the capabilities of States and localities and their legal responsibilities poses difficult dilemmas for policymakers.

This chapter provides a snapshot of the three major environmental public works service areas: drinking water supply, wastewater treatment, and solid waste disposal. It examines related management and financing issues and technologies and the ways Federal standards and programs affect the State and local governments responsible for carrying out the requirements and providing services.

Drinking Water

The drinking water supply system includes the sources, facilities, and activities needed to transmit, store, treat, and distribute water to residential, commercial, industrial, and agricultural consumers. Groundwater is the source of about one-half of drinking water supplies by volume, with surface water (rivers, streams, lakes, and reservoirs) providing the remainder. Many groundwater and some surface water sources need very little treatment, usually simple disinfection with chlorine. However, some local water sources have been contaminated and require filtration, aeration, or chemical treatment. For example, technologies to remove nitrates contaminating aquifers must now be used in parts of the Midwest after decades of agricultural fertilization.[2] Federal and State Governments regulate and oversee the local suppliers of drinking water to ensure that it is free from biological and chemical contaminants.

Water Storage and Supply

supplying drinking water has historically been a local government service, provided by municipally owned systems, investor-owned water utilities, homeowner's associations, and water wholesalers. About 30 percent of all public water systems are

[1] Stephen S. Light and John R. Wodraska, "Forging a New State-Federal Alliance in Water Management," *Natural Resources Journal*, vol. 30, summer 1990, p. 479.

[2] James Manwaring, American Water Works Association Research Foundation, personal communication, Dec. 15, 1989.

Table 4-l-Major Federal Environmental Public Works Legislation

1948	Water Pollution Control Act authorized the Federal Government to conduct research and grant loans to States.
1956	Water Pollution Control Act Amendments gave permanent Federal authority to become involved in water pollution policy and make construction grants to States.
1963	Clean Air Act asserted Federal interest in controlling air pollution.
1965	Solid Waste Disposal Act established the Federal research and development program.
	Water Quality Act authorized Federal water quality standards on interstate waters and required States to set standards.
1966	Clean Water Restoration Act increased Federal grant share to 50 percent of project costs and increased grant funding.
1967	Clean Air Act amendments authorized Federal standards and enforcement.
1969	National Environmental Policy Act required impact statements on all major Federal actions.
1970	U.S. Environmental Protection Agency (EPA) formed to administer numerous media programs.
	Clean Air Act Amendments expanded Federal regulatory authority and required States to adopt implementation plans.
1972	Federal Water Pollution Control Act (Clean Water Act) set minimum wastewater treatment standards and established construction grants.
	Coastal Zone Management Act authorized Federal grants to States to develop coastal zone management plans under Federal guidelines.
	Marine Protection Act regulated the dumping of waste products into coastal waters.
1974	Safe Drinking Water Act set standards for water quality.
1976	Resource Conservation and Recovery Act (RCRA) supported recycling and discouraged landfills.
	Toxic Substances Control Act authorized EPA to regulate the manufacture, sale, or use of any chemical threatening the health of humans or the environment.
1977	Clean Air Act Amendments strengthened EPA enforcement.
1980	Comprehensive Environmental Response, Compensation and Liability Act established Superfund for chemical dump site cleanup.
1984	Hazardous and Solid Waste Amendments (of the RCRA) targeted hazardous waste management.
1986	Safe Drinking Water Amendments strengthened Federal requirements.
	Water Resources Development Act initiated user fees and cost sharing for water projects.
1987	Clean Water Act Amendments required that wastewater construction grants be phased out by 1991 and replaced until 1994 by capitalization grants to State Revolving Loan Funds.
1990	Clean Air Act reauthorization with additional controls on autos, buses, and trucks.
	Superfund extended through 1994.

SOURCE: Office of Technology Assessment, 1991.

community water systems, providing service year round to about 219 million people, primarily residential users. A few very large community water systems (0.5 percent of the total) serve more than 43 percent of the population, while at the other end of the scale are a huge number of small systems (see table 4-2), which serve less than 2.7 percent. About 40 million people draw drinking water from private wells, which are not subject to the Federal drinking water standards and are not regularly tested for contaminants. Noncommunity water systems provide intermittent service primarily to transient and nonresidential users.

Siting and constructing new reservoirs is increasingly difficult because the number of available sites is diminishing, new water supplies must be protected, and resistance for environmental reasons is high. Furthermore, the costs of developing new supplies and storage facilities rise as better sites are

Table 4-2-Community Water Systems in the United States

Number of people served	Number of systems
25 to 500	37,425
501 to 3,300	13,995
3,301 to 10,000	4,029
10,001 to 100,000	2,802
More than 100,001	279

SOURCE: Office of Technology Assessment, based on U.S. Environmental Protection Agency data, 1991.

preempted.[3] Thus, water utilities find it easier and cheaper to protect raw water supplies than to develop new supplies or treat water contaminated in storage. Many have programs to control erosion and protect reservoirs, watersheds, and well-heads so as to reduce chemical and equipment requirements, efforts that require extensive monitoring and enforcement of waste discharges and surface runoff.[4]

Water Distribution, Consumption, and Pricing

Drinking water distribution systems transport water from the treatment plant to the customer. The elevated storage tanks, ground storage reservoirs, pumps and pumping stations, mains from 6 to 54 inches in diameter, pipes, valves, and connections for distribution can account for up to 80 percent of drinking water costs. Systems in poor repair lose treated water through leakage, raising costs even higher. An examination of eight systems ranging in output capacity from 0.3 MGD (million gallons per day) to about 75 MGD showed amounts of such unaccounted-for water ranging from less than 1 percent up to 37 percent.[5] Small systems generally had a higher percentage of unaccounted-for water.

Average water usage is from 80 to 150 gallons per capita per day in the United States, although actual human consumption is between 1/2 to 1 gallon per capita per day. The cost of drinking water is typically $1.00 to $1.50 per 1,000 gallons; annual cost per person ranges from about $30 to $80 annually. Wide regional cost variations exist in the United States, because water is not evenly distributed geographically. This uneven distribution creates difficulties in matching supply with demand.[6]

Managing Supply and Demand

In localities where water shortages have prompted mandatory reductions, water use is declining; short-term conservation rules due to drought conditions have also reduced usage. For example, Massachusetts' plumbing code now requires new and replacement toilets to use not more than 1.6 gallons per flush v. 3.5 gallons per standard flush.[7] Mandatory reduction rules have been enacted in some communities on Long Island, New York, and in California. Greater attention is being paid to reservoir management and operation and optimizing multipurpose water systems through regional compacts such as the Washington Sanitary Sewer Commission.

Optimizing site-specific characteristics, such as storage, flow, and quality, of surface and groundwater supplies, a process known as conjunctive use,[8] can increase the amount of good quality water and improve supply quality. Tacoma, Washington, has a conjunctive use strategy by which it augments water from its principal source, the Green River, during periods when large amounts of suspended clay materials create high turbidity, with high-quality groundwater to reduce treatment requirements.[9]

Water utilities require large investments, partly because high seasonal demands usually occur during periods of low stream flows, necessitating large storage facilities. Thus, water systems generally operate at levels of output well below capacity, creating an incentive for utilities to encourage consumption, often through low prices for high-volume users. Although human consumption is a small percentage of total water used, almost all water must be treated to drinking quality standards.

[3] Kenneth D. Frederick, Resources for the Future, "Water Resource: Status, Trends, and Policy Needs," discussion paper ENR88-02, 1988, p. i.

[4] Wade Miller Associates, Inc., *The Nation's Public Works: Water Supply (Washington* DC: National Council on Public Works Improvement, May 1987), p. 53.

[5] Patrick C. Mann and Janice A. Beecher, *Cost Impact of &@ Drinking Water Act Compliance f& Commission—Regulated Water Utilities,* NRRI *report 89-6* (Columbus, OH: The National Regulatory Research Institute, January 1989), p. 19.

[6] Frederick, op. cit., footnote 3, p. i.

[7] Average household savings is estimated to be from 9,400 to 25,700 gallons per year.

Sues. Army Corps of Engineers, The Hydrologic Engineering Center, *Elements of Conjunctive Use Water Supply,* Research Document No. 27 (Washington, DC: March 1988), p. iv.

[9] Ibid.

Drinking Water Standards

Regulating drinking water to protect public health was historically a State and local responsibility. During the late 19th century, the threat of cholera and typhoid epidemics prompted many States and localities to establish sanitary commissions, which evolved into departments of public health, to supervise sewage treatment and monitor drinking water purity. During the first half of this century, continued small-scale outbreaks of waterborne infectious diseases motivated numerous States and local governments to adopt ordinances to control pollution and protect drinking water supply from contamination.[10] However, growing concern in the 1960s and early 1970s over the purity of the Nation's drinking water prompted passage of the Safe Drinking Water Act (SDWA) of 1974[11] as an amendment to the Public Health Service Act. The act and its amendments require EPA to set standards for drinking water quality and for the protection of underground sources; the States must enforce the standards. All public water supply systems—whether publicly or privately owned-are subject to the mandate.

Dissatisfied with EPA's implementation of the 1974 act and faced with the threat of suits by environmental advocates, Congress enacted the SDWA Amendments of 1986[12] to simplify the EPA regulatory process, stiffen the requirements, and accelerate the schedule for EPA to establish and implement new National Primary Drinking Water Regulations. Congress specified 83 contaminants for which EPA was required to promulgate regulations and identify the best available technology by June 1989, and required that 25 contaminants be added to the list every 3 years. To assure compliance, EPA has imposed various requirements for monitoring water quality, maintainingg records, and issuing reports. All public water systems are required by the statute to test on a scheduled basis for all contaminants for which EPA has established standards. The 1986 amendments also authorized continued, but relatively small, grants to States and localities, as well as new Federal assistance intended to help small systems monitor for unregulated contaminants and install disinfection equipment.

The Water Quality Act Amendments of 1987 addressed such issues as nonpoint source pollution, storm water discharges, the National Estuaries Program, toxics control, and sewage sludge management. Other laws with provisions aimed at improving U.S. water quality include the Resource Conservation and Recovery Act; the Comprehensive Environmental Response, Compensation, and Liability Act; the Federal Insecticide, Fungicide, and Rodenticide Act; and the Toxic Substances Control Act.

If a State assumes primacy, or primary enforcement authority, for drinking water, it takes on responsibility for ensuring that its localities meet the requirements of the national laws and regulations, and most States have done so. The 1986 SDWA Amendments, while providing some flexibility to the regulations, added to the States' workload by requiring additional review and analysis to ensure compliance. Some States voice concern that they cannot meet these requirements with their available resources and personnel (see box 4-A) and must consider abandoning primacy; they are apprehensive about the responsibility, liability, and costs associated with failed systems.[13]

Recent Regulatory Changes

Water systems are currently trying to comply with recent changes in drinking water regulations such as testing for the additional contaminants listed in the SDWA and seeking technology alternatives. Controlling the frost set of contaminants requires systems to change their processes without knowledge of future regulations or the identities of additional contaminants. New regulations call for all surface water supplies to be filtered, and EPA has combined this requirement with disinfection regulations into one set of standards for surface water. Systems that do not filter must now do so, regardless of existing water quality.

In addition, legislation also requires that new disinfection standards be promulgated for water supplies. One goal of the new standards is reducing trihalomethanes (THM) and other byproducts of chlorine disinfection. However, EPA faces a dilemma in setting standards: reducing the level of

[10]Council on Environmental Quality, The *16th Annual Report of the Council on Environmental Quality* (Washington DC: U.S. Government Printing Office, 1985), p. 7.

[11]Public Law 93-523, 88 Stat. 1660.

[12]Public Law 99-339, 100 Stat. 642.

[13]John Trax, National Rural Water Association, personal communication, Apr. 17, 1990.

chlorine is likely to increase biofilm growth in water distribution systems, because less residual disinfectant will remain in treated water. This may well lead to a new set of operating problems. How best to regulate lead in drinking water is also problematic, because lead has been widely used in service lines and solder for household plumbing.

Coliform monitoring regulations have been changed to determine simple presence or absence as opposed to a density (parts per volume) measurement. These changes will increase the number of samples needed by a utility to show compliance and are likely to increase substantially the number of utilities in violation because low levels of coliform, which do not pose a public health risk,[14] are likely to be present.

Risk and Uncertainty in Standard Setting

Although an appendix to the EPA National Interim Primary Drinking Water Regulations of 1976 mentions that ". . . priority should be given to the selection of the purest source. . . ,"[15] this approach is not stressed in legislation or in EPA regulations. EPA's water quality standards are based on maximum contaminant levels (MCLs) determined by animal studies. While monitoring equipment can measure some contaminants in parts per trillion, standards determined by animal modeling cannot project human toxicity to this accuracy. Moreover, MCLs ". . . for one contaminant do not recognize the additive or synergistic behavior of the many contaminants that are present together in wastewaters.[16] Scientists' ability to develop new chemicals and to measure their presence in the environment in minute amounts far surpasses the ability to understand and evaluate long-term human health risks.

Removing a contaminant from drinking water to meet an MCL standard is more costly than preventing its introduction in the first place. Complex and specific EPA regulations for drinking water and sewage treatment may conflict with regulations of other Federal agencies, creating problems for operators and raising costs. For example, the process of removing radionuclides from drinking water creates radioactive sludge that is difficult to dispose of because it is a radioactive waste. If engineers adjust water disinfectants to reduce corrosion in distribution systems, the changes may reduce chlorine's effectiveness, yet adding more chlorine to achieve the same disinfection level will increase the carcinogenic THMs.

Photo credit: Dan Broun, OTA Staff

Americans count on being able to draw safe drinking water from every household tap.

Technologies for Safe Drinking Water

Most newer water treatment methods are specialized, expensive, and not designed for amass market, making it difficult for localities to introduce new technologies.[17] SDWA regulations are aimed at THMs, volatile organic compounds (VOCs), and soluble organic compounds (SOCs), with more contaminants to be added overtime. As standards for each new contaminant are promulgated, new methods or new chemicals become important. 'Although the SDWA can be expected to stimulate the development of alternative treatment processes, at this time

[14] Edward Geldreich, senior research microbiologist Drinking Water Research Division, U.S. Environmental Protection Agency, personal communication, Sept. 10, 1990.

[15] Daniel A. Okun, ' 'Philosophy of the Safe Drinking WaterAct and Potable Reuse, " *EnvironmentalScience & Technology*, vol. 14, No. 1 l, November 1980, p. 1298.

[16] Daniel A. Okun, "Reuse: Panacea or Pie in the Sky," *Journal of the American Water Works Association*, vol. 77, No. 7, July 1985, p. 26.

[17] See for example, Wade Miller Associates, Inc., op. cit., footnote 4.

Box 4-A—State Water Quality Programs and New Technologies

State public works officials and engineers play important and often pivotal roles in the difficult process of ensuring the quality of a State's drinking water systems and wastewater treatment plants. For example, in Ohio, the Ohio Environmental Protection Agency (OEPA) has primacy in the approval process for new construction, upgrades, improvements, and expansions of drinking water facilities.[1] The system's engineer or a consultant must prepare project plans and submit them to OEPA's office of Drinking Water for approval. OEPA engineers provide initial advice and suggestions about project feasibility and acceptance through the State office or one of four regional offices. Following initial acceptance, project designs can be completed and submitted for a more detailed review for compliance with State construction and environmental standards.[2]

Ohio uses the "Ten State Standards," which are guidelines for conventional treatment equipment and procedures. Developed before many of today's environmental regulations or more sophisticated treatment technologies, these standards are considered very conservative. Although Ohio is trying to move away from these *standards* to encourage innovative technologies, the permit process favors familiar technologies with a proven track record. Moreover, public works operators often must back up innovative systems with conventional technology in case the new process fails, resulting in costly redundant systems.[4]

The Office of Drinking Water is short of experienccd engineers, and current salaries are not sufficient to attract or retain needed staff.[5] Because the State currently has a 6- to 9-month backlog of project design approvals, State engineers do not have time to examine thoroughly proposals that include new technologies, The State legislature has considered increasing the staff and raising salaries in response to pressure from contractors and construction companies that are losing money because of the delays.

Oklahoma *has* a more decentralized approach for environmental decision making,[6] and five different State agencies have authority in environmental permitting. Municipal drinking water or wastewater treatment plants require approval from the State's Department of Health, while permits affecting water and agriculture involve the

[1]Robcrt Stevenson, manager of operations, Toledo Water Treatment Plant, personal communication, Oct. 18, 1989.

[2]Ashley Bird, manager, Engineering Section, Division of Public Drinking water, Ohio Environmental Protection Agency, personal communication, Oct. 20, 1989.

[3]Wade Miller Associates, Inc., *The Nation's Public Works: Report on Water Supply* (Washington, DC: National Council on Public Works Improvement, May 1987), p. 75.

[4]Whit van Cott, commissioner of water, Toledo, Ohio, personal communication, Oct. 18, 1989.

[5]Other States have the same problem. Virginia and Pennsylvania report that their salaries make it difficult to compete with private engineering firms for young engineers; they also cite the lack of institutional memory due to high turnover. Virginia attempts to give young engineers broader experience and a sense of how systems operate in practice by rotating newly hired engineers in the regional offices for 2 months before they begin reviewing plans. The rationale is that newly hired engineers will be better able to judge a new process if they have seen some of the technologies in the field.

[6]Jon Craig, chief for Wastewater Construction Grants, Oklahoma Department of Health, personal communication, Oct. 11, 1989.

there is no single technology that will remove all regulated contaminants.''[18] The complexity of the water treatment process, coupled with variations in water supply characteristics, make the search for major new technologies difficult. Moreover, new treatment methods will bring new difficulties. For example, research on treating surface water supplies with granular activated carbon (GAC) found that dioxins were formed in the carbon reactivation process; after evaluation, an afterburner was installed to eliminate dioxin byproducts.[19]

Current Basic Treatment

Natural waters contain dissolved inorganic and organic substances, bacteria and plankton, and suspended inorganic material. Customary treatment methods to remove these substances include flocculation, sedimentation, filtration, and chemical precipitation.[20] Raw water is brought to a mixing tank where chemicals are added; the water is then transferred to a flocculation tank for additional mixing. Particulate matter, chemical floe, and pre-

[18]Mann and Beecha, op. cit., footnote 5, p. 9.

[19]Robert Clark et al., "Removing Organic Contaminants From Groundwater,' *Environmental Science and Technology, vol. 22,* October 1988, pp. 1126-1130.

[20]"Water Treatmen," Standard Handbook *of Environmental Engineering (New York ,NY: McGraw-Hill),* pp. 5.76~5.123.

State Department of Agriculture. Discharge permits for industry fall under the State Water Resources Board. If an oil or petroleum facility needs a discharge permit, the State Corporation commission has jurisdiction, and the Department of Mines has jurisdiction over mining activities. If an environmental issue is not clearly defined, it is handled by the Pollution Control Coordination Boarb, made up of representatives from all these agencies plus private citizens.

The State of Oklahoma does not have primacy in wastewater discharge permitting; thus permits are issued by the U.S. EPA. The State submits National Pollutant Discharge Elimination System permit applications to the EPA regional office in Dallas for review. Primacy can have an impact on technology choice, since a State review agency is more likely than the ERA regional office to recommend technology appropriate to the location. Also, if a small community system is in violation, or about to be, the State agency can act more quickly to assist or solve the problem.[7] Although Oklahoma's various agencies do not conduct evaluations of new or innovative systems, the Department of Health has indicated interest in the use of more such technologies. The State's Revolving Fund also encourages their use, and a municipality will be placed higher on the funding priority list if its plans incorporate innovative systems. The Water Resources Board sets standards in line with the Clean Water Act, providing some incentive to develop new technologies.[8]

Virginia uses a two-part permitting process for drinking water facilities comprised of standard technologies.[9] One permit is issued for construction and one for beginning operation of the completed facility. construction plans for standard technology are submitted to one of the State's six regional offices for review. Engineers in Virginia's regional offices perform the complete engineering review of the plans and then send them to the head office in Richmond for approval. The two top administrative engineers of the Division of Water Supply and the Comissioner of the Health Department must approve the plans. Like Ohio, Virginia has a large plan review backlog, largely due to staffing shortages. Moreover, a more rigorous process is required for innovative technologies. The manufacturer or supplier of a new technology must bond the product or system, discouraging promoters of unproven equipment After bonding, the plans follow the same mute.

Pennsylvania has a special "Innovative Technologies" permit for new technologies,[10] which requires a 12-month pilot test including source water checks to rneasure their effectiveness. Unlike the standard technology permitting process, innovative technology permits require oversight approval from the Division of Water Supplies in Harrisburg. This approval, however, is required only on the new technology portion of the plan. Although special requirements, such as those in Virginia and Pennsylvania eliminate some risk associated with new technologies, they tend to inhibit some systems from trying innovative technologies.

7Ibid.

8James Barnet, director, Oklahoma State Water Resources Board, personal communication, Oct. 12, 1989.

9Allen Hammer, director, Division of water Supply Engineering, Virginia Department of Health, personal communication, Oct. 20,1989.

10Fredrick A, Marrocco, chief, Division of Water Supplies, Pennsylvania Department of Environmental Resource% personal communication, Oct. 20, 1989.

cipitates from suspension are then removed through gravity in settlement tanks. Filtration removes matter held in suspension by passing the water through a porous medium. Disinfection, using chlorine, chlorine dioxide, ozone, or potassium permanganate, destroys pathogenic bacteria.

Chlorine has been the disinfectant of choice for more than 70 years and is currently added to about 90 percent of U.S. potable water supplies.[21] Chlorine is readily available and inexpensive and its characteristics are well known; water treatment specialists depend on it and rely on residual chlorine in the storage and distribution system. U.S. consumers do not object strongly to the levels applied; some suggest the taste of chlorine is proof that the water is properly treated.

However, the byproducts of chlorination include potentially carcinogenic halogenated byproducts, principally THMs.[22] Reducing chlorine to achieve the THM standard can lower the disinfection ability

21National Research Council, "News Report," informational document, October 1989, p. 14.

22Much is written about the THM byproducts of chlorination, but they represent only about 10 percent of the chlorine byproducts. Factors affecting byproduct components include source water quality, seasonal factors, water treatment process selection and operations, and disinfection processes and chemicals.

to the point that pathogenic bacteria are not killed,[23] and may require the addition of other treatment steps (See box 4-B).

Most European systems have well-protected storage facilities and short distribution systems, and rely on oxidation and disinfection with ozone[24] combined with biological treatment and postfiltration **GAC** for water treatment. Large amounts of THMs are not formed in treatment plants, since chlorine is used sparingly and is carefully monitored, because consumers do not want a chlorine taste in the water.[25] However, ozonation does have its own set of byproducts, some of which are also chlorine byproducts.[26]

Alternatives to Chlorine

Other processes, such as adsorption, aeration, ion exchange, oxidation, and distillation, are being used to remove dissolved substances. For each of these operations, the quantity and concentration of chemicals added, speed of mixing, technique, and settlement times will have an impact on the final results. The pH, turbidity, chemical composition of the water, type of coagulant, and such physical factors as water temperature and mixing conditions also affect the results.

EPA has investigated technologies for removing SOCs and VOCs from groundwater. Each technology must be tested under field conditions before EPA will advocate its use. GAC adsorption, a broad-spectrum technology for treatment of organic contaminants, has been field tested, and tests on packed tower aeration are still under way. Other technologies being evaluated are powdered activated carbon, alone or in combination with other processes such as ozone oxidation, reverse osmosis, and ultraviolet treatment. Although many of these processes are effective for removing SOCs, they have high capital and/or operating costs.

Reverse osmosis (RO) takes advantage of the phenomenon that solutions passed under pressure through a semipermeable membrane will result in solutions with lower concentrations of dissolved substances.[27] Membranes are very thin films capable of selectively separating suspended or dissolved solids from water depending on size and molecular weight. They can be constructed from a number of synthetic polymers, including cellulose acetate, cellulose-based polymers, polyamides, and polysulfone. RO and electrodialysis are currently the membrane processes with the most applicability for drinking water treatment; in fact, RO has proven successful in desalination plants. Ultraviolet light is effective for disinfection when the water supply is highly clarified and bacterial loads are moderate, although it does not provide any residual disinfection.[28] Ultrafiltration, an emerging technology, nanofiltration, and RO all rely on applied pressure **to** drive water through the membrane. In electrodialysis, an electrical current separates the salts.

Membranes limit the amount of chemicals needed for water purification, reduce the size of treatments, and can reduce operations and maintenance costs. New developments in membrane technology may lower energy requirements (less feed pressure), improve centaminant removal rates, and resist permanent organic fouling. However, membrane processes do require pretreatment, periodic cleaning, and disposal of filtration residue.

Work on innovative technologies must be carefully monitored to see whether performance meets the design criteria. However, ". . . once treatment units are installed, . . . there is generally little follow-up to see if designs are proper or are adequate mechanically to stand up for a reasonable period of time. ' '[29] Without the followup evaluations much of the value of the demonstration projects is lost.

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[23] Studies have shown, though, that precursor control through physical removal mechanisms may be the best way to minimize all chlorination byproducts. See Alan A. Stevens et al., "Formation and Control of Non-Trihalomethane Disinfection By-Products," *Journal of the American Water Works Association,* vol. 81, No. 8, August 1989, pp. 54-60.

[24] Ozone is an oxidizing agent that controls bacteria in the water and destroys taste and odor compounds. It oxidizes iron and manganese, leaving insoluble compounds that can be removed by filtration. Ozone gas is a hazardous material, requiring special care in handling.

[25] Rip Rice, president, Rice International Consulting Engineers, personal communication, Dec. 13, 1989.

[26] "Report on the Workshop on By-Products of Ozonation," *Water Research Quarterly, vol. 6, No. 4,* July-September 1988, pp. 13-15; and ibid.

[27] Talbert N. Eisenberg and E. Joe Middlebrooks, *Reverse Osmosis Treatment of Drinking Water* (Stoneham, MA: Butterworth Publishers, 1986).

[28] Mann and Beecher, op. cit., footnote 5, p. 8.

[29] James A. Goodrich and S. Bala Krishnan, "Drinking Water Treatment Technology for Groundwater Remediation," paper presented at the Third National Outdoor Action Conference on Aquifer Restoration Groundwater Monitoring and Geophysical Methods, Orlando, FL, May 22-25, 1989.

Box 4-B—Alternative Process for Water Treatment[1]

If the reactions of disinfectants with organic compounds in a water supply pose major problems, then procedures to remove dissolved organics can minimize the amount of chlorine needed and reduce the concentrations of halogenated byproducts and nonhalogenated organics. Such an alternative process might include the following steps:

1. abandon prechlorination and enhance physical removal of organics by flocculation and sedimentation;
2. oxidize organics, through ozone, permanganate, or advanced oxidation processes such as ozone/hydrogen peroxide or ozone/ultraviolet treatment;
3. follow oxidation with biological filtration in sand, in dual media filters, or in filters having some granular activated carbon (GAC) as media replacement;
4. add postfiltration GAC adsorbers, primarily to remove disinfection byproducts, and to ensure the adsorption of soluble organic compounds; and
5. add small amounts of chlorine or chlorine dioxide to provide a stable residual disinfectant, protect the distribution systems against biological regrowths, and produce high-quality water with virtually no chlorine taste.

[1]This box is based on Rip Rice, president, Rice International Consulting Enterprises, personal communication, Dec. 13, 1989.

Dual Systems

Dual systems, which supply potable and nonpotable water through separate pipes, although not a new concept,[30] offer an alternative to ***the high cost*** of treating all water to drinking water quality, particularly for new systems. Dual systems can be used for systems of any size but are attractive for small systems where high treatment costs must be met by relatively few customers. Wastewater treatment requirements produce a high-quality effluent that may be too valuable to be discarded;[31] using reclaimed wastewater for nonpotable purposes in **dual** distribution systems can:

- relieve the pressure on high-quality waters so that these can serve larger populations;
- cost less than developing additional high-quality freshwater sources for nonpotable uses;
- reduce the burden of pollution on the receiving body of water; and
- reduce the risk of utilizing water drawn from polluted sources.

Although the installation of a dual system requires additional capital expense for parallel pipe networks and additional valves and connections, the construction excavation is performed only once, and the system operating costs are lower. These systems have proven economical; operating systems include the Irvine Ranch Water District (California), Colorado Springs (Colorado), and St. Petersburg (Florida). The City of San Diego recently passed an ordinance establishing a water reclamation master plan and implementing strategy for the city. These systems will become more economically attractive as water source development and wastewater treatment become more costly due both to inflation and environmental regulations. However, retrofitting dual systems in mature water utilities may be too costly an alternative, and some public works officials have voiced concerns about the potential health risks of an inadvertent connection of potable and nonpotable supply lines.[32]

Technologies for the Distribution Network

Although the SDWA requires that regulations be met at the consumer's tap, most compliance efforts focus on water as it leaves the treatment plant.[33] However, distribution systems are related to 20 percent of waterborne disease outbreaks.[34] If the distribution system loses its integrity, treated water can change in quality through chemical or biological

[30]The Roman aqueduct supplied water that was used for nonpotable purposes. Drinking water was drawn from other sources.

[31]David A. Okun, University of North Carolina, "Feasibility of Dual or Multiple Water Supply Systems," unpublished manuscript, 1982.

[32]Richard H. Sullivan, executive director, American Public Worka Association, personal communication, J@ 17, 1990.

[33]Ibid.

[34]Robert Clark et al., "Contaminant Propagation in Distribution Systems," *Journal of Environmental Engineering,* vol. 114, No. 4, August 1988, pp. 929-941.

Photo credit: American Consulting Engineers Council

Using sludge from wastewater treatment plants to fertilize reforestation projects can be a oost-effective disposal method.

transformations.[35] Untreated water may enter the system through pipe breaks, and bacteria can be introduced from a variety of sources, including enclosed reservoirs to which chlorine is not added and living organisms in mains that, when disturbed, may release bacteria into the drinking water.[36]

Leak detection and control are essential both for ensuring against contamination and controlling cost. Significant savings can be achieved through leak detection and repair programs, even where water treatment costs are low. Minor repairs can prevent more serious problems and avoid the expense of additional water damage. Metered systems and those that have full information about their distribution network are more likely to be able to locate and repair problem sections. Leak detection surveys utilize a number of techniques, including visual observation, sonic technology, miniprobe sensors, tracer gases, and infrared photography.[37]

However, many water companies lack even rudimentary data about distribution systems. Useful data would include pipe information such as manufacturer, location, length, pressure, installation contractor, installation date, diameter, material, and placement method; and maintenance information such as maintenance crew or contractor, location, problem type, depth, corrective action, and local surface and subsurface conditions.

Studies indicate that a few pipes in a network account for most maintenance problems,[38] and that each repair shortens the time to the next repair. Pipe breaks are caused by: 1) quality and age of pipe, connectors, and other equipment; 2) the environment in which the pipe is laid, such as the corrosiveness of the soil, frost and heaving, and external loads; 3) quality of the workmanship used in the laying of the pipe; and 4) service conditions, such as pressure changes and water hammer. Additional research is needed to increase understanding of these relationships and to guide future repair and replacement efforts and design and placement activities.

Corrosive water can cause problems by increasing the concentrations of the metal compounds from pipe systems in the water. Lead, cadmium, and other heavy metals are generally present in various amounts in pipe solder material, and other contaminants such as copper, iron, and zinc can be leached from distribution systems. Corrosion is such a costly problem for pipes, valves, pumps, and reservoirs that the higher initial expense of more corrosion-resistant materials is often a sound investment. (See chapter 5 for further details.)

Proposed rules for monitoring water quality within the distribution system prescribe a minimum number of samples based on the population served

[35] Safe Drinking Water Committee, *Drinking Water and Health, vo1. 4* (Washington, DC: National Academy Press, 1982).

[36] Robert M. Clark et al., "Distribution System: Cost of Repair and Replacement" paper presented at the Conference on Pipeline Infrastructure, Pipeline Division of the American Society of Civil Engineers, Boston, MA, June 6-7, 1988.

[37] Stephen Maloney et id., *Preventing Water Loss in Water Distribution Systems: Money Saving Leak Detection Programs,* Technical Report N-86/OS (Washington, DC: U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, March 1986).

[38] James Goodrich et al., ''Data Base Development and Analysis for Water Distribution Systems," *Hydraulics and Hydrology in the Small Computer Age-'Vol. 1, Proceedings* of the Specialty Conference Sponsored by the Hydraulics Division of the American Society of Civil Engineers, Lake Buena Vista, FL, Aug. 12-17, 1985.

by the system,[39] and suggest that the number of sites sampled be at least three times the number of the required monthly samples. This represents at least an order of magnitude increase over the number of sites currently sampled.[40] When the bacteriological samples exceed the standards, resampling at five additional sites within the immediate neighborhood is required until the problems disappear or the source of the problems is identified and corrected. The proposed regulations do not provide procedures for locating monitoring stations in a water distribution system and assume that water customers will permit the utility to take samples at the tap on request.

Technologies for Small Systems

Small systems serve only 8 percent of the population, but they account for 93 percent of maximum contaminant level violations and 94 percent of monitoring/reporting violations. Package plants, self-contained units that are premanufactured and shipped to a location, are one way to ensure that a small system has an up-to-date treatment plant. These plants have lower installation and operating costs than conventional treatment plants, and offer highly integrated and compact systems and a high degree of automation.[41] Package plants can be economical up to 2 million gallons per day (MGD), a size that accounts for about 90 percent of U.S. water utilities.[42] While package treatment plants can meet SDWA standards,[43] technology change has been slow. Small systems have not yet been subjected to the same level of enforcement as larger systems, and localities that are not in compliance have not had to make changes to meet the regulations. Thus there is little demand for such systems and little incentive for potential manufacturers.[44]

Where centralized treatment is not feasible or cost-effective or where private wells are common, point of use (POU) equipment can be installed at the tap and provide whole-house or single-tap treatment. The equipment is easy to install, treats only the water used for consumption, simplifies operation and maintenance, and generally has lower capital costs.

Point of entry (POE) devices include water treatment equipment installed outside a home or serving a group of homes or businesses and are accepted by EPA for complying with drinking water regulations. Their major use is in sparsely populated areas.[45] POU devices must be used to remove contaminants that are of concern with ingestion, whereas POE devices should be used when skin adsorption or inhalation of a specific contaminant is of concern.

POU and POE systems are operator-intensive and require regular maintenance, monitoring for contaminant breakthrough, and collection and disposal of contaminated media.[46] They also pose a safety risk; they provide untreated supplies that can be accidentally ingested. POU and POE treatment does not alleviate the responsibility of a water utility to provide safe drinking water to its customers.

Bottled water, while not anew technology, can be an alternative source for drinking water in small communities, although in most cases piped water is less expensive[47] Since human consumption amounts to only about 1/2 to 1 gallon per day, treatment of water to drinking quality may not be necessary at some remote locations. Bottled water is regulated by the Food and Drug Administration and meets EPA SDWA regulations.

[39] 52 *Federal Register* 42224; and 40 CFR 141 and 142 (Nov. 3, 1987), "Drinking Water: National Drinking Water Regulation; Total Coliforms; Proposed Rule."

[40] Rolf A. Deininger and Byung H. Lee, School of Public Health, The University of Michigan, "Monitoring Strategies for Water Distribution Systems," unpublished manuscript, n.d.

[41] Wade Miller Associates, Inc., op. Cit., footnote 4, p. 57.

[42] Richard G. Stevie and Robert M. Clark, "Costs for Small Systems To Meet the National Interim Drinking Water Regulations," *Journal of the American Water Works Association,* vol. 74, No. 1, January 1982, pp. 13-17.

[43] Robert M. Clark and James M. Morand, "Package Plants: A Cost Effective Solution to Small Water System Treatment Needs," *Journal of the American Water Works Association,* vol. 73, No. 1, January 1981, p. 30.

[44] Donna Cirola, Culligan Water Systems, personal communication, Feb. 5, 1990.

[45] Benjamin Lykins et al., "POU/POE Devices: Availability, Performance, and Cost," paper presented at the 1989 ASCE National Conference on Environmental Engineering, Austin, TX, July 10-12, 1989.

[46] Kim R. Fox, "Field Experience With Point-of-Use Treatment Systems for Arsenic Removal," *Journal of the American Water Works Association,* vol. 81, No. 2, February 1989, pp. 94-101.

[47] Daniel A. Okun, in *Proceedings:* Cooperation in *Urban Water Management* (Washington, DC: National Academy Press, 1983), p. 49.

Management and Operating Tools

Technologies to improve the performance of public water systems range from computerized control systems to improved maintenance information systems. Gradually, operators of larger systems are replacing much of their electrical and mechanical control equipment with programmable logic systems that are more reliable and require fewer operator hours.[48]

These systems, called supervisory control and data acquisition systems (see box 4-C), monitor a wide range of data and information on motors, valves, meters, feeders, and sensors, for example, and are oriented to plant operations such as those seen in water treatment facilities.[49] Detroit expects to save at least 20 percent on energy and chemical costs and to boost staff productivity with its new control system.[50] The city also hopes to have better control of the combined sewer system and effluent quality and of supply to its suburban customers.

Maintenance for environmental public works is often neglected and underfunded, leading to higher costs when major repairs are necessary. "It can be five times as expensive to replace sewer pipe after it breaks than to repair it while it is still in one piece: as much as $100 per foot compared to $14."[51] Technologies to improve maintenance performance begin with information systems that tie together information on the facilities and equipment and repair and replacement activities so that managers can have up-to-date information on equipment inventory, current condition, and maintenance and repair requirements. Such information systems enable managers to devise optimum maintenance strategies, perform life-cycle cost analyses, and avoid losses due to maintenance failures.

Condition assessment is becoming a critical function for operating systems as funds for capital facilities diminish and the need to get the most from existing equipment increases. For water supply and wastewater treatment operations, it is especially important because the majority of the investment is underground and out-of-sight. In addition, using inaccurate condition assessments to prepare bid documents for repair projects results in change orders, inefficient contracts, and lost productivity with the contracting agency. (See chapter 5 for discussion of nondestructive evaluation technologies).

The provision of drinking water involves heavy capital expenditures, long lead times in planning and construction, and high freed costs. Construction is often undertaken well in advance of established demand because of the need to take advantage of economies of scale and the need for coordination of other public services in an area. Recent experience coupled with increasing costs for public service provision underscore the lack of analytical models available for predicting future demand. Very little work has been done to develop models that integrate public works information into demand modeling.[52]

Accurate consumption data are needed for preparing billing materials, developing cost-based rate structures, controlling system losses, planning for future demand, and estimating the need and costs for future facilities. Portable hand-held data entry devices, borrowed from the inventory industry, provide savings by eliminating the printing of meter reading cards and reading them into the billing system. Automatic meter reading equipment based on integrated circuitry and advanced telecommunications technology can provide additional cost savings by totally automating this function. The technology utilizes a device that collects information on utility usage, packages it into a data stream, and sends it through a telephone, cable, radio, or power line carrier to a computer for storage and analysis.[53] Benefits include eliminating the extra work and costs involved in "lock-outs," estimates, call backs, and premature cancellations; improving customer service with more accurate and up-to-date

48David Mohler, McNamee, Seeley, & porter, personal communication, Mar. 2, 1990.

49American Society of Civil Engineers, *Proceedings: Critical Water Issues and Computer Applications, 15th* Annual Water Resources Conference (New York, NY: June 1988).

50David Fisher, Detroit Water and Sewerage Department, personal communication Jan. 19,1990.

51 Virginia K@ Dorris, "Systems Link Geography and Data," *Engineering News Record,* vol. 222, June 1, 1989, p. 30.

52Robert M. Clark et al., U.S. Environmental Protection Agency, "Cost Models for Small Systems Technologies: U.S. Experience, " unpublished manuscript, n.d.

53Donald Schlenger, "Telemetering—State of the Art," *Proceedings,* First *International Conference* on *Infrastructure Research, November 15-17, 1988* (Washington, DC: URISA, 1988), pp. 117-138.

Box 4-C—Supervisory Control and Data Acquisition (SCADA) and Distributed Control Systems (DCS)

SCADA systems were initially used by electric power companies to control remote equipment and facilities and to diagnose system failure and monitor operating efficiency in large, geographically dispersed sites. A variant, DCS, is used to control a small number of individual sites close to a central location and is oriented to plant operations. Advances in computer technology have made these systems more affordable and user *friendly enough* to enjoy wide application,[1] and as system costs have dropped,many utility companies have begun to use these systems.

Orlando, Florida's system is designed to automatically monitor and control removal of effluent from the water system. This system uses microprocessors, called master terminal units (MTUs) at each remote ''pressure zone." At each master terminal is a cable-based local area network, similar to those used in many offices today. The MTU's are connected via UHF radio transmission to the central control station. In addition, remote control and data acquisition devices are located at the individual elements of the SCADA system.[2] An operator at a computer terminal can communicate directly with the remote units to control pumps and valves. The effluent removal system can be controlled locally, at the area control center, or remotely, at the central control center. For data acquisition the central computer queries the MTU's, and each MTU queries each local unit. Since the system is distributed rather than centralized, it is easy to diagnose problems and expand system coverage.[3]

These systems make it possible to perform distribution systems analysis in real time and enable the operator to optimize pumping operations and use of water storage facilities, and avoid process and permit violations. At Oakland's East Bay Municipal Utilities District, for example, a DCS monitors sewer system water levels at **eight** remote locations, so that remote treatment facilities can be brought on-line before the main treatment plant **is** overloaded.[4]

[1]Herb Fiddick, Black & Veatch Engineers, personal communication Jan. 12,1990.

[2]Orelan R. Carden, Jr., "Distributed Control Optimizes Wastewater Reuse," InTech, October, 1988, p. 52.

[3]Ibid.

[4]Michael J, Vandaveer, East Bay Municipal Utilities District, personal communication, 1990.

billing information; shortening read-to-bill turnaround and enhancing cash flow; and reducing bad debts. These automated systems can be shared by other utilities, such as gas and electric, as well, reducing expenses for installation and operation. Associated issues involve telecommunications regulations, standardization, cooperation among the utilities, compatibility, legal, and other institutional considerations .54

Decision models can help in budgeting future improvement projects by evaluating resource allocation and maintenance management information within a capital budgeting framework.[55] For example, the additional costs incurred for losses in service and repairs to aging pipes[56] must be considered in the decision process together with a host of other more obvious costs. In addition, cost evaluations for system improvements as well as modifications needed to ensure compliance require more thorough consideration in the decision process. Models are needed to assist decisionmakers with these system details.[57]

Since many of the issues and operations with which local government and local utilities are concerned relate to land or location, a geographic information system (GIS) is a useful tool for

[54]Automatic meter reading configurations include: 1) telephone dial-inbound which uses an electronic meter interface unit (MIU) on the customer'S premises through the telephone companies test equipment without ringing the customer's telephone; 2) telephone dial-outbound in which the MIU dials the utility's computer and transmits the latest meter reading, usually at a preset time; 3) a cable TV-baaed system in which the utility communicates with individual MIUs over the cable to obtain the meter reading; and 4) a radio system in which the MIU transmits to a utility receiver. About 50 percent of the existing systems are telephone systems although these are restricted by court rulings related to AT&T; cable systems are a very small part of existing and potential systems.

[55]Lonnie Haefner, Lonnie Haefner Enterprises, Inc., ''Impacts of Advanced Technology Innovation on Public Worka Management and Decision Making," OTA contractor report, June 28, 1989, pp. 22-28.

[56]Fadi A. Karaa et al., ''Budgeting of Water Distribution Improvement Projects," *Journal of Water Resources Planning and Management*, vol. *113, No. 3*, May *1987, pp. 378-391.*

[57]Robert M. Clark et al., ''A Spatial Costing System for Drinking Water,'' *Journal of the American Water WorksAssociation*, January 1982, pp. 18-26.

planning, management, and operations.[58] A GIS can assist utilities in collecting, storing, analyzing, and disseminating data and information. A GIS also has the ability to manage and display graphic map images, to manage large volumes of nongraphic data that are related to a geographic location, and to perform various retrieval and analytical functions on the combination of graphic and nongraphic data. Public works agencies, departments of transportation, port authorities, and planning organizations have recognized the value of these systems to store, manage, and integrate several related databases.[59] (See chapter 5 for discussion of geographic information systems.)

Wastewater Treatment

Wastewater is a significant component in the water cycle because all treated (and some untreated) wastewater flows into the Nation's waterways. Wastewater (sewage) treatment includes the facilities and activities needed to collect, transport, and treat residential, commercial, and industrial wastewater, and, in the case of combined sewers, surface runoff and groundwater. The Nation has more than 15,000 publicly owned treatment works (POTWs), which can treat approximately 37 billion gallons per day (see table 4-3). Commercial establishments and about 160,000 industrial facilities also discharge their wastes into collection systems served by POTWs. About 39,000 industrial facilities discharge effluent (most of it treated) directly into waterways.

POTW system components include collector sewers, interceptor sewers, combined sewers for wastewater and storm water, flow equalization facilities, wastewater treatment plants, on-site systems and septic tank systems.[60] Collection systems range from low-capacity sanitary sewers that transport wastes from homes to higher capacity sewers that transport industrial sewage and storm water to wastewater treatment plants. Higher capacity sewers consist of both interceptor sewers (that use gravity for transport) and force mains (that use pumps to transport to interceptor sewers at a higher elevation).

Table 4-3-Size, Number, and Capacity of POTWs in the United States

Actual flow range (MGD)	Number	Capacity (MGD)
0.01 -0.1	4,960	251
0.11 - 1.0	7,003	2,671
1.01 - 10.0	2,893	9,372
10.01+	577	24,383
Totals	15,433	36,677

POTW Treatment Levels

Level of treatment	Number	Capacity (MGD)
Less than secondary	2,122	5,529
Secondary	8,403	15,714
More than secondary	3,115	14,373
No discharge	1,762	973
Unknown	46	88
Totals	15.448	36.677

KEY: MGD _ million gallons per day.
POTWs = publicly owned treatment works.

SOURCE: Apogee Research, Inc., from U.S. Environmental Protection Agency, 1986Nee& *Survey Report to Congress: Assessment of Publicly Owned Wastewater Treatment Faclities in the United States* (Washington, DC: February 1987), p. 4.

Combined sewers transport both wastewater and storm water to wastewater treatment facilities. Flow equalization facilities are sometimes used to store wastewater during storm events and discharge to the wastewater treatment plant during low-flow periods. At the wastewater treatment plant, pollutants are removed and/or treated by screening, settling, biological treatment, and disinfection.

Primary treatment removes settleable solids. Prior to the 1972 Clean Water Act this was the maximum amount of treatment provided by most treatment plants. Secondary treatment removes 85 percent of oxygen-demanding materials and suspended solids and destroys most bacteria by disinfection. All municipal plants must now provide at least this level of treatment. Advanced treatment using chemicals and filtration can remove over 99 percent of pollutants from wastewater. All processes except disinfection produce a sludge that must be disposed of by incineration, by application on the land, or by burying it in landfills.

[58] Rebecca Somers, "GeographicInformation Systems in Local Government: A Commentary," *Photogrammetric Engineering and Remote Sensing*, vol. *53, No.* 10, October 1987, pp. 1379-1382.

[59] "Locational Referencing and Highway Segmentation in a Geographic Information System," *ITE Journal*, March 1990, pp. 27-31.

[60] About 25 percent of the U.S. population is served by septic tank/soil absorption systems. James Kreissl, "Alternative Sewers in the United States," paper presented at the 1985 International Symposium on Urban Hydrology, Hydraulic Infrastructures and Water Quality Control, University of Kentucky, Lexington, KY, July 23-25, 1985.

Photo credit:American Safety of Civil Engineers

Pretreatment and treatment programs are aimed at ensuring that industries adequately treat wastewater before discharging Into rivers, streams, and sewers.

Wastewater Treatment Regulation

Until 1972, responsibility for controlling water pollution rested primarily with State and local governments. With the passage of the Federal Water Pollution Control Act of 1972 (Public Law 92-500, the Clean Water Act), Congress significantly increased the Federal role in water quality,[61] and increased Federal assistance for the construction of wastewater treatment plants. EPA was made responsible for setting water quality standards, developing water quality criteria, establishing technology-based effluent limits, and developing a national system of discharge permits.

The Clean Water Act replaced in-stream water quality standards with limits on the pollution levels of discharge from municipal treatment plants and industrial point sources. EPA established the National Pollutant Discharge Elimination System (NPDES) permit system, which made Federal approval mandatory for every point source of wastewater discharge. To ensure permit approval, localities were required to use technologies for wastewater treatment approved by EPA, even if a lower degree of treatment would not reduce water quality.

Pretreatment and treatment programs are aimed at ensuring that POTWs and industry adequately treat wastewater before discharging it into rivers, streams, and sewers. Pretreatment programs are designed to prevent the passage of toxic substances into waterways. When pretreatment fails, toxic substances can kill or inhibit the growth of bacteria that remove pollutants in treatment processes, and interfere with plant operations, contaminate sewage sludge, and create safety and health hazards. Nonetheless, many cities do not bring strong enforcement actions against industries that violate pretreatment requirements.[62]

More flexible regulatory strategies could reduce treatment costs if they include trading between point/nonpoint sources. Reducing pollutant loadings through nonpoint source controls maybe considerably cheaper than increasing treatment standards at the local sewage treatment plant. Even though $400 million was authorized for a nonpoint source program in the 1987 reauthorization of the Clean Water Act, no money was appropriated, and EPA has been slow to implement trading programs.

Wastewater Treatment Issues

Wastewater treatment requirements are being stiffened, and new standards for toxic chemical controls dictate that sludge treatment, handling, and disposal receive more attention. Toxics emitted in off-gases from treatment facilities have already become a major air pollution problem in some U.S. cities. The major issues facing POTWs are discussed below.

Upgrading Existing Facilities

Many POTWs must upgrade facilities to meet NPDES permit requirements that increase treatment requirements, improve plant performance, and meet increased demand from growing communities. Although routine maintenance becomes very costly as systems age, the significant investment in existing facilities and the high cost of replacement may make

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[61] Prior legislation includes the Rivers and Harbors Act of 1899, the Water Pollution Control Aet of 1948 and several subsequent laws (see table 4-1).

[62] U.S. General Accounting Office, *Improved Monitoring and Enforcement Needed for Toxic Pollutants Entering Sewers,* GAO/RCED-89-101 (Washington, *DC: 1989).*

repair and rehabilitation of the present system a cost-effective choice.[63]

Infiltration of groundwater and the flow of rainwater and surface runoff into sanitary sewers increase the demand on treatment facilities and can, on occasion, overload them. Flow surges caused by infiltration or inflow can force the bacterial solids used in the treatment process out of the plant, reducing treatment efficiency for long periods. Broken pipes, defective pipe joints, illegal connections of foundation drains, cross connections between storm sewers and sanitary sewers, and illegal connections with domestic storm drain systems are common reasons for flow surges.[64] Many communities already treat as much as one-third more wastewater than necessary because of cracked or loosely fitting sewer pipes.[65] These problems can be solved by a combination of sewer line repair/rehabilitation, adding flow equalization facilities, and increasing treatment plant capacity. However, plant operators are often unable or ill-equipped to collect the data needed to assess and correct these problems.

Combined Sewer Overflows

Combined sewers are conduits that transport domestic and industrial wastewater during dry weather conditions and storm water runoff during wet weather. Combined sewer systems currently serve 12,000 communities nationwide, but approximately 60 communities account for over 80 percent of the total area served by combined sewers.[66]

When storm water runoff exceeds the capacity of the treatment facility, the combined sewer overflow (CSO) enters a receiving water without being treated. Because these discharges are subject to the Clean Water Act regulations, prohibiting discharges with less than secondary treatment, storms create potential for violations and enforcement actions for many communities.

Managing the storm water flows to bring CSO discharge points into compliance has evolved from simple removal of runoff to comprehensive appreaches.[b7] Control measures include nonstructural methods, such as improved urban development and resource planning, natural drainage, sewer ordinances and discharge permits, chemical use controls, surface sanitation, and erosion and sedimentation control. Structural controls, often the most feasible alternative in heavily developed urban areas, include onsite storage and infiltration facilities, overland flow modification, and solids separation. Successful and cost-effective storm water management strategies integrate several appropriate, feasible, and economic components for control.[68]

Sludge Management

The addition of chemicals in coagulation, softening, and settling operations yields an unwanted byproduct-sludge. The Nation's POTWs produce about 7.7 million metric tons of sludge annually and production will probably double by the end of the century, since higher level treatment of wastewater will increase sludge production. Sludge management and disposal can consume from 30 to 60 percent of a wastewater treatment operations and maintenance budget.[69] Sludge-related problems include odor objections, incinerator ash disposal, public acceptance of land disposal, and the potential for high concentrations of toxics in sludge. Because of the chemicals used in water treatment and the solids that precipitate out in the treatment process, the sludge can be classified as a hazardous waste. When this occurs, the cost of sludge disposal can exceed the capital and operating costs of treated drinking water.[70]

63U.S. Environmental Protection Agency, Center for Environmental Research Information, *Handbook: Retrofitting POTWs*, EPA/625/6-89/020 *(Cincinnati,* OH: July 1989), p. 1.

64U.S. Environmental Protection Agency, Office of Municipal Pollution Control, *Infiltration and Inflow Analysis and Project Certification* (Washington, *DC:* May *1985).*

65Discussions at the Environmental Protection Agency "Municipal Wastewater Treatment Technology Forum," Ann Arbor, MI, June 6-8, 1989.

66U.S. Environmental Protection Agency, *Combined Sewer Overflow Toxic Pollutant* S@, EPA 440/1-84/304 (Washington, DC: A@ 1984), pp. 5, 10.

67J. Marsalek, "Stormwater Management Technology: Recent Developments and Experience," NATO *Urban WaterResources AdvancedResearch Workshop, June 22-27,1989, Douglas, Isle of Man,* presentation preprints (Brussels: North American Treaty Organization, 1989), p. 1%.

68Ibid., p. 209.

69Richard Kuchenrither, Black& Veatch Engineers, personal communication Feb. 13, 1990. As transport costs increase and treatment options diminish, the percentage of total costs is likely to increase.

70"Water Treatment," op. cit., footnote 209p. 5.96.

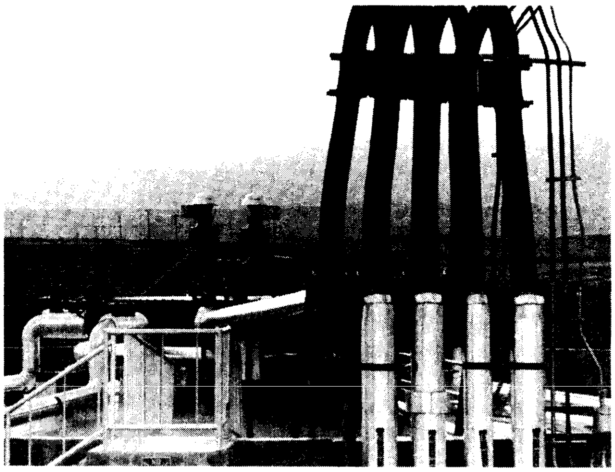

Photo credit: American Consulting Engineers Council

Sludge management, using new equipment (such as that pictured here), and disposal can consume from 30 to 60 percent of a wastewater treatment operations and maintenance budget.

Legislation in 1988 prohibited sludge disposal in the ocean. Although EPA has little information on sludge types, characteristics, quality, amounts, and fate, its proposed rulemaking for disposal makes conventional methods difficult to pursue. The new rules imply support for beneficial use and land application,[71] and will increase sludge reporting and recordkeeping requirements for POTWs.[72] The regulations are risk-based and cover five different types of sludge disposal: incineration, nonagricultural land application, agricultural land application, distribution/marketing, and monofills/surface impoundments. A sludge survey of 200 POTWs will be completed by EPA in mid-1990 and should prove helpful in determiningg the nature and extent of sludge management problems.

Air Toxics

Wastewater treatment is fast becoming an issue in air quality debates. Air quality districts in California have proposed regulating air contaminants from POTWs by requiring additional monitoring and analyses of air toxics, changes in wastewater treatment facilities, and changes in plant operation and maintenance. The proposed regulations include ". . . newly regulated substances, some of which are not detectable in wastewaters entering POTWs."[73] Control measures will involve pretreatment or product substitution, air flow management, and the use of best available technologies. Activated carbon adsorption is a candidate technology, but little is known about its use for removal of VOCs in the wastewater treatment environment. No other methods have been demonstrated in research or commercial facilities for air toxic control.[74] Attempts at remediation of air toxics have brought severe corrosion problems for POTW facilities.[75] Furthermore, little is known about the limitations of existing technologies for treating toxics in exhaust gases from treatment facilities.

Nonpoint Sources

Treated wastewater often contaminates drinking water sources less than nonpoint sources (NPS). The five major contributors to NPS pollution are farms, urban areas, construction sites, mines, and forests where logging is conducted. Contaminants range from sediments and pesticides to spilled solvents and asbestos brake linings. Because NPS pollutants, mostly heavy metals, sediment, and salinity, come from thousands of diffuse sources, controlling them will require monitoring and changing the daily activities of individuals and businesses in every watershed. Agricultural activities, such as tillage practices and animal waste management, are the greatest source of NPS pollution, accounting for 70 percent of the total nitrogen and phosphorus deposited in surface waters.[76] NPS pollutants are the limiting factors in improving or maintaining water quality for both surface water and groundwater. "If Federal and state clean water regulations were totally successful in eliminating pollution from

[71] "Standards for& Disposal of Sewage Sludge," U.S. Environmental Protection Agency Proposed Rule, *Federal Register*, PP. 5746-5902 (Feb. 6, 1989). A range of professional groups, including the Cooperative State Research Service Technical Committee W-170 in its Peer Review Report published July 24, 1989, has raised questions about the scientific and risk assessment methods and quality of data used by the Environmental protection Agency to develop this proposal.

[72] Industrial pretreatment programs can improve sludge quality dramatically and make sludge qualities for all but a few POTWs suitable for beneficial use. Kuchenrither, op. cit., footnote 69.

[73] Kris P. Lindstrom, K.P. Lindstrom, Inc., and Farouk T. Ismail, State Water Resources Control Board, "The Impact Of Toxic Air Q@.@ Regulations on California Publicly Owned Treatment Works: Final Report for the State of California," October 1988, pp. 1, VI-1.

[74] 1bid., p. VI-5.

[75] Blake Anderson, director of technical services, Orange County Sanitation Districts, personal communication, June 6, 1989.

[76] Lyse D. Helsing, "Water Treatment: Solving the Second Generation of Environmental problems," *Chemical Week*, vol. 142, May 18, 1988, p. 32.

(single sources like wastewater treatment plants that convey their pollutants to the stream in a pipe) the Arkansas River would be little changed from the polluted river it is today."[77] Nationally, EPA reports that 65 percent of all water pollution comes from NPS sources. In Western States, with fewer people and less industry, that figure is often closer to 90 percent, and nearly every river is affected.

Wastewater Treatment Technologies

A few systems rely on advanced instrumentation (see box 4-C in section on drinking water) and nondestructive evaluation techniques for locating leaks and breaks, and assessing the condition of the system, including plant, the pipes, and connectors. However, most systems lack accurate information on facility condition.

Pipe and Collection System Technologies

Underground construction, rehabilitation, and pipe replacement using trenchless technologies (equipment that makes it unnecessary to dig trenches to remove or replace pipes) can be extremely cost-effective. Direct savings come from reduced trenching and shoring work and reduced surface restoration requirements. In urban or developed areas, delays due to construction and disruption to buildings and surface plantings are very costly. Indirect benefits include reduced road closures and rerouting of traffic, and reduced destruction of difficult to replace items such as trees, shrubs, and gardens. A variety of trenchless technologies provide widely different benefits.[78] (See chapter 5 for additional information about trenchless technologies.)

Collection system technologies include sewer separation, inlet controls, sewer pipe controls, and severe flow control by overflow regulators. They can also include real-time control of sewer flow and pollutant routing by using peripheral monitoring and telemetry stations and computer-based sewer and pollutant flow prediction methods. Real-time control systems also permit operating the sewer system remotely to release overflows of less polluted batches of combined sewage at points where the environmental impact is the least.[79]

Storage tanks or tunnels outside the sewer system, but connected to it, permit stored combined sewage to be drained during off-peak periods into the wastewater treatment plant. Such facilities allow modifying flow patterns, reducing overflows, and some treatment of the stored volume by sedimentation.[80] They also serve as flood protection and hazardous spill containment during dry weather.[81]

Corrosion can also be a serious problem for concrete and other materials used in sewers, and alternative pipe materials are being examined for their durability and reliability. In sewers the corrosion is generally caused by acids, such as hydrogen sulfide, or by industrial chemicals and solvents. Using lined concrete pipes has prevented corrosion in a number of systems, most notably in southern California where communities that installed the lined pipes have had few corrosion problems. Neighboring systems that chose to use unlined concrete pipes to save initial costs have suffered excessive corrosion. (See chapter 5 for more information on materials and corrosion.)

Treatment Plant Technologies

Treatment plant technologies encompass pretreatment, physical processes, advanced treatment (physical, chemical, and biological), natural systems, disinfection, treatment plant instrumentation, control, and operations. While new technologies can bring real benefits, systems investing in new equipment or turning to new processes are likely to encounter new maintenance problems.

Filters and membranes are increasingly important in advanced wastewater treatment, particularly as materials and manufacturing techniques bring production improvements and lower costs. An advanced wastewater treatment plant in Orange County, California, reclaims treated municipal wastewater for injection into an underground seawater barrier system. The process, which meets

[77] *High Country News*, vol. 21, No. 22, Nov. 20, 1989, p. 11.

[78] D.T. Iseley, Department of Civil Engineering, Louisiana Tech University, "Trenchless Technology-Alternative Solutions to Complicated Underground Utility Nelwork Problems," seminar notes, Second Annual Alumni Appreciation Seminar, Ruston, LA, Nov. 3, 1989.

[79] Ibid., p. 206.

[80] Ibid., p. 207.

[81] Richard Field, "Urban Stormwater Runoff Quality Management: Low Cost Structurally Intensive Measures and Treatment," *Urban Runoff Pollution, NATO* ASI Series G: Ecological Sciences 10 H.C. Torno et al. (eds.) (Heidelberg, Germany: Springer-Verlag, 1990), pp. 677-699.

current EPA drinking water standards, includes reverse osmosis for removal of both organic and inorganic compounds. (See discussion in water treatment section of this chapter.)

Polymers (long, charged hydrocarbon chains) mixed with ferric chloride electrochemically precipitate out suspended particles. Polymer technology has proven successful for advanced primary treatment, because polymers can eliminate up to 85 percent of the suspended solids that remain after secondary clarification. (A secondary treatment plant that is operating properly removes about 85 to 93 percent of influent, suspended solids.)

Although EPA has recently emphasized removing toxics within the plant and using filtration to reduce toxicity, POTWs do not have the equipment or monitoring devices to identify and measure toxics at their facilities. Moreover, information about the nature and amounts of toxics released into municipal waste streams from industrial facilities rarely reaches POTWs.

Sludge Disposal

EPA defines and regulates any residual with a portion of sludge as sewage sludge.[82] Sludge has beneficial plant nutrients and soil conditioning properties, and estimates suggest that nearly 40 percent of municipal sewage sludge is applied to land in the United States. However, sludge contaminants, such as heavy metals, and organic carcinogens and pathogens, must be reduced so that land application does not create a potential health or safety threat.[83] A recent study of the technologies available for sludge disposal listed five primary options: 1) comporting, 2) heat drying, 3) land application, 4) landfilling, and 5) incineration.[84] (See box 4-D for more information.)

Technologies for Small Rural Systems

Many rural communities rely on individual, onsite septic systems to treat wastewater. Although such systems are often inexpensive and cost-effective, age, lax maintenance, thin or poor soil, and a simple lack of space have contributed to septic systems failures or untreated sewage polluting groundwater and entering ditches and streams. Problems are widespread; 80 percent of counties surveyed in one study reported system failure and potential contamination of groundwater and surface water.[85] Moreover some States and counties are not enforcing local sanitation and land-use codes, and in some cases, the codes themselves have led to failures.[86]

Lower cost alternatives to conventional gravity systems include pressure sewer systems, vacuum sewer systems, and small diameter gravity sewers. Pressure systems, which depend on pumps to move wastes from the customer location to the pressure main, are dependent on pump and grinder technology. Vacuum systems use a vacuum to draw wastes into a collection main and then into a collection tank before being pumped to a treatment facility. Small diameter gravity sewers are connected to septic tanks that collect dirt, grease, and solids and prevent them from entering the main collection system. Each of these systems has been used advantageously in rural communities and has unique characteristics that recommend its use under specific circumstances. Thus they demand more of the design engineer than conventional systems. Moreover, even with improvements in materials and design, each of these systems requires regular maintenance and access to on-lot facilities for maintenance and emergency repairs.

Natural systems, aquatic plant systems, land treatment, and wetlands can provide waste treatment for the substantial range of hydraulic and pollutant loading and temporal fluctuations that are characteristic of small systems.[87] Aquiculture systems have

[82] U.S. Department of Agriculture, Cooperative State Research Service Technical Committee W-170, "Peer Review—Standards for the Disposal of Sewage Sludge," unpublished report, July 24, 1989.

[83] U.S. Environmental Protection Agency, Center for Environmental Research Information *Control of Pathogens in Municipal Wastewater Sludge*, EPA/625/10-89/006 (Cincinnati, OH: September 1989).

[84] Black & Veatch, Inc. "Draft Report on Assessment of Technologies," prepared for the Massachusetts Water Resources Authority, Feb. 27.1987.

[85] Study by the American Planning Association for the Illinois Department of Energy and Natural Resources, cited in Paul Tarricone, "Big Trouble in Little America," *Civil Engineering, vol. 59, No. 8,* August 1989, pp. 57-59.

[86] Ibid., p. 58; and James Kreissl, U.S. Environmental Protection Agency, personal communication, Jan. 24, 1990.

[87] U.S. Environmental Protection Agency, Office of Research and Development, Center for Environmental Research Information, *Design Manual: Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment,* EPA/625/1-88/022 (Cincinnati, OH: September 1988).

Box 4-D—Sludge Handling Techniques

Aerobic composting involves the decomposition of sludge organics by microbiological organisms in the presence of oxygen. Nuisance odors can be produced if anaerobic organisms replace the aerobic organisms due to reduced oxygen supply. The end-product can be used as a soil conditioner, or it can be co-composted with municipal solid waste, although the result is a poor-quality product.

Heat drying is used to dewater sludge, generally after mechanical dewatering; and the end-product is a soil conditioner. The specific techniques used include rotary drum dryers, rotary disc dryers, multiple-effect evaporation, and flash drying. Because of the capital costs and operating and maintenance costs, and the operating complexity of these systems, they are used primarily by large POTWs.

Land application refers to the surface application of dewatered sludge and the surface application or below surface injection of liquid sludge to agricultural or other land. Land application is limited by the possible detrimental effects of surface runoff, groundwater leachate, and odors. It is most suitable to small communities because of the large land areas required, but large cities have used the technique as well.

Sludge or sludge ash from combustion can be placed in landfills after sludge is preprocessed by stabilization, dewatering, or some form of chemical treatment to minimize environmental impacts. The freeze-thaw method of dewatering sludge raises by 20 percent the amount of solids after the freeze-thaw cycle; further drying raises the increase to over 50 percent. Such high concentrations are virtually impossible with mechanical dewatering equipment. This method is best suited to small and moderate-size communities in the northern tier of States.[1] Current problems with landfilling are the limitations of existing landfills and problems of siting new landfills.

Sludge can be incinerated and the heat from exhaust gases recovered to produce hot water or steam. Incineration exhaust gases can contain pollutants such as the oxides of nitrogen and sulfur, carbon monoxide, unburned hydrocarbons, and airborne particulates. The ash produced, about 20 to 40 percent of the volume of the sludge solids, may contain heavy metals. Its composition, including ash leachate and chemical characteristics, will determine the appropriate disposal technique, most likely landfilling. Sludge incineration can include co-combustion with processed municipal solid waste or fossil fuels, although this limits the volumes of sludge that can be disposed of and makes the incinerator ash more complex.

Although each technique has limitations for POTW sludge disposal, other methods of sludge disposal have undergone some testing, including:

- *Earthworm conversion*—This does not reduce volume, and the worm population is susceptible to injury from sludge ingredients, cold temperatures, and ammonia.
- *Fuel, made from sludge mixed with alkali and heated under pressure*—Laboratory tests have proven successful, but scale-up and commercialization have not occurred.
- *Oxyozosynthesis or pelletized sludge*—The existing batch process is low capacity.
- *Pyrolysis and gasification*—No full-scale systems exist.
- *Road aggregate production*—The reliability and marketability of large quantities of the product are unknown.
- *Wet-air sludge oxidation via a vertical-tube reactor process*—The commercial process exists, but no facilities are in operation.

[1]U.S. Environmental Protection Agency, "Innovations in Sludge Drying Beds—A Practical Technology," pamphlet, October, 1987; and S. Reed et al., "A Rational Method for Sludge Dewatering via Freezing," *Journal of the Water Pollution Control Federation*, vol. 58, September 1986, pp. 911-916.

been studied for several years, but have limitations, such as climatic effects, pest control, and anaerobic conditions.[88] Rapid infiltration land treatment uses specially constructed basins for draining partially treated wastewater that seeps through the earth, joins the groundwater, and eventually emerges in adjacent surface waters. In some systems treated water is directed to underdrains or storage basins for future use in irrigation.[89]

Wetlands can effectively remove or convert large quantities of pollutants, including organic matter,

[88]Kreissl, op. cit., footnote 86.

[89]U.S. Environmental Protection Agency, Center for Environmental Research Information, ***Design Manual for Land Treatment of Municipal Wastewater--Supplement on Rapid Infiltration and Overland Flow,*** EPA 625/1-8 l-013a (Cincinnati OH: October 1984).

Photo credit:American Consulting Engineers Council

Natural systems and wetlands can provide effective waste treatment for small systems or, as pictured here, drainage for stormwater overflows for larger immunities.

suspended solids, metals, and excess nutrients from point sources and nonpoint sources. Natural filtration, sedimentation, and other processes help clear the water of many pollutants. Some are physically or chemically immobilized and remain still until disturbed; decomposition breaks down other compounds into simpler substances. Research into wetlands for treating discharges from mining operations indicates the potential for successful treatment, with some limitations, especially during cold weather periods.[90] However, the mechanisms that modify and/or immobilize pollutants, especially toxic substances, in wetlands are poorly understood. No adequate design criteria have been established, and wetlands systems operate more like experiments.[91] No long-term operating data exist to confirm that manmade wetlands can continue to function reliably for long periods of time as natural wetlands have. Other disadvantages include the large land area requirements for treatment, the lack of understanding of important biological and hydrological process dynamics, and possible problems with pests.

Operations and Maintenance Technologies

EPA has developed an evaluation methodology for determiningg specific causes of inadequate POTW performance. The first step is a review and analysis of a POTW's design capabilities and administrative, operational, and maintenance practices[92] to determine if significant improvements in treatment can be achieved without major capital expenditures. Typical performance limiting factors are inadequacies in staffing, understanding of process adjustments, and maintenance programs.[93] The

[90] Thomas R. Wildeman and Leslie S. Laudon, "The Use of Wetlands for Treatment of Environmental Problems in Mining: Non-Coal Mining Operations," paper presented at the International Conference on Constructed Wetlands for Wastewater Treatment, Chattanooga TN, June 1988.

[91] Many small cities in the South use lagoons for sewage treatment. The addition of rock/reed filters creates an inexpensive system for wastewater treatment. Such falters are, however, subject to clogging. Jon Craig, chief for Wastewater Construction Grants, Oklahoma State Department of Health, personal communication, June 1990.

[92] U.S. Environmental Protection Agency, *Handbook: Improving POTW Performance Using the Composite Correction Program Approach (Cincinnati,* OH: October 1984).

[93] Ibid.

second step consists of implementing corrective measures to achieve desired effluent quality, and compliance with permit requirements. Environment Canada has successfully demonstrated an operational process audit technique that uses a microcomputer-based, real-time monitoring system with extensive instrumentation to analyze operational improvements.[94] This technique could be used as part of a correction program to obtain additional information.

Computerized control systems can be applied to wastewater treatment facilities in much the same manner as for drinking water treatment. (See discussion on operations and maintenance in water supply section.) Such systems can take undercapacity treatment units off-line and/or use them to equalize flow; they can also equalize flows to use off-peak electricity, recover waste heat, and monitor and optimize chemical dose rates. Expert systems, a branch of artificial intelligence, can be designed to provide assistance to POTW personnel charged with operating and maintaining complicated wastewater treatment processes. Prototype systems have been developed to diagnose problems associated with activated sludge treatment plant operations. Since studies have shown that treatment plants exhibit more problems due to faulty operation than any other cause, expert systems might prove useful in closing the gap between design capability and operational performance.

Planning and Management Tools

Reclaiming or reusing treated wastewater, primarily for nonpotable purposes, is not a new concept; water shortages caused by droughts, the rising costs of developing reliable water supplies, and modem wastewater treatment technologies are making reuse projects more economically attractive than ever.[95] California alone had nearly 400 nonpotable reuse projects by 1985;[96] Florida lists 188 recovered water reuse systems. Nonpotable uses include agricultural irrigation, industrial processing, and toilet flushing. To meet water quality requirements, reused water must be adequately disinfected and a chlorine residual must be present.[97]

Florida adopted a rule in 1988 that includes a mandatory reuse of reclaimed water in critical water supply problem areas.[98] The State's five water management districts will designate critical areas and will implement the program through their permitting program for recovered water. The State has developed comprehensive rules on water reuse, particularly for irrigation in public access areas, of residential property, and of edible crops. Specific requirements have been set for preapplication treatment, reliability, operation control, buffer zones, storage, cross-connection control, and other features. The driving force for water reuse in Florida has been effluent disposal rather than water shortage due to low stream flows. Applicants for surface water discharge permits must demonstrate that reuse of domestic reclaimed water is not economically or technologically feasible for them.[99]

Municipal Solid Waste[100]

Man has long used open dumps and landfills to dispose of solid waste, and early landfills were considered a way to fill in or "reclaim" land areas that were considered unusable otherwise.[101] By the 1970s, hydrogeological investigations showed that in many locations, harmful liquids were leaching through the soil into the groundwater supply, and the search for alternatives for municipal solid waste (MSW) disposal was on. Planning and constructing new landfills began to require extensive subsurface investigations to determine hydrogeological and geotechnical conditions that affect contaminant discharge from waste sites. However, landfill cri-

[94] Gordon Speirs, "Wastewater Treatment Plant Recess Audit," paper presented at the 1989 Municipal Wastewater Treatment Technology Forum, U.S. Environmental Protection Agency, Ann Arbor, MI, June 6-8, 1989.

[95] Daniel A. Okun, "Water Reuse in Developing Countries," paper presented at the Annual Conference of the Water Pollution Control Federation, San Francisco, CA, Oct. 17,1989.

[96] Okun, op. cit., footnote 16, p. 26.

[97] Ibid.

[98] Reclaimed water is water that has received at least secondary treatment and is reused after flowing out of a wastewater treatment plant.

[99] David W. York and James Crook, "Florida's Reuse Program: Paving the Way," paper presented at the 62d National Conference of the Water Pollution Control Federation, San Francisco, CA, Oct. 17, 1989.

[100] This section is based on U.S. Congress, Office of Technology Assessment, *Facing America's Trash: What Next for Municipal Solid Wrote,* OTA-O-424 (Washington, DC: Us. Government Printing Office, October 1989).

[101] William L. Rathje, "Rubbish," *The Atlantic Monthly,* December 1989, P. 103.

teria promulgated in 1979 by EPA had little immediate effect on the practices at MSW sites, and almost 80 percent of MSW still ends up in landfills.

Disposal of MSW is primarily a local responsibility. However, new criteria, proposed in 1988 and now under revision, would extend Federal control over landfills and include regulations on location, facility design, operating criteria, groundwater monitoring, financial assurances, and postclosure responsibilities. According to EPA, most MSW landfills do not have equipment to monitor air, surface water, or groundwater for pollutants. As of November 1986, only about 35 percent monitored groundwater, 15 percent monitored surface water, 7 percent monitored methane gas, and 3 percent monitored other air emissions.

The majority of MSW landfills, 86 percent, are publicly owned, and most are small, receiving less than 30 tons per day. Privately owned landfills tend to have more capacity; one representative of private operators estimated that about 50 percent of total landfill capacity may be privately owned,[102] Perhaps because their larger size gives them economies of scale and because of more stringent State regulations promulgated in recent years, privately owned MSW landfills are more likely to have leachate collection systems, groundwater monitoring, and surface water monitoring.

Issues

EPA predicts that about one-third of all existing landfills will close by 1994, and that 80 percent of currently operating landfills will close in the next 25 years.[103] Many of these are old landfills that cannot meet the requirements of the Resource Conservation and Recovery Act. Few new, technologically advanced landfills have opened, accelerating the decline in capacity.[104]

However, raw data on landfill closings does not provide a complete picture. While landfill capacity in many States, such as New Jersey, Florida, Massachusetts, and New Hampshire, is running low, some States have expanded their landfill capacity.

Photoo *credlt:* Office of Technology Assessment

About 80 percent of municipal solid waste is disposed of in landfills, most of which do not have equipment to monitor air, surface water, or groundwater for pollutants.

Pennsylvania, for example, closed 13 MSW landfills in the last 2 years, but available capacity has actually grown from 4.2 years to 5.5 years, because the State permitted one very large, new facility to open and allowed two others to expand.

Regulatory Concerns

EPA has issued guidance on pollution controls considered to be "Best Available Control Technology." Although regulations regarding emissions were issued in late 1989, those regarding ash will not be issued until Congress clarifies whether or not ash will be managed as hazardous waste. In the absence of clear Federal guidance, several States have issued their own emissions and ash management guidelines and standards. A meeting of leading experts in incinerator technology organized by the U.S. Conference of Mayors endorsed recycling and waste reduction and found that technologies exist today to control pollutants from incinerators to levels of risk

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lo%. Prindiville, personal communication, November 1988, as reported in Office of Technology Assessment, Op. cit., footnote 100.

103Most environmentally sound landfills are designed with a lifespan of about 10 years. At any given moment, one-half of these landfills will be full in 5 years.

104Howard Levenson, senior associate, Office of Technology Assessment, personal communication, Dee. 7, 1989. In addition, finding new sites for new landfills is a major problem, particularly in Northeastern States.

below regulatory concern.[105] Mercury and chromium, however, remain vexing problems in emissions and in incinerator ash.

Recognizing the limitations of current knowledge, EPA is coordinating with industry, States, and universities to develop a research and development R&D) agenda. Study areas are likely to include emerging commercial technologies, appropriate MSW incinerator operating conditions and emissions control technology, ash management, landfill design and operation, siting and monitoring methods, recycling techniques, and toxic products substitutes.[106]

Institutional Concerns

About 10 percent of U.S. solid waste is recycled, and most observers believe more MSW could be recycled. The major roadblocks are not technologies, although some technical refinements could provide measurable increases. EPA is promoting a national recycling goal of 25 percent by the year 1992, although the goal does not appear to be based on a quantitative evaluation of the market potential of individual MSW components. Some components, such as office paper and aluminum, are "supply-limited," that is, they are not collected in sufficient amounts or are too highly contaminated for current manufacturing processes. Others, such as used oil and newspapers, are "demand-limited," because markets for them are insufficient, even though supplies may be available. These distinctions are not constant and may change due to many factors.

Pricing is the other serious market consideration, one made complex by fluctuations in markets for recycled products. Increased public sector collection of recycled materials provides a supply of materials that is not sensitive to demand. Municipal collectors can even afford to pay manufacturers to take materials, if doing so is less expensive than disposal. This means that private sector suppliers may have difficulty marketing their recycled goods, which would drive down profits and reduce the employment and tax revenue they generate. Municipalities must thus consider their recycling policies and programs carefully.

Although MSW is primarily a local responsibility, States have begun promoting incentives for multicommunity facilities or for nonlandfill waste disposal, and some States are providing financial assistance to communities. Maryland's Solid Waste Facilities Loan Program provides loans to local governments to improve environmental and human health aspects of their solid waste programs. Since 1983, over $1.4 million has been obligated for loans from State general obligation bonds.

Minnesota established the Solid Waste Processing Facilities Capital Assistance Program in 1980 to assist counties in moving from landfills to recycling and resource recovery for solid waste. Priority is given to programs developed under joint powers agreement between counties. Grants totaling $20.2 million have been awarded from the General Fund since 1980. Minnesota also established the Waste Management Board in 1980 as an independent agency of the State. Its purpose is to provide technical, financial, and planning assistance for solid and hazardous waste management to communities and technical assistance to industry in recycling, resource recovery, and hazardous waste management. The Legislative Commission of Waste Management provides oversight of the board's grantmaking and advocacy to facilitate waste management.

MSW Technologies

MSW technologies include landfill liner materials, collection and treatment of leachate, monitoring and controlling landfill gas and other potential contaminants, comporting and other processing equipment, and techniques and equipment for better subsurface analysis.[107]

Landfill Liners

Liners are used at the bottom of a landfill to prevent or reduce migration of leachate (liquids that percolate through the landfill carrying contaminants) into groundwater beneath the site or away

[105]Water Schaub, U.S. Conference of Mayors, personal communication, Oct. 13, 1989. Regulatory concern relates to a one-in-a-million chance of a person over a lifetime developing a health problem linked to an incinerator.

[106]U.S. Environmental Protection Agency, office of Solid Waste, *The Solid Waste Dilemma: An Agenda for Action* (Washington, DC: February 1989), p. 31.

[107]Jeffrey Clunie and R.W. Beck& Associates, *The Nation's Public Works: Report on Solid Waste* (Washington, DC: National Council on Public Works Improvement, May 1987), p. 49.

from it laterally. About 66 percent of U.S. landfills use a soil liner such as clay. Many of these, however, were not constructed using sound soil engineering techniques (compacting and remolding). A soil or clay liner can use compacted and uncompacted soil to absorb the chemicals leached into them. However, certain chemicals, xylene or carbon tetrachloride, for example, dehydrate the soil, causing water to migrate downward. The dehydrated soil may crack, forming pathways for liquids to leach into deeper soil.

Presently, only 1 percent of landfills use synthetic membrane liners, and only 6 percent of planned landfills will use them. Other less common liners include paving asphalt, sprayed liners of liquid rubber, and soil sealants. Synthetic membrane liners are typically made of rubber, polyvinyl chloride, or various polyethylene. Most synthetic liners are virtually impermeable to water; their permeability to other chemicals varies.[108] Data suggest that the toughest liner is made of high-density polyethylene, though some experiments show it was easily permeated by trichloroethylene. The lack of definitive data indicates that additional research is needed on the frequency with which synthetic liners are actually exposed to high concentrations of volatile organic chemicals and on long-term performance of the liners under these conditions.

The effectiveness of synthetic liners also depends on how well the seams of the different liner segments are joined together. The chemical compatibility of liner materials is critical in determiningg bond strength, and liner manufacturers' recommendations on compatible materials must be followed to assure proper bonding. Composite liners, or engineered soil overlain with a synthetic flexible membrane, combine the best qualities of both types by being nearly impervious to most leachate while providing an absorbent layer should the synthetic liner rupture.

Covers

During the useful life of a landfill, some type of cover, usually about 6 inches of compacted earth, is applied on a daily basis to control against mosquitoes and vermin, prevent odors and fires, and discourage scavenging. Proposed EPA regulations would require this.[109] When a landfill is closed, it is covered to reduce water infiltration. Unlike daily cover, the final cover needs to be of an easily compacted soil type and should be sloped to increase runoff and reduce infiltration. EPA estimated that almost all active and planned units have or will have some type of earth cover of soil, sand, or clay, but only about 2 percent have or will have a synthetic membrane cover.

Although for the most part, MSW is placed below ground level, the concept of confining waste above ground was developed for hazardous waste. If a sloped, above-ground storage mound is used, complete with liners and requisite drainage and gas collection equipment, simple gravity will aid in a more reliable leachate control system, and leaks can be found more easily before they contaminate groundwater.

Leachate Collection and Removal Systems

Leachate collection and removal involves placing a series of perforated collection pipes in drainage layers filled with sand or gravel, or above the liner, to collect leachate. If the landfill is designed with a slope, leachate will drain into a central collection point. The collected leachate can be recirculated back into the landfill, but in most cases it is trucked to a municipal sewage treatment plant or sewer, discharged to a treatment plant through a sewer, or treated onsite with biological treatment processes. However, only 11 percent of existing landfills use leachate control systems, and available data do not allow a determination of how much leachate is collected.

Gas Production, Collection, and Use

Gas produced by decomposition in landfills is primarily equal parts methane and carbon dioxide, with a few trace organic chemicals. Landfill gas can be allowed to escape into the atmosphere through vents, or it can be "flared" or burned as it leaves collection pipes. More expensive and complicated pumping and collection systems are used only when a landfill has been at least partially closed and a cap

[108] Permeability is one performance measure of a liner. One measure of the rate at which leachate permeates a liner is in centimeters per second. A clay liner is relatively permeable, allowing water to seep through it at 1 millionth to 10 millionths of a centimeter per second. Synthetic liners resist seepage and pass water much more slowly—between 100 millionths and 10 trillionths of a centimeter per second. While clay liners are more porous, they do have the ability to absorb and hold organic chemicals.

[109] Currently, 45 States require that cover be applied daily. The Environmental Protection Agency's proposed landfill regulations also would require the application of daily cover. 53 *Federal Register 33314* (Aug. 30, 1988).

installed. Active pumping systems are the most effective means for collecting landfill gas and can recover from 60 to 90 percent of methane produced.

While over 1,500 MSW landfills use venting, flaring, or collection and recovery of methane, only 123 landfills collect methane for energy recovery. Wells are dug into landfills or adjacent soil, and pipes are laid to collect the landfill gas. Contaminants, such as carbon dioxide, are removed, and the methane is injected into natural gas systems pipelines and can fuel an internal-combustion engine or gas turbine that generates electricity for general use.[110] If all methane emissions were collected and processed for energy recovery, the energy recovery potential would amount to 5 percent of all natural gas consumption or 1 percent of all energy demand in the United States.

Enhancing Degradation Rates

Landfills for waste disposal are based on the premise that what is buried will eventually decompose. Core samples taken recently from various landfills indicate that all kinds of waste can remain virtually intact even after 50 years; buried newspapers were used to verify the dates. Thus even biodegradable wastes decompose much differently and more slowly than expected.[111] Appropriate landfill design requires additional research on subjects such as the conditions under which different components degrade, how rapidly they degrade, whether degradable plastics would have much effect on landfill capacity, and what environmental problems they might create.

The idea of recycling leachate to enhance degradation has been examined in the laboratory, and several MSW landfills in the United States are using this technology in some way. The potential benefits of this system include reducing decomposition time from 15 to 20 years to only a few years, increased methane production, and reduced amounts of leachate to dispose of or treat. However, current EPA regulatory proposals would ban addition of any liquid to landfills, and careful controls to prevent offsite migration would be essential.

Incineration Technologies

Three basic types of incinerators are used today: mass bum, refuse derived fuel, and modular. Mass bum facilities are designed to bum unsorted MSW, and require only a small amount of handling of MSW. They generally have only one combustion chamber, and they operate using more air than would be needed to complete combustion if the fuel could be uniformly burned. Some incorporate combustion grates that vibrate, reciprocate, or pulsate to agitate MSW for better combustion.

Refuse derived fuel (RDF) facilities process or separate MSW mechanically before burning. The separation can be done at curbside or at a central processing center. The remaining waste is shredded and sometimes mixed with other fuel, such as oil, and injected into the combustion chamber. Waste coming into these plants is sometimes compacted under pressure for easier handling and burning. Many mass burn and RDF facilities are designed to recover energy, which can be used or sold; these are known as waste-to-energy facilities.[112]

Modular facilities are small and often factory fabricated for disposing of manufacturing-related byproducts. A ram is used to advance MSW through a two-combustion-chamber arrangement. The first chamber has a ‘‘starved” or oxygen deprived condition and the second chamber is oxygen rich to promote burning of uncombusted gases. This type of facility uses unsorted MSW, and its units are smaller than those for mass bum facilities and thus better for small communities. Disadvantages include incomplete burning and generally low efficiency for energy recovery.

Every incinerator must shut down periodically for maintenance. Mass bum incinerator manufacturers claim 85 percent reliability. Early RDF facilities had mechanical problems that caused frequent shutdowns, but recent changes in design have improved their reliability considerably. Occasional combustion "upsets," or temporary changes in combustion quality caused by changes in MSW composition, sometimes cause shutdowns. Air supply adjustments controlled by computer monitoring systems

[110] Philip R. O'Leary et al., "Managing Solid Waste," *Scientific American*, vol. 2S9, No. 6, December 1988, p, 42.

[111] W.L. Rathje et al., "Source Reduction and Landfill Mytbs,' paper presented at NASSWMO National Solid Waste Forum unintegrated Municipal Solid Waste Management, Lake Buena Vista, PL, July 17-20, 1988.

[112] Energy recovery facilities were given a boost by the Public Utilities Regulatory Policies Act of 1978, which requires power companies to buy electricity generated from an incinerator at a price equal to what it would cost the company to generate the same power.

can help avoid these problems. Although most new facilities utilize computer monitoring technologies, mass burn facilities remain simpler and more reliable than RDF units.

Several other incineration technologies are in current use generally in small commercial settings. Fluidized bed combustion is a process in which burning waste is entrained with very hot particles of sand in an upward flow of turbulent air. Both "bubbling," where material stays at the bottom of the furnace, and 'circulating' designs, where waste is allowed to move upward and then returned to the bed for further combustion, are utilized.

Pyrolysis is heating the MSW in the absence of oxygen. It produces a solid residue, which must be managed, and liquid tar and gas, which can be used as fuels. Although pyrolysis plants are operated in some European countries and Japan, U.S. experience is limited.

Controlling Air Emissions

The major types of flue gas pollutants generated by MSW incinerators are: carbon monoxide, particulate matter, nitrogen oxides (NOx), chlorinated hydrocarbons (e.g., dioxins), acid gases (e.g., hydrogen chloride), and metals such as lead and mercury. Problem emissions result from incomplete combustion and combustion temperatures that are either too high or too low.

Three basic technologies are commonly used for controlling incinerator emissions: 1) preseparation of materials from MSW before combustion, 2) destruction of harmful elements during combustion, and 3) removal of pollutants from flue gases by control equipment after combustion. The effectiveness of each of these approaches varies for each of the different categories of air emissions. Preseparation effects are hard to measure. Removing a hazardous material before it gets to the incinerator will prevent it from creating a harmful emission, but its ultimate disposal may be equally dangerous. Limited data show that preseparation has little effect on the production of dioxins/furans. However, at some older facilities, presorting for certain materials, such as aluminum, iron, glass/grit, and auto batteries, has reduced hydrocarbon emissions.

Metals in flue gas and ash can be reduced as much as 25 percent by sorting out certain items such as car batteries. Presorting can increase the combustion temperature (because of a more uniform fuel), lower ash content by about one-half, and decrease carbon monoxide emissions by a factor of two to three. Removing yard wastes from incinerator input can significantly reduce NOx emissions.

Combustion management using computer controls can yield improvements by regulating heat and MSW flow. Sensors monitor combustion temperature, output emissions, and adjust MSW flow to promote complete burning.

Three combustion and postcombustion controls are used to manage NOx emissions. Combustion improvements can be achieved through better grate and furnace design and flue gas recirculation. Selective catalytic reduction, which involves injecting ammonia into flue gases to preclude formation of NOx, can reduce emissions. A proprietary noncatalytic process, Thermal DeNOx,[113] involves the injection of ammonia into the upper furnace where it reacts to produce nitrogen and water. Three U.S. facilities are currently using this technology, and reductions in NOx emissions have been as high as 45 percent.

Postcombustion gases are controlled by devices called scrubbers. These devices fall into two categories and several types. The first category applies to postboiler scrubbers and includes wet, or "quench," scrubbers; dry scrubbers; and spray dry scrubbers. The second category includes dry injection scrubbers used in a preboiler location. In the mid-1980s, because of increased concern for the impact of acid gases on the environment, many new facilities were constructed with acid gas scrubbers.[114]

Wet scrubbers add alkaline absorbents in the boiler, which react with exhaust emissions to form salts, which are then landfilled. Although capable of removing most of the pollutants, wet scrubbers use large amounts of water, which must be treated before disposal. Dry scrubbers spray a solid alkaline powder into the flue gas to react with exhaust emissions. Because dry scrubbers use no water, they avoid water pollution and some corrosion problems. However, they do increase both the capital and

113 This is a trade name.

114 Clunie and R.W. Beck & Associates, op. cit., footnote 107, p. 46.

operating costs of waste-to-energy facilities by as much as $5 to $10 per ton.[115]

Other systems inject a solid dry absorbent directly into the boiler or onto original MSW prior to the production of flue gases; lower flue gas temperatures to as low as 40 degrees C to condense acid gases, organics, and volatile metals; or spray an atomized slurry into the flue gases and collect the dry particulates after the water in the slurry evaporates.

The majority of volatilized metals are caught in scrubbers. Metals are condensed onto fly ash particles, which are then picked up by the scrubbers. Low flue temperature has been found to be critical in this process. For example, below 285 degrees F up to 99 percent of cadmium is removed, and a 53 percent reduction of copper was achieved with flue temperatures of between 230 to 260 degrees F.

Precipitators and fabric containers called "baghouses" are commonly used to control particulate emissions from incinerators. Electrostatic precipitators (ESPs), located in the exhaust area of the facility, electronically charge particles and then pass them between parallel plates of opposite charge, drawing the particles to the plates. The plates are unloaded periodically and the residue landfilled. Multiple "fields" of plates can be used to increase efficiency, and ESPs work best when plates are large and gas flow is relatively slow. Efficiency has been shown to be as high as 99.7 percent.

Fabric/bag filters are installed over incinerator exhaust outlets to trap particulate matter in the flue gases. The bags are designed to "cake up" with particulate, adding to their efficiency. A combination of fabric filters and a scrubber has proven to be the most effective at controlling emissions. The scrubber reduces acid gases (which degrade the bag filters), reduces "blinding" the bag filters by sticky particles, and cools the exhaust gases.

Cooling flue gases before they reach pollution controls will condense most dioxin and furans into fly ash particles, which can then be controlled by scrubbers. The combination of scrubbers and fabric filters has been shown to remove 97 to 99 percent of total dioxins in postcombustion flue gases, and most new facilities have these controls.

Incinerator Ash

Incinerators produce both bottom ash and fly ash, the light particles that are carried off the grate by turbulence or that condense and form in the flue gas in the boiler section. Each year the United States generates 2.8 to 5.5 million tons of ash, or 25 to 35 percent by weight and 5 to 15 percent by volume of the original MSW.

Over 50 percent of fly and bottom ash is estimated to be disposed together with MSW in landfills, where rainwater can leach out toxic chemicals from the ash, including metallic compounds and acids. The toxicity of incinerator ash can be predicted through laboratory tests,[116] and ash residues can be treated chemically or thermally to decrease the likelihood of leaching.

Untreated ash can be stabilized or solidified and then used in road or artificial reef construction, construction blocks, and landfill cover, for example. Questions about the long-term effects of reused ash hinder more extensive use, however.

Reduction Tech Techniques[117]

Waste reduction techniques focus on reducing the amount and toxicity of materials before they become waste, to lower the demand for capacity increases and requirements for technologies. Fewer toxics in MSW would reduce the amounts and types of chemicals in landfills that create toxic air emissions and toxic leachate. Packaging accounts for 30 percent of the weight of all solid waste, paper products make up over 40 percent, and yard wastes comprise another 20 percent, making all of them candidates for waste reduction.

Toxicity Reduction

Toxics are found in many household products that end up as MSW. In fact, household maintenance and cleaning products are estimated to make up almost one-half of the household hazardous waste discarded from residences. Lead, cadmium, and mercury are used as coatings-in light bulbs, in cables and electrical products, and in batteries. Such items are major contributors to the residues of these chemicals in MSW. Identifying substances in MSW that pose the greatest risks to humans and removing or

[115] Ibid., p. 47.

[116] Office of Technology Assessment, op. cit., footnote 100, p. 251.

[117] This section is based on ibid., ch. 4, "MSW Prevention."

substantially reducing them from products that enter the waste stream is an effective way to reduce toxicity.

Many organic chemicals are used, often intentionally, in common consumer products. Examples include formaldehyde in particle board, toluene in inks, chlorobenzene in cleaners, and methylene chloride in spray propellants. Industry has successfully reformulated a number of products to reduce or eliminate hazardous components. The substitution of chloroflourocaxbons (CFCs) with hydrocarbons as a propellant in aerosol spray cans after a ban on CFCs by EPA and the Food and Drug Administration in 1978 and the substitution of titanium and zinc pigments for lead in exterior house paints are examples. However, reformulating products is time-consuming and costly; R&D leading to approval of one new pesticide can take 10 to 15 years and cost up to $10 million.

Studies have shown that consumers favor buying products that pose fewer potential risks when discarded and that providing information on the toxicity content of a product will affect purchasing decisions. Making such information available is one way public officials can affect the amount of toxic substances in the waste stream and reduce costs of MSW disposal.

Recycling[118]

Recycling is another method of reducing waste management costs, increasing landfill capacity, and reducing incinerator emissions. MSW recycling is carried out principally by private entrepreneurs in the scrap industries, nonprofit groups, and scavengers. Municipalities, however, usually initiate curbside collection programs, drop-off centers, and buy-back centers. The preparation of collected materials involves both manual and automated methods and takes place at central facilities, commonly referred to as material recovery facilities.

The type of equipment used depends on the type of MSW that is being handled: mixed waste, commingled, or separated. Mixed waste facilities separate recyclable from other waste that is then landfilled or incinerated. In some areas, several types of recyclable (e.g., glass, aluminum, and paper) are collected together and later separated. This commingled waste is easier to manage than mixed waste, because items that could pose a hazard, such as disposable razors or diapers are excluded. However, a different collection system than for the rest of MSW is needed, and the program depends on public participation. Even items separated at curbside need some preparation to meet the needs of commercial buyers. Equipment may include scales, conveyors, and balers, as well as other processes for separating different types of materials that are collected together.

Technical Difficu!ties in Recycling

Paper and paperboard waste represent 41 percent of total MSW discard, and estimates indicate a 22 to 28 percent recovery rate. Some short-term opportunities exist to increase recycling paper and paperboard, but technical and capacity barriers may preclude dramatic increases. Since most high-quality waste paper is already collected, additional supplies from new sources and de-inking of lesser quality waste will be more costly. Contaminants in recycled waste paper limit its use in making newsprint, and consumer preference limits increased use of recycled paperboard.

Glass recycling rates are in the neighborhood of 10 percent. Presently, because of chemical differences, certain types of glass, such as flat glass, safety glass, pressed and blown glass, optical glass, and industrial glass, cannot be manufactured with recycled waste glass (known as cullet). The largest use of virgin materials, primarily silica sand, is for containers, accounting for 68 percent of U.S. silica sand production in 1986. While cullet is 100 percent recyclable, color separation processes are not as efficient and limit its use. Technologies have yet to be developed to reprocess non-color-sorted glass.

Less than 200 million pounds of postconsumer plastic discards (less than 1 percent of the amount in MSW) were recycled in 1986. Plastics are resilient materials not easily crushed; thus, plastic bottles take up more space on a collection truck than other MSW components, making household collection difficult.

The large variety of plastics in MSW poses other problems. Presently, only containers made from two types of plastic (high-density polyethylene and polyethylene tetraphalate) are being recycled in substantial amounts, because these containers are

[118] This section is based on ibid., ch. 5, "Recycling."

not degraded significantly by processing. The Food and Drug Administration restricts the use of recycled plastic in food packaging because of the risk of contaminants migrating into the food.

Finally, the presence of contaminants and the effects of natural degradation processes affect plastics recycling. Separating plastics from paper, metals, adhesives, pigments, and dirt is necessary but difficult. While proven separation technologies are commercially available, automated separation techniques (primarily based on differences in density) do not work well for complex mixtures of products containing many types of plastics. The performance of recycled resins is not as good as that of virgin materials, and since reprocessing accelerates the degradation process, durability and dimensional stability are reduced.

Hazardous Waste[119]

Public works officials must comply with EPA's hazardous waste regulations. The most effective way to minimize the risks associated with hazardous wastes would be to reduce the production of the materials and the wastes. Once hazardous wastes are generated, they must be managed by one of two broad categories of technologies: 1) treatment by one or more steps to reduce the hazard level of the waste, or 2) disposal through containment or dispersal on land or in the oceans.[120] Treatment technologies reduce the hazard level directly or facilitate reduction in other steps by changing the physical or chemical nature of the waste, by separating waste constituents, or by reducing the concentration of hazardous substances in the waste. The treatment technologies include chemical, thermal, and biological treatments.

Containment technologies, such as landfills, surface impoundments, and underground injection wells, hold waste in a manner that inhibits release of hazardous components into the environment or keeps releases to acceptable levels. With most containment options, releases are likely to occur at some time. Some surface impoundments are designed, in fact, to transfer material to the ground. Dispersal techniques, such as land treatment (spreading waste on the land) or ocean dumping, rely on naturally occurring processes to reduce the hazard level of waste constituents, or to transport them into and through the environment thereby diluting concentration to acceptable levels, or both. Some geographical locations are considered good sites for land disposal facilities because their hydrogeological characteristics make releases unlikely and because the probability that people or sensitive elements of the environment would be exposed to releases is extremely low.

The feasibility and appropriateness of a management technology for a specific waste depends on many factors, including the characteristics of the waste and the environmental features of the facility site. Regulatory requirements and the goals and economic calculations of waste generators and handlers will also influence technology choices.

Waste type is an important determinant in choosing treatment technology; for example, some wastes are incompatible with a specific technology because they would damage the equipment. Well-established chemical and physical treatments are available for wastes characterized as hazardous because of their reactivity, corrosiveness, and ignitability. However, the choices are not clear for a waste for which toxicity is the major hazardous characteristic. Toxic constituents may be organic, inorganic, or metallic, and many technologies could be used. The major issue is whether to use a treatment or containment approach; treatment is preferable in most cases, if it is technically feasible.

In general, the kinds of waste most suitable for land-based containment are residuals from treatment operations, pretreated or stabilized waste, untreatable waste, and relatively low-hazard waste. However, some untreatable wastes, such as polychlorinated biphenyls (PCBs), are so highly toxic that land disposal is unacceptable, and waste elimination is the only feasible alternative.

Technology Alternatives

The goal for a hazardous waste treatment and disposal technology is to reduce the probability of release of hazardous constituents, but no technology can eliminate this probability entirely, because

[119] This section is based on several OTA publications—*Technologies and Management Strategies for Hazardous Waste Control, summary,* OTA-M-197 *(Washington DC:* March 1983); *Superfund Strategy, summary,* OTA-ITE-253 *(Washington DC:* March 1985); and Serious *Reduction of Hazardous Waste, summary,* OTA-ITE-318 (Washington, *DC:* September 1986).

[120] Office of Technology Assessment, Technologies *and Management Strategies for Hazardous Waste Control*, op. Cit., footnote 119, pp. 19-20.

toxics in waste usually affect more than one medium. For example, high-temperature incinerators destroy most of the toxins in waste, but some air pollution may occur, and the incinerator ash must be disposed of. Chemical treatment, such as dechlorination, detoxifies the waste itself, but may produce some residue requiring additional treatment or disposal. Treatment efficiencies, such as degree of destruction, degree of containment, degree of stabilization, and reliability, also differ. Emerging thermal, physical, and chemical treatment technologies offer the potential for preventing emissions of hazardous constituents, providing resource recovery, and reducing toxicity.[121]

EPA has emphasized cleanup for control of hazardous substances.[122] Resource Conservation and Recovery Act (RCRA) regulations emphasize keeping landfill costs low by not requiring comprehensive, stringent monitoring at landfills, or retrofitting of existing, active landfills. The agency has exempted from some of the new regulations portions of existing landfills that do not yet contain wastes, has limited postclosure monitoring requirements to 30 years, and has not required locating waste management facilities so as to protect drinking water sources. The Comprehensive Environmental Response, Compensation, and Liability Act (Superfund) is aimed at the cleanup of uncontrolled hazardous waste sites abandoned by industry and municipalities; in many cases there were no formal mechanisms or funds to respond to the hazardous spills and leaks at these sites.

Reducing Hazardous Wastes

Because many hazardous wastes cannot be destroyed by known pollution control methods, reducing the production of hazardous wastes brings higher benefits to environmental protection and public health. Source segregation or separation, widely used in industry, is usually the easiest and cheapest way to reduce wastes before they require management by communities as hazardous waste. The basic principle is to keep waste in concentrated, isolated forms rather than to produce large amounts of indiscriminate mixtures that must be separated later.

End-product substitution may bring long-term benefits if the substitute product is adopted in many industrial sectors and markets. Changing only one product or application is likely to have a relatively small effect on hazardous waste generation. Moreover, waste reduction is likely to be a secondary benefit of such changes, since product performance improvements are the main driving forces. However, as hazardous waste management becomes more expensive and costs are passed on to consumers, public awareness of the amount of hazardous waste in products may contribute more to end-product substitutions.

Monitoring Strategies and Technologies

Monitoring is essential to environmental protection and public health to establish baseline data and data for setting regulatory standards, verifying compliance with regulations, helping identify R&D priorities, and assessing contamination. Surveillance monitoring can verify compliance with regulatory requirements and provide limited data about changes in environmental quality. Assessment monitoring helps determine the extent of deterioration in environmental quality and provides data that indicate cause-effect relationships for specific hazards. Sampling procedures, data comparability, and limitations in available analytical methodologies must be developed for both types of monitoring. Difficult choices are necessary about the location and number of sampling sites and the frequency with which the samples are taken.

Even though monitoring is essential to controlling risks, RCRA regulations call for only limited monitoring activities for incinerators and land disposal facilities. Such an approach can lead to delays in detecting releases of harmful contaminants.

Treatment

Although industry and Federal officials are more likely to use them than local public works officials, several innovative technologies to deal with serious hazardous waste sites are on the horizon. A new process, known as in-situ radio frequency heating, has been developed to decontaminate soil tainted with volatile or semivolatile waste. This process

[121] Ocean disposal appears to be technically feasible, but adequate scientific information is unavailable for deciding what the appropriate locations are for specific wastes. Ibid., p. 20.

[122] The Resource Conservation and Recovery Act Of 1975 (R_) regulates the management and disposal of newly created industrial hazardous waste. The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 finances the cleanup of waste spills and the uncontrolled disposal sites of past industrial practices.

uses microwave technology to heat contaminated soil from 200 to 1,000 degrees F, incinerating the toxins. Up to 5,000 tons can rehandled at a time, and preliminary tests show costs to be 60 percent less than for other types of thermal incineration.[123]

An electrochemical oxidation process is being developed and tested at the United Kingdom's Atomic Energy Authority. The technique converts PCBs, pesticides, and other hazardous materials to carbon dioxide and water through feeding a solution or slurry of the chemical into an electrochemical cell. The rapid oxidation in the chamber is achieved at atmospheric pressure and with temperatures at or below 100 degrees C. It may also be possible to dispose of CFCs with this process.[124]

Issues and Concerns

Public perceptions of environmental risks are shaped almost entirely by the common understanding of health and environmental effects from past management practices and failures. Risks and potential damages-the direct harmful effects of pollution and contamination, as well as indirect effects, such as losses in property values-are borne largely by local communities. Although the public calls for better management, citizens also frequently oppose the siting of specific environmental public works facilities, such as waste treatment plants.

Coping With an Anxious Public

Public works officials can build public confidence and expand understanding of the risks involved by: 1) improving the quality of information dissemination to the public to better describe facility needs, uses, characteristics, and risks; 2) using decision processes based on sound technical criteria to ensure that specific technologies and locations have been chosen to reduce present and future risks as well as to satisfy waste generator and management needs; and 3) increasing efforts to promote demand management, conservation, and alternatives such as source reduction and recycling. Although both technical and institutional approaches can be used to address public concerns, a combination of nontechnical and institutional approaches, especially at the State and local level, may be more effective. Siting concerns can never be completely eliminated, but they may be resolvable through compromise.

Small Systems

Small systems are modest undertakings; a system serving **5,000** persons is likely to have limited budgets, yet must meet the same regulations as larger systems with greater economic capability. Small systems cannot benefit from economies of scale as do larger systems; certain processes and functions-for example, maintaining a chlorinator—in water treatment must be provided regardless of the number of connections.[125] Lacking sufficient technical and financial resources, many small system operators have had to defer capital outlays, and cannot meet the investment required for growth and system upgrading. The amount of capital they can access is limited and their financing costs are relatively high. Finally, the sheer number of small water systems, which are the most likely type of public services to be private sector operations, and what has been steady growth in that number, complicate the task of State agencies charged with regulating this industry. In many States, small systems find it difficult to retain employees with the skills necessary to deal effectively with new standards, with operating problems associated with decaying infrastructure, with expansion requirements, with fair and equitable rate-setting practices, or with some types of financing problems. (See box 4-E for information about the circuit rider program to assist small systems operations.)

State legislatures can adopt clear statutory authority for State regulatory agencies to deny appropriations and operating permits to new systems unless they comply with minimum design, operating, and construction standards and undergo financial, operational, and management evaluations.[126] Washington State initiated the first nationally known program for controlling potentially nonviable small systems. Connecticut has authority to require proposed sys-

[123] "Weston to Microwave Toxics," *Engineering News Record,* vol. *222, No. 25,* June *22, 1989,* pp. 17-18.

[124] Dermot O'Sullivan, "Electrolytic Oxidation Destroys Toxic Wastes,'" *Chemical and Engineering News,* vol. 67, No. 24, June 12, 1989, p. 27.

[125] Robert M. Clark, "Package Plants: A Cost-Effective Solution to Small Water Systems Treatment Needs," *Journal of the American Water Works Association,* January 1981, pp. 24-30.

[126] John J. Boland and Daniel Serrs, The Johns Hopkins University, "Improving the Management of Community Water Systems: Survey and Recommendations," prepared for the Maryland Department of State Planning, February 1988.

Box 4-E--Circuit Riders: Helping America's Rural Water Operators

More than 55,000 water treatment systems in the United States serve populations under 10,000 persons. Small communities often cannot afford an experienced highly trained, full-time public works engineer. To assist such systems, most of them rural, nearly every State has a visiting engineer who can provide advice, trouble-shoot problems, and ensure proper operation and compliance with Federal and State regulations. These engineers, or circuit riders, as they are called traditionally provided technical support in emergencies; however, now they also provide financial and management guidance, technical training, and technology transfer.

In 1980, the Farmers Home Administration (FmHA) began funding a comprehensive national program for circuit riders,[1] expanding an existing program of 16 circuit riders in 22 to 24 States. By 1989 there were circuit riders working in all the contiguous 48 States. Most States have one circuit rider, five States, Arkansas, Texas, Oklahoma, Louisiana and Mississippi have two. Some small States, especially in the Northeast, share circuit riders. FmHA provided $2.8 million in fiscal year 1989 to the National Rural Water Association (NRWA) which, in turn, has agreements with its State affiliates to provide the State circuit riders. The appropriation for fiscal year 1991 is $3.25 million. A State circuit rider office is not large, usually consisting of the circuit rider, a program manager, and a secretary. In some cases, U.S. Environmental Protection Agency and State environmental agency money helps supplement State office costs.

FmHA regulations require at least 35 half-day site visits per month, and a typical circuit rider will spend around 20 days per month on the road. Newer circuit riders may make as many as 70 visits a month to meet as many operators as possible and demonstrate their utility to those unfamiliar with the service. The program is attractive for young engineers, and experienced circuit riders are actively recruited by larger urban systems that can provide higher salaries.[2]

The services provided by circuit riders are free, and any small water system serving under 10,000 persons can request a visit, although priority is given to water systems with outstanding FmHA loans. Assistance can be requested by calling the State NRWA office or through the State environmental agency. Circuit riders are on call 24 hours every day, and the hard work and long hours cause high turnover.

South Dakota has an active rural water program that supported a State circuit rider before the NRWA'S program.[3] The State's Rural Water Office is staffed by six full-time employees, including a program manager and a circuit rider, paid by NRWA. The South Dakota Rural Water Association (SDRWA) supports staff for lobbying, group insurance, and extra training services for managers, operators, and clerical workers. Technical training courses in subjects such as electricity and chemistry frequently are contracted to area vocational/technical schools and paid for through State membership dues, and SDRWA also provides onsite technical training.

In the last several years, South Dakota has constructed many new, technically complex, regional water systems, which provide piped water to towns, homesteads, and farms in up to seven counties. Because many of the State's system operators are still uncertified, SDRWA is working with the State environmental agency to improve the skills of these rural operators so that they can be certified

[1] The Farmers Home Administration is a credit source for eligible rural communities for various kinds of projects, including water supply and wastewater treatment, which together account for about 50 percent of loans and 55 percent of grants. Congress appropriated $440 million for water and wastewater projects in fiscal year 1989.

[2] Larry Bowman, project officer, Farmers Home Administration, personal communication, Sept. 28, 1989.

[3] Denis Davis, executive director, Rural Water Association, South Dakota, personal communication, Oct. 2, 1989.

terns to interconnect with an existing system, if feasible.[127]

States can also support regionalization, consolidation, and satellite systems, in which a large system agrees to assume ownership, management, or operation of a small system. However, small systems have successfully blocked consolidation efforts,[128] and EPA has the legal authority to exempt small systems from the SDWA provisions, if the exemption does not pose an unreasonable health risk. The program

[127] ***U.S. Environmental Protection*** Agency, ***Ensuring the Viability of New, Small Drinking Water Systems: A Study of State Systems, EPA Report 570/9-89-004*** (Washington, DC: April 1989).

[128] Suffolk County, Long Island, NY residents believed that improved water service would generate unwanted development and blocked efforts to consolidate their system with others. Cirola, op. cit., footnote 44.

has never been an active one and EPA is currently preparing a new set of procedures for it.[129]

Small systems also need information about low-cost, simple wastewater treatment technology. While alternative systems for application in small communities are available,[130] they are not widely used. Conventional collection systems often represent more than 80 percent of the capital cost for the wastewater system in small and rural communities[131] and are rarely cost-effective.[132] Communities find that available funds are quickly consumed for operations and maintenance expenses, and some are considering deliberate noncompliance because they are unable to meet the requirements of their discharge permits.

Financing and Management

Consumer demands and stricter Federal and State regulations have raised costs of environmental public works dramatically, and the upward trend is expected to continue through the 1990s. In addition to mounting outlays for new construction and major upgrading, costs for operations and maintenance, administration, and monitoring are climbing rapidly. In 1987, EPA and State and local governments spent $40 billion for environmental protection, and EPA estimates that just to maintain standards current in 1987 will cost $56 billion per year by 2000. The amount climbs to $61 billion, if costs for selected new regulations described later in this chapter are included.[133] However, a high degree of uncertainty surrounds these cost estimates; if costs were calculated for ***all*** prospective regulations, the price would be significantly higher.

The burden of these rising costs will fall predominantly on local governments, In 2000, local government outlays for sewers, drinking water, and waste management are expected to total almost $54 billion, or 87 percent of all governmental spending for these services, up from almost $33 billion or 82 percent in 1987 (see table 4-4). The State share-mainly for administrative and technical assistance-will remain steady at 5 percent, while the Federal portion is anticipated to decrease from 13 to 8 percent, primarily because of the phase-out of EPA's wastewater treatment facility grants.

Capital Costs

By **2000,** local governments will have to raise an estimated $19 billion per year in new capital—mainly through bond issues—for waste and drinking water and solid waste projects.[134] However, costs can double once projects are designed and the backlogs of deferred maintenance are taken into account. The need for expensive capital improvements will put particularly heavy pressure on small, low-income communities that have limited resources and poor access to capital markets, and on older cities already burdened with large debt and where competition for revenues is acute.

Operating and Maintenance Costs

More sophisticated and energy- and chemical-intensive treatment processes required by new governmental regulations will add substantially to local operating and maintenance costs. Expenses are expected to climb steadily from $23 billion in 1987 to $35 billion in 2000.[135] To cover these increased operating costs, many utilities will have to raise rates substantially. Ironically, one result will be that issuance of new debt for capital outlays will be somewhat more difficult. In addition, the careful and frequent system monitoring required by new regulations will add to local costs, especially if the utility is unequipped to do complex chemical testing in-house, or if private laboratories are not easily accessible.

129David Schnare, U.S. Environmental Protection Agency, personal Communication Apr. 27, 1990.

130For examples, see the following pamphlets from the U.S. Environmental Protection Agency, "Emerging Technologies: Alternative Wastewater Collection Systems," December 1983; "OverlandFlow: An Update," October 1984; "Less Costly WastewaterTreatment for Your Town," September 1983; and "Land Treatment: Rapid Infiltration," June 1984.

131U.S. Environmental Protection Agency, "Emerging Technologies: Alternative Wastewater Collection Systems," Op. cit., footnote 130.

132Kreissl, op. cit., footnote 60.

133U.S. Environmental Protection Agency, Administration and Resources Management, *A Preliminary Analysis of the Public Costs of Environmental Protection: 1981-2000* (Washington, DC: 1990), p. ii.

134Ibid., p. 15.

135Ibid., p. 54

Table 4-4-Summary of Local Government Environmental Expenditures by Media
(In billions of 1988 dollars)

Program	1987	Percent of total	2000[a]	Percent of total	Percent increase 1987-2000
Water quality	$11.4	35.O%	$21.1	39.3%	85%
Drinking water	14.8	45.4	22.2	41.4	50
Solid waste		18.7	9.7	18.0	59
Others	0.3	0.9	0.7	1.3	133
Total local spending	32.6	100.0	53.7	100.0	65

a Cost of maintaining 1987 levels of environmental quality plus costs Of new regulations.
b Includes costs to deliver services.

SOURCE: Apogee Research from U.S. Bureau of the Census and data prepared in 1988 by the Environmental Law institute from Environmental Protection Agency Regulatory impact Analyses.

Table 4-5-Average Annual Household Payments for Environmental Services for a Sample of 8,032 Cities, Towns, and Townships **(in 1988 dollars)**

City size	Average payments in 1987	Additional payments to maintain current levels of environmental quality in 2000	Additional payments to comply with new environmental and service standards in 2000	Total estimated household payments for environmental protection in 2000
500 or less	$670	$593	$317	$1,580
501 -2,500	473	223	67	763
2,501 - 10,000	433	143	29	605
10,001 - 50,000	444	197	24	665
50,001- 100,000	373	142	24	539
100,001 - 250,000	291	111	34	436
250,001 - 500,000	335	126	68	529
500,001 or more	393	140	93	626
Population weighted average . . .	419	180	48	647

SOURCE: Apogee Research, inc., from data compiled by the U.S. Bureau of the Census, and 1986 Survey of Community Water Systems, conducted by the Research Triangle institute for the Environmental Protection Agency, Office of Drinking Water, Oct. *23, 1987.*

Impacts on Households

Although some communities will continue to subsidize environmental public works, the major financial impact of regulatory compliance will fall on individual households through higher rates. If current trends continue through 2000, the average household will spend about $650 a year on chinking water, wastewater treatment, and solid waste management, or 54 percent more than in 1987[136] (see table 4-5). However, rates and increases will vary substantially from community to community. For example, Boston is anticipating a tripling of sewer and water rates to finance the mandated cleanup of Boston Harbor. In Cedar Park, Texas, a recently developed suburb of Austin, rates are now relatively high, but are not expected to increase much because capital requirements are low, and no expenditures are anticipated for compliance with new regulations. In recently built communities, rate increases tend to be lower, because facilities are newer and more efficient.

Across the board, system size is the major determinant of rate increases (see table 4-5 again). Utility charges in very small systems are anticipated to increase about 135 percent compared to 50 percent in mid-size cities and 60 percent in large jurisdictions. Small system costs are high because they lack economies of scale and technical and management expertise and usually pay more for credit.

Wastewater Issues

In 1988 EPA estimated that $84 billion in capital investment would be needed to bring all municipal wastewater treatment facilities into compliance with the Clean Water Act standards.1[37] These estimates are probably low, because many of the regulations are not in final form. In addition to construction and upgrading facilities to comply with secondary treat-

[136]Ibid., p. 29.
[137]Ibid., p. 3.

Table 4-S-New Regulations That Will Impose Local Costs

Regulation	Status
A. Drinking water	
Inorganic compounds (IOCs)	in development
Soluble organic compounds (SOCs)	in development
Volatile organic compounds (VOCs)	Promulgated
Fluorides	Promulgated
Lead and copper corrosion control	Proposed
Lead and copper maximum containment level	Proposed
Coliform monitoring	Proposed
Surface water treatment rule: filtered	Proposed
Surface water treatment rule: unfiltered.	Proposed
Radionuclides	in development
Disinfections	in development
B. Wastewater treatment	
Secondary treatment of municipal wastewater.	Promulgated
Pretreatment requirements	Promulgated
Sewage sludge disposal-technical regulations for use and disposal.	In development
Storm water management	In development
C. Solid waste disposal	
Municipal landfill Subtitle D	Proposed
Municipal waste combusters-air standards	in development
Municipal waste combusters-ash disposal	in development
D. Miscellaneous regulations	
Underground storage tanks-technical standards.	Promulgated
Underground storage tanks-financial standards	In development
Asbestos in schools rule	Promulgated
Superfund Amendments and Reauthorization Act Title iii requirements	Promulgated

SOURCE: U.S. Environmental Protection Agency, Administration and Resources Management, *A Preliminary Analysis of the Public Costs of Environmental Protection: 1981-2000* (Washington, DC: 1990), p. 44.

ment requirements, communities are mandated to solve other problems such as combined sewer overflow (CSO). (See wastewater treatment section of this chapter for details.) Elimination of CSOs in large cities like Boston and Chicago will cost billions of dollars. Costs are likely to be proportionally large for mid-size jurisdictions. Nashville, for example, anticipates spending $633 million on construction of deep tunnels and storage tanks in the city's downtown to hold CSOs and to expand treatment capacity.[138] Prospective governmental regulations on sludge disposal, toxics, nonpoint source pollution, and wetland protection may impose additional costs.

Federal grants have played a key role in financing wastewater treatment facilities. During the early 1980s, Federal construction grants, averaging $4 billion a year, supplied roughly one-half of all investment in wastewater facilities;[139] municipal bonds, general fund revenues, and States provided the rest. Beginning in 1989, construction grants were replaced by grants capitalizing State Revolving Loan Funds (SRFs). Authorization for the program, which was designed as a transitional effort to establish self-sufficient State loan programs, expires in 1994. While all 50 States and Puerto Rico have established SRFs and each has received at least one capitalization grant, SRFs will fall far short of meeting local investment needs. Even if capitalization grants are leveraged, at least 20 States face combined financing needs of nearly $57 billion.[140]

Drinking Water Issues

Detailed costs of compliance with the SDWA are just beginning to be calculated, because final rules are in place for only a handful of regulations. At a minimum, local governments will have to absorb an anticipated 50 percent increase in annual outlays for water. The majority of costs will be imposed by efforts to comply with EPA regulations for filtering surface water, controlling contaminants, providing

138 "Nashville Plan Hits $633 Million," *Engineering News*, Aug. 9, 1990, p. 11.

139 Environmental protection Agency, op. cit., footnote 133, p. 19.

140 Ibid., p. 19.

Table 4-7—Total National Cost Impact of Compliance With Office of Drinking Water Regulations (In millions of 1986 dollars)

Rule	Number of systems affected	Capital cost	Annual O&M cost	Annualized capital and O&M cost	Average annual monitoring cost	Total annual compliance cost
Final:						
Fluoride	385	$ 32.5	$ 3.0	$ 6.8	$ 0.2	$ 7.0
Volatile organic compounds	1,824	164.4	13.4	32.7	23.1	55.8
Surface water treatment	10,288	2,938.5	166.4	511.6	17.1	528.6
Total coliforms	200,183	0.0	0.0	0.0	75.2	75.2
Proposed:						
Phase II soluble organic compounds	2,284	288.4	11.5	45.4	32.2	77.5
Phase II inorganic compounds	192	79.6	6.6	15.9	6.0	21.9
Lead and copper:						
Maximum contaminant level rule	947	333.7	35.4	74.6	0.9	75.5
Corrosion byproducts	42,980	599.0	157.3	227.6	32.0	259.7
Prospective:[a]						
Radionuclides	22,867	3,771.1	347.4	790.3	2.6	792.9
Disinfection requirement	103,354	1,352.0	316.0	474.8	12.8	487.7
Phase V sulfates	1,089	214.0	33.2	77.0	6.2	83.2
Arsenic	230	59.0	5.1	23.5		23.5
Total		*9,832.2*	*1,095.3*	*2,280.2*	*208.3:*	*2,488.5*

KEY: O&M = operations and maintenance.

[a]Mandated by the U.S. Environmental Protective Agency; has not yet developed proposed regulations.

SOURCE: U.S. Environmental Protective Agency, Office of Drinking Water, *Estimates of the Total Benefits and Total Costs Associated With Implementation of the* 1986 *Amendments to the Safe Drinking* Water Act(Washington, DC: Nov. 27, 1989), p. 12.

adequate supply and storage capacity, and replacing corroded and leaking distribution systems (see table 4-6).

The impact of EPA drinking water standards will vary among systems depending on what rules apply (see table 4-7). Nationally, regulating radionuclides has the highest price tag-about $793 million annually-because of high capital costs and the relatively large number of systems affected. However, the per-system cost of meeting surface water treatment regulations (SWTR) will be greater, because fewer systems are out of compliance now. SWTR, controlling total coliforms and meeting disinfection requirements, comprises 40 percent of all local compliance costs, because the problems are pervasive and costly to address. Expected rules for well-head protection and regulating disinfection byproducts are likely to add significantly to compliance costs.

System size is also important in determining compliance costs, since large systems benefit from economies of scale. Over one-half of total capital requirements are attributed to small systems serving less than 10,000 persons, and within that group one-half of the costs fall on systems serving fewer than 3,300 persons.[141] In Pennsylvania, 90 percent of drinking water violations occur in small systems.[142]

Solid Waste Management Issues

The cost of solid waste collection and construction and operation of landfills and incinerators is expected to rise to about 60 percent from approximately $6 billion per year in 1987 to $10 billion in 2000 and will account for 18 percent of environmental spending (see table 4-4 again). Existing landfills are rapidly reaching capacity, and bitter siting disputes are forcing new facilities further out and increasing per-unit disposal costs. While waste-to-energy plants and incinerators are preferred by local governments, they are more expensive to build and operate and also face siting problems. Rules for controlling gas pollutants and ash from incinerators, under development by EPA, are likely to increase costs.

[141]U.S. Environmental Protection Agency, Mice of Drinking Water, Estimates *of the Total Benefits and Total Costs Associated With Implementation of the 1986 Amendments to the Safe Drinking Water Act* (Washington DC: **1989), p. 19.**

[142]Commonwealth of Pennsylvania, Department of Environmental Resources, Division of Water Supplies, *Community Waler Supply: Issues and Policy Options* (Harrisburg, PA: February 1990), p. 6.

Financing and Management Strategies

The impact of sharply rising operating and capital costs can be reduced by increasing revenues and more cost-effective management. Historically, municipal sewer and water services and, to a lesser extent, waste disposal have been underpriced. The difference between the rates users pay and full costs, including maintenance, depreciation, and capital improvement reserves, has been subsidized by General Fund revenues and intergovernmental aid, in the case of wastewater treatment. Loca1 officials have been reluctant to raise rates, fearing a political backlash from consumers who think of environmental public works as rights, rather than as capital intensive services. Through the years, underpricing, coupled with rising costs, has led utilities to cut investment in system maintenance and improvement, a major cause of the deteriorated condition of many municipal systems. A rational methodology for rate-setting would seek to cover marginal or incremental costs rather than average costs, which can lead to excessive demand and inflated estimates of future needs.

Full-Cost Pricing

In response to tightening local budgets, some communities are raising sewer, water, and trash collection charges to cover full costs and adopting new rate structures. Rate structure options include raising seasonal or peak rates when demand is high, and block rates that charge a higher or lower per-unit rate for each additional block, depending on the local policy objectives to conserve or use excess capacity. Encouragement to raise rates is coming from many sources, from environmentalists to private and governmental creditors, who insist on full-cost pricing to ensure debt repayment. Independent sewer and water authorities, removed from political pressure and with mandates to be fiscally self-sufficient, are in a better position than local elected officials to carry out rate reforms.[143] The American Water Works Association is in the process of developing a new manual on alternative rate structures that will help local systems determine their best approach.[144]

Attracting Private Capital

Where State laws permit, local jurisdictions can charge developers impact fees to pay for construction of sewer and water improvements required by their development. In some communities, officials have raised capital funds by selling developers access rights to prospective water or wastewater plants. These strategies and their variations provide public works departments with upfront capital and ensure that facilities are built to local standards and can be easily integrated into the larger community system. Because the real estate market must be strong to attract developers willing to pay impact fees or purchase access rights, these strategies are used most frequently in high growth areas, such as California, Florida, and Colorado.

Operating service contracts are another form of private sector participation. While they do not lower capital needs for local governments, they can cut operating costs and allow a buildup of revenues for capital outlays.

Although enthusiasm for private ownership of environmental facilities has waned since the passage of the 1984, 1986, and 1988 Tax Reform Acts, solid waste management is one of the few areas in which private ownership is still considered profitable. However, private investment is more likely to be in collection, recycling, and resource recovery than in ownership of landfills.

Demand Reduction

Raising user rates is an effective way to reduce demand and system expansion costs, but few communities have consistently used rate increases to manage demand. However, in 1987, officials in Orange County, Florida, added a 50 percent premium for drinking water above 15,000 gallons per month; as a result, demand dropped by amounts ranging from 11 to 25 percent within the county service areas. Experience in California indicates that price changes must be substantial to reduce demand; moderate increases do not change behavior. Furthermore, over time users adjust to price changes and return to former use patterns unless rates are increased steadily.[145]

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143 Apogee Research, Inc., "Wastewater Management," a report prepared for the National Council on Public Works Improvement, 1987, p. 153.

144 Christopher Woodcock, Camp, Dresser& McKee, Inc., personal communication, Mar. 5, 1990.

145 Claudia Copeland, Water *Conservation: Options for the Residential Sector* (Washington DC: Congressional Research Service, September 1989), p. 41.

Consumer education about costs can reduce demand. Most consumers are unaware of how much water they use, but when they are informed, by advertisements and inserts in utility bills, their usage can decrease as much as 15 percent. Moreover, providing consumers with retrofit kits for shower heads and toilets can result in a 5 to 9 percent water savings, although over time 15 to 20 percent of those who install the equipment remove it.[146] In solid waste management, controlling demand through public education about source reduction and recycling are promising strategies, although only about 10 percent of U.S. solid waste is recycled. The unpredictable nature of the market and prices thwarts development of the industry at present.

Timely maintenance of sewer and water pipes can reduce demand by minimizing water loss and preventing the contamination of drinking water sources. Dual systems offer an alternative to the high cost of treating all water to drinking water quality, and water reuse can reduce demand.

Regional Planning

European experience shows that regional planning can improve the efficiency of water supply development and wastewater and solid waste management,[147] but few regions in the United States can boast of such achievements. Uncoordinated development of land use and public works plans and lack of integration of drinking water, wastewater, and solid waste plans ignore cross-media impacts and lead to inefficiency and increasing operating and capital costs. To be effective regional planning needs reliable funding and a strong State legislative mandate coupled with financial leverage to encourage local cooperation.[148]

Groundwater protection is an important planning and management issue. Sources of groundwater contamination include many types of waste disposal (including septic systems and hazardous waste) leaking storage tanks, fuel transportation and spills, well operations, agricultural practices, road salting, and urban runoff, as well as mine drainage. Groundwater standards ".. . can be used. . . to establish limits on contaminants in effluents (that is discharges), evaluate ambient groundwater quality, define the level of protection to be achieved, establish a goal for remedial clean-up, trigger enforcement, and help establish preventive programs to protect groundwater.' '[149] Other measures to control sources of contamination include reducing the disposal of wastes on or in the land, enforcing strict standards for sources of contamination, and prohibiting the placement of potential contamination sources above aquifers that are particularly vulnerable to contamination.

Conclusions

Air, earth, and water are parts of the Nation's common resources. They are essential to human health and to community development and deserve protection by far-sighted and well-integrated policy. However, governmental policy tools for providing the protection are the products of numerous, disparate laws, EPA regulations, State actions, and court rulings. In the aggregate, these address obvious pollution problems from specific sources, but do not comprise comprehensive policy guidance for environmental stewardship. For example, relatively little is known about groundwater movement and the intrusion of pollutants into drinking water supplies from landfills, sewer overflows, and other manmade facilities. Although about two-thirds of stream pollutants are from nonpoint sources, primarily from agriculture, data about these pollutants are inadequate and regulatory tools are scarce for controlling the contamination. It is extremely hard to shape good policy and legislation and to justify the costs of meeting standards when problems are so poorly understood.

EPA has recently released a report from its Science Advisory Board that urges the agency to focus on the environment as an integrated whole.[150] Congress could help State and local agencies that

[146] Ibid., p. 42.

[147] Apogee Research, Inc., op. cit., footnote 143, pp.130-145.

[148] For details, see U.S. Congress, Office of Technology Assessment, *Rebuilding the Foundations: A Special Report on State and Local Public Works Financing and Management, OTA-SET-447 (Washington DC:* U.S. Government Printing Office, March 1990).

[149] U.S. General Accounting Office, *Groundwater Quality: State Activities To Guard Against Contaminants,* Report to the Chairman, subcommittee on Hazardous Wastes and Toxic Substances, Committee on Environment and Public Works, United States Senate (Washington.L DC: U.S. Government printing Office, February 1988), p. 12.

[150] U.S. Environmental Protection Agency, *Reducing Risk: Setting Priorities and Strategies for Environmental Protection,* Report by the Science Advisory Board to the Administrator (Washington, DC: September 1990).

must comply with EPA standards by articulating the Nation's goals for environmental policy in a comprehensive mandate for the agency, and by directing it to undertake research to improve its data and analysis of environmental risk so it can set achievable standards. If EPA standards were based on their overall impact on water quality and on their potential health effects, local decisionmakers might have wider choices for treatment technologies. Consulting more frequently with State and local operating officials during the standard setting process could help identify alternative approaches and avoid future problems.

Adequate financial resources must also be provided for the agency. If Congress considers legislation to elevate EPA to Cabinet status, it would be timely to consider a clearly stated mission to preserve environmental quality from degradation across media as part of the legislation.

Changes at EPA

The Nation does not have an estimate of the overall improvements in water quality since the 1972 amendments to the Clean Water Act. Insufficient data and lack of a methodology to measure improvements to water quality and health effects make estimates of the benefits of standards very difficult. The high costs of regulatory compliance indicate that EPA should make developing data to support estimates of benefits and to direct future regulations a top priority.

Information on local environmental conditions is also limited. Data are lacking on types and amounts of sludge produced, about the purity of water at the tap, about the condition of underground pipe systems in many cities, and the efficiency of specific treatment plants. Some cities do not even have an accurate inventory of their systems. Local inventory and condition assessment information is sparse; many system managers do not have the resources to initiate a program to accumulate the information, and cannot correlate the information they do have with a preventive maintenance program. Federal or State technical assistance programs and incentives are needed to address these problems.

Communities adopt new EPA standards slowly, because their experience has shown that EPA is likely to change pollutant standards as more data accumulate. The cost of meeting EPA regulations is already high, and frequent and inconsistent changes in standards impose enormous hardships on the operating agencies that must implement them.

Environmental regulations focus on single-media effects, and environmental research has followed the same course, although recognition of cross-media effects and interest in research in this field are growing (see chapter 6 for further details). Continued research on a hazard, such as lead in drinking water or dioxin, usually brings better understanding of the risks. Once regulations or standards have been issued and if subsequent research shows that the risks have been overestimated, it is extremely difficult to roll back or change the standard. The costs of reducing many hazards to levels indicated by early estimates may be excessive. Informed regulatory and policy decisions can be made only after extensive research, testing, and evaluation. Although it can ensure that standards are set, requiring EPA to develop standards by a specific date may result in unworkable requirements.

Standards and Regulations

State and local officials responsible for compliance contend that EPA standards afford uneven protection and can create difficult interjurisdictional issues, when pollutants from one jurisdiction cause a neighboring municipality to violate regulatory standards, for example.

EPA's wastewater treatment regulations are based on strict definitions of primary and secondary treatment and biochemical oxygen demand and suspended solids in outflow. Despite the fact that the standards are intended to specify performance, their effect is often to steer jurisdictions to a specific facility design that has a proven record of meeting effluent standards (in the case of wastewater treatment). Absent effective incentives for trying new technologies, regulations based on best available technology tend to stifle the search for innovative alternatives. Many State and local agencies lack the technical ability to consider and weigh treatment and disposal alternatives for different circumstances. Moreover, standards for environmental public works often limit options for local authorities, since the burden of proving that an alternate but untried treatment method or facility falls on the requesting agency, which lacks data to show its effectiveness.

EPA could seek ways to develop regulations that are more likely to have the effect of improving and measuring protection performance, rather than controlling end-of-the pipe pollutants. Such standards could provide localities and equipment suppliers with flexibility to meet health and environmental goals and to reward improved system performance. In addition, methodologies for setting risk-based regulations and better methods for assessing the consequences of regulations are needed.

Protecting Public Works Investments

OTA concludes that the Nation's enormous investment in environmental public works can best be protected by upgrading existing infrastructure to obtain optimal performance and to meet new standards. Other priorities include rehabilitating systems to ensure against water loss or contamination due to leaks, initiating programs to prevent the intrusion of contaminants into supplies and treatment facilities, preventive maintenance, and education and training for personnel. With some notable exceptions, localities can meet many of the costs for these activities by pricing services at full cost.

Costs of maintaining and upgrading facilities to ensure compliance fall disproportionately heavily on small systems because of their small scale and high unit costs. Many small treatment systems are not in compliance with current regulations, and those with limited financial resources will have difficulty meeting new environmental standards, even using known technologies. Although EPA and some States have initiated programs to slow the formation of new, small systems and to provide technical assistance to existing systems, these efforts are not sufficient. Congress could encourage EPA to develop incentives for States to establish consolidation programs and for manufacturers to focus on equipment for small systems. Large, older jurisdictions with declining populations and shrinking economic bases may also have fiscal difficulty renewing and upgrading their public works to meet Federal standards. Congress may wish to address the issue of environmental enforcement policy, given the wide discrepancies in financial resources, technical information, and management capabilities. OTA concludes that such difficulties are likely to result in noncompliance in large numbers of jurisdictions, with small systems having particular problems. Additional Federal fiscal assistance would help States and jurisdictions with low economic bases to avoid this alternative.

Federal tools for affecting State and local rehabilitation, conservation, and maintenance policies are limited, but can be focused through standards and incentives. Since pollution prevention is far less costly than cleanup, Congress could stiffen measures that identify and penalize polluters. The manufacture, sale, and use of consumer products that pollute through use or disposal could be limited, and attempts to measure the environmental costs of products as well as the potential economic loss of nonproduction could be encouraged. A pollution remediation fee on items that pollute on use or on disposal is one possible source of income for Federal assistance to State and local governments to support compliance efforts.

Training and Education

Already complex, environmental technologies are becoming more complicated and more dependent on highly trained personnel. Environmental infrastructure utilizes a host of highly sophisticated electronic communications, electrical, and mechanical equipment as well as intricate microbiological and chemical testing apparatus. Yet the Nation's supply of well-trained managers, engineers, and technicians to install, operate, and maintain advanced treatment facilities is inadequate. Even at the State level, filling positions with well-trained personnel is a constant struggle; smaller systems, while required to meet the same standards as larger systems, do not have the resources to train their staff or to hire already-trained personnel. Existing technical assistance, such as the circuit rider programs, have provided some assistance, but more needs to be done. Congress could support programs for training and education of State environmental agency personnel and provide incentives to operating systems that undertake training. Professional organizations could assist by developing and carrying out mentor programs for young and/or inexperienced agency personnel. Any Federal financial assistance could be tied to ratemaking that covers the costs of staffing for operations and maintenance.

Technological Innovation

New and innovative technologies can address many public works problems and can help agencies design, construct, operate, and maintain complex systems more efficiently and productively. For example, instrumentation and measurement technologies are available to monitor contaminants entering or leaving a facility and eliminate the guesswork now associated with operations and maintenance.

However, public works managers are slow to introduce new technologies, because they lack information, funding, training, and incentives to change. New technologies often address only one part of a system's problems; they must also fit into the existing staffing and infrastructure framework. Market characteristics do not encourage manufacturers to develop innovative equipment for small systems, and consequently new technologies are aimed mainly at large and medium systems. The demonstration of innovative treatment technologies is stifled without a Federal program to support risk-sharing arrangements among public and private participants; engineering firms and local decision-makers will continue to choose technology with a long track record. Federal actions to provide financial incentives for development of innovative technology, and to stimulate evaluation of new technologies through applied R&D pro-**grams, technical assistance, and information dissemination, could improve the efficiency and productivity of environmental public works.**

Environmental problems are very complex, and technology choices are often costly and inflexible. The speed with which manufacturers create new products that degrade the environment once in the waste stream puts great pressure on those responsible for dealing with the results. Because environmental technologies are often developed as solutions for a specific medium and not to address the root cause of the problem, they may create new and unexpected difficulties. The rapid pace of change means that a technology choice often represents both a financial and a facility commitment that does not allow much adjustment once implementation begins. Incentives to discourage waste generation should encourage manufacturers to avoid products that have adverse effects on the environment. If properly designed, **such incentives would affect the raw materials, the manufacturing process, manufacturing byproducts, and/or the ultimate disposal of the product.**

CHAPTER 5

Cross-Cutting Technologies for Infrastructure

Photo credit American Consulting Engineers Council

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CHAPTER 5

Cross-Cutting Technologies for Infrastructure

. . . infrastructure choices [including technologies] are choices of resource allocation [and] must be dealt with in the political arena.[1]

Technologies for public works have come a long way since the days of open sewers and roads made of stones embedded in the soil; and the technologies and materials available to designers, construction engineers, and managers continue to evolve. As the need to maintain and repair the Nation's infrastructure becomes more acute and the value of greater efficiency and higher operating standards grows, advances in technology and materials can provide many opportunities to save time and money for public works. Most technologies are applicable to more than one type of infrastructure, and the most useful of these cross-cutting technologies for public works may be clustered into the following general categories:

- measurement and nondestructive evaluation tools,
- information and decision systems,
- communications and positioning systems,
- field construction technologies, and
- materials and corrosion.

These categories are not new, but a number of technological advances have led to devices and systems of remarkable versatility, precision, and power that can decrease costs and increase reliability. This chapter describes some of the most useful technologies for infrastructure and discusses the reasons that many of them are used today in private industry, but have not yet found wide application in public works.

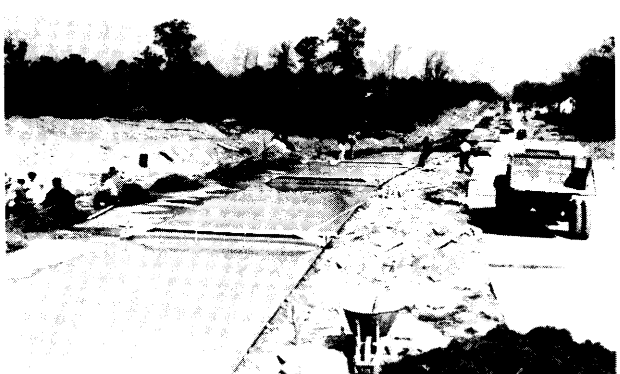

Photo credt: Library of Congress

Today's technologies make this nonmechanized highway construction project of the 1940s look outdated.

Measurement, Instrumentation, and Nondestructive Evaluation Tools

High-speed, noncontact, sensing technologies—radar, infrared thermography, laser optics, ultrasound, and others-make it possible to survey hundreds of miles of pavement, piping, or a number of bridge decks with great accuracy in a single day. The applications already commercially available or under development include radar to detect pavement voids, infrared thermography to identify delamination in concrete bridge decks, automated imaging and image processing for high-speed surveys of pavement surface distress, and lasers for evaluation of pavement profiles and continuous measurement of pavement deflection.[2]

Sensors and Measuring Instruments

Today's advanced sensors, made smaller and more accurate by silicon microchips, include ultrasound, fiber optics, and infrared optics. Radiation, sound, temperature, moisture, pressure, and other phenomena can be measured with a high degree of precision using appropriate sensors.

However, the major areas stimulating new sensor development include advanced manufacturing, power generation, security, waste technology, and environmental protection, rather than public works.[3] Sensitive electronic devices do not function well under the adverse operating conditions-including dirt, humidity, temperature and pressure extremes,

[1] Scott Johnson, comments, in Royce Hanson (ed.), *Perspectives in Urban Infrastructure* (Washington, DC: National Academy Press, 1984), p. 171.

[2] Kenneth R. Maser, "From Guesswork to Guarantee?" *Civil Engineering,* vol. 59, No. 9, September 1989, p. 78.

[3] Kenneth B. Steinbruegge, "New Sensors for Today's Industry," *Design News,* vol. 42, July 7, 1986, p. 109.

and the presence of harsh chemicals-that characterize much of public works. Nonetheless, a number of sensors have been developed that can monitor under such conditions. For example, detecting leakage or the chemical composition of fluids in large public works systems, such as drinking water and wastewater treatment plants, has been made easier by advances in sensor technology for detecting fluid content and flow rates.

Remote sensing, automated control, and measurement instrumentation can enhance marine dredging operations. A position indicator coupled with an automatic control system to orient and position equipment precisely can increase dredging efficiency and reduce the amount of material dredged unnecessarily. Modern instruments used to measure material flows and partial automation of maintenance dredging can reduce annual costs by 40 percent.[4]

Automated railroad track measurement, using equipment mounted on railcars, can give dynamic measurements of track geometry under loaded conditions. Using electro-optical or electromagnetic sensors coupled with inertial sensors, the equipment measures and records such parameters as track location, gage, profile, alignment, and crosslevel. Such systems provide repeatable track geometry measurements at close intervals in a fraction of the time required by track walking crews measuring at longer intervals.[5] These data can be fed into computerized maintenance planning tools, which can identify and set priorities for needed track maintenance. "Smart sensors," which indicate their own breakdown, will enter the market soon, Table 5-1 provides information on other major types of sensing technologies for public works.

Japanese manufacturers have made wide use of pressure sensors on computer-controlled machine tools, hydraulic robot limbs, and vacuum-assisted picking tools.[6] Sensitive pressure sensors, implanted in robot "hands,' can make machines more tactile, while optical sensors enable robots to discriminate among the patterns that are being examined. Research and development (R&D) is under way to develop micromachined sensors that would measure acceleration and vibration of machinery. Although these sensors can be very useful in especially hazardous construction or maintenance activities, much of the public works environment is too harsh to make use of such sensitive equipment reliable and cost-effective.

Nondestructive Evaluation (N DE)

NDE describes any method of examining the physical or mechanical properties of a structure or component (pavement or a machine part) without affecting it permanently or significantly. Human inspection is the most common NDE method. More automated inspection tools include visual, optical, liquid penetrant, magnetic particle, eddy current, ultrasonic, radiography, and leak detection techniques. Widely used in industry, nondestructive testing instruments have become very powerful, especially when coupled with microprocessors. Because they can improve productivity, NDE instruments are becoming indispensable for automated inspection in computerized manufacturing plants. Computers are now being interfaced with NDE instruments from every category, including those used for public works.[7]

No single NDE method is appropriate for all types of materials, structures, and types of damage. Some methods are suitable for detecting surface cracks, others for examining deep within structures, although resolution deteriorates the deeper one looks inside a structure. To minimize error, many methods may be used in combination to determine a structure's condition. Field conditions such as changing weather, moisture content, and shock waves from moving vehicles also make nondestructive testing of public works extremely difficult. Moreover, heterogeneous materials, such as the asphalt and concrete widely used in infrastructure are relatively difficult subjects **for NDE. The judgments of trained experts are still needed to determine infrastructure condition, because NDE, particularly for public works, is not yet a purely scientific process.**[8]

[4] National Research Council, Co remission on Engineering and Technical Systems, Marine Board, Dredging *Coastal Ports* (Washington, DC: National Academy Press, 1985), p. 112.

[5] Public Technology, Inc., "Track Geometry Measurement System,'' *Transit Technology Briefs,* vol. 2, No. 3, fall 1982.

[6] Steinbruegge, op. cit., footnote 3, P. 30.

[7] John E. Dwight, "NDT Is Changing—Slowly But Surely," *Quality, vol.* 27, No. 1, January 1988, pp. 20-22.

[8] John Broomfield, Strategic Highway Research Program, personal communication, Aug. 9* 1989.

Table 5-l—Measurement Technologies for Public Works

Physical property	Technology	uses	Comments
Surface pressure	Silicon crystal-based sensors	Truck weighing systems for highways; robotic handling devices	Applications limited because sensitive equipment cannot tolerate harsh public works environment.
Temperature	Fiber optics; infrared detectors	Process control if temperature is a factor; pavement inspection equipment; overheating	
Fluid properties	Moisture sensors: electrolytic cell, aluminum oxide, and chilled mirror; pressure wave viscosity sensor	Treatment plants and pipe networks; treatment plants for chemical composition	Limitations in harsh and rapidly changing environments.
	Infrared optical sensors	Detect presence and amount of organic materials in treatment plants	Expense limits use in public works.
	Chromatography	Chemical composition of liquids and gases	Used in various environmental public works testing activities.

SOURCE: Office of Technology Assessment, 1991.

Sound waves are frequently **used NDE methods. A simple procedure to determine flaws in relatively thin pavement areas, such as bridge decks, is to drag a set of chains across suspect areas. A loud, drum-like sound results if delamination, or separation of the pavement into layers, has Occurred.[9] More advanced techniques involve transmitting ultrasonic** waves through target materials or test structures and measuring the echo response as the waves bounce back.[10] Ultrasonic devices have benefited from advances in circuit design on silicon chips, and portable devices that produce high-frequency sound waves and accurately record the signals from the tested object have become common. A commercially available, ultrasonic instrument tied to a microprocessor is being used for testing corrosion cracking in pipes.[11]

Tagged materials are a promising method for NDE in the future. If detectable particles are embedded in concrete and other materials, inspectors can quickly trace structural changes over time. Magnetic detection devices can be used to examine the density distribution of embedded particles; damaged areas show changes in the average distribution of the particles.[12] Sonic devices emit a sound wave into the structure and measure the vibrations of the embedded particles. The particles in damaged material vibrate more than those in solid concrete, and **a** different echo is produced.[13] Table 5-2 summarizes **a spectrum of** current NDE methods suitable for public works.

Photo credit: American Consulting Engineers Council

Nondestructive evaluation methods, such as ultrasonics, help inspectors determine the physical condition of bridges or other structures without affecting them permanently.

Public Works Experience

Measurement and nondestructive evaluation tools are most useful for relatively homogeneous materials and in controlled operating environments. Under other circumstances, including many typical infrastructure environments, the most sensitive NDE

[9] Ron Frascoia, Materials and Research Division, Vermont Agency of Transportation personal communication, Aug. 10, 1989.

[10] Jim Murphy, Materials Division, New York Department of Transportation personal communication, Aug. 9, 1989.

[11] Robert H. Grills and Mike C. Tsao, Nondestructive *Inspection With Portable Ultrasonic Imaging System*, Special Technical Publication No. 908 (Washington DC: American Society for Testing and Materials, 1987).

[12] Ivan Amato, "Making Concrete *Smarter Than* It bolts," Science News, vol. 135, May 6, 1989, p. 284.

[13] "Vibrating Iron Particles to Sound Out Problems," *Engineering News Report, vol. 223, No. 2,* July 13, 1989, p. 15.

Table 5-2-Nondestructive Evaluation Techniques for Public Works

Technique	Use	Comments
Ultrasonic waves	Detect flaws in pavement, voids in materials.	Used for lockand dam inspections, up to 30 foot within a structure.
Impact echo	Detects flaws by measuring structural strength of materials.	Requires access to only one side of structure.
Radiographic (x-ray radiation)	Detects flaws on materials and machinery.	Requires access to both sides of subject material; involves high-energy radiation, well-trained technicians, and safeguards.
Eddy-current method	Detects flaws at or near surface of electrically conducting materials.	
Magnetic particle	Detects surface cracks of ferrous materials.	Very reliable.
Liquid penetration	Detects small discontinuities on a solid surface.	Useful for nonmagnetic materials.
Infrared thermography	Detects surface flaws in almost all materials.	Can detect voids and cavities around sewer pipes as well as delamination and cracks in bridge decks.
Ground probing radar	Detects subsurface voids.	Requires trained specialist to interpret recorded data.
X-ray fluorescence	Analyzes chemicals in solids and liquids.	Commercially available equipment is highly specialized and expensive; not widely used in public works.
Electronic acoustic sensor	Detects leaks in underground pipes or tanks.	Used in New York City, which has an old water system.
Fiber optic probes	Detect leaks, surface flaws, and other conditions.	Monitors provide visual information; machine (or robotic) vision can be used to detect surface flaws.

SOURCE: Office of Technology Assessment, 1991.

techniques are much less precise.[14] Moreover, many newer technologies, such as infrared thermography and laser impulse interferometry, are still too expensive to be used routinely in the field. Furthermore, the expertise required to operate the sophisticated equipment and analyze the test results is beyond the capabilities of most State departments of transportation (DOTS) and municipal water and sewage agencies.

Nevertheless the technologies hold great promise for many public works applications. Highway researchers envision an NDE system combined with information technology to record dynamic changes in structures and predict reliably when bridges and roads need repair or rehabilitation. Cost-effective, nondestructive life prediction systems may be available within the next 5 years to help less experienced inspectors predict structural life and plan for operations and maintenance costs. However, the initial costs of these new technologies will be relatively high.

State Programs

New York State has one of the most advanced nondestructive testing programs in the United States,[15] but it is not linked to an advanced information system. To detect flaws in metal structures, the New York DOT has used. eddy current, magnetic particle, and x-ray radiography techniques and is experimenting with thermography, radar, and ultrasound for checking pavements. Bridge decks are subjected to electrochemical analysis to detect corrosion, and the agency uses the chain drag method to determine delamination. However, the State DOT cannot afford to purchase and maintain the necessary NDE equipment, so it contracts with private firms to perform the tests, and it does not have total cost estimates for its NDE activities.[16]

The Vermont agency for transportation does its own inspection of transportation infrastructure, and contracts out as well. The agency estimates that its direct cost for conducting an in-house, predominantly manual, bridge deck evaluation is 5 cents per square foot, compared with 15 to 20 cents per square foot for infrared evaluation done by a private firm. However, bridge traffic is not interrupted during the infrared evaluation, justifying its higher costs.

The Pennsylvania Department of Transportation's (PENNDOT) NDE program includes visual inspection, friction and skid testing, electrochemical corrosion detection, thermographic and radar testing, and underwater sonar testing. PENNDOT also

[14] Broomfield, op. cit., footnote 8.

[15] Ibid.

[16] Murphy, op. Cit., footnote 10.

utilizes information technology, maintaining computer databases of over 100,000 road segments and 54,000 bridges, and creating models to evaluate different management plans. Their software is available to other DOTS. The cartographic division at PENNDOT is developing techniques to use the TIGER geographical information system (GIS) for sustaining and expanding the infrastructure. Finally, PENNDOT is researching machine vision techniques and expert systems for pavement inspection and management.[17]

Information and Decision Systems

Management information and decisionmaking systems are already proving valuable tools for public works agencies where they have been implemented. The categories of these tools range widely and include artificial intelligence systems and decision models. Public works managers have found maintenance management systems and GIS particularly useful in their activities.

Maintenance Management Information Systems

Maintenance Management Information Systems are essentially database management systems that allow managers to set priorities and schedule preventive maintenance. The systems can track all maintenance activities (both scheduled and unscheduled) and work crews, materials, and time to repair data, permitting planning for future activities. Such systems are not new, but their application to public works infrastructure was slow until microcomputers became commonplace, and appropriate, user-friendly, and cost-effective software was developed.

Geographic Information Systems

GIS are computer systems designed to manage information related to geographic locations. They can also store, analyze, and retrieve large volumes of nongraphic data from other systems and display graphic map images and tie them to descriptive (nonnumerical) data from a specific location. The systems allow the user to enter, store, retrieve, manipulate, and display geographic information quickly and accurately; these decisionmaking aids are particularly valuable. See box 5-A for more details on these powerful and versatile tools.

Artificial Intelligence

Artificial intelligence uses computers configured to provide automated reasoning. Examples of technologies that use artificial intelligence are expert systems, computer vision, and robotics.

Expert Systems

Expert systems are computer programs that attempt to duplicate an expert's reasoning process to solve problems in a given field. Unlike conventional computer programs that process algorithms, expert systems use heuristics ("if-then" rules) to advise and guide users. Since they can be programmed to explain their reasoning, expert systems can be used as training tools to expand the expertise of a few specialists to a larger group of individuals.

Systems that could be useful to a public works manager include a computer model used in Canada to determine whether a contaminated industrial site can be cleaned up or whether the contamination poses enough of a health hazard to require permanent abandonment.[18] The expert system asks prospective users of the site a series of questions, such as what type of construction is planned for the site. The database includes information on the land users, possible land uses, more than 30 organic compounds, physical characteristics of soil types, and the underlying geological formation.[19] Prototype systems have been developed to assist in such areas as highway and bridge design, traffic operations and control, tra.file incident detection, urban sewer system design, and highway noise barrier design.[20]

Although organizations see expert systems as a substitute for trained or experienced specialists, very few sophisticated systems are routinely used today. The systems that are in use are devoted to training people about complicated procedures and to diagnosing complex equipment and system problems. Moreover, current systems address clearly structured conditions, and experts recognize that human

[17] Gary Hoffman, Pennsylvania Department of Transportation, personal communication Aug. 9, 1989.

[18] Dianne Daniel, "AI Decides Safety of Contaminated Sites," *Computing Canada*, vol. 15, No. 15, July 20, 1989, pp. 1-4.

[19] Ibid.

[20] U.S. Army Corps of Engineers, "Survey of the State-of-the-Art Expert/Knowledge Based Systems in Civil Engineering," USA-CERL Special Report P-87/01, October 1986.

Box S-A-Geographic Information Systems

A geographic information system (GIS) is a computer-based system designed to manage information with a spatial or geographic element. With geographic location as a basis, information (spatial and nonspatial, or attribute) pertaining to a particular location can be stored, analyzed, and retrieved A multipurpose GIS can meet many different local government needs and provides automated tools to enter, store, retrieve, manipulate, and display geographic information quickly and accurately. Scanning technology allows rapid capture of everything from old engineering drawings to recent aerial photos. Once entered into a GIS, information can easily be updated and redrafted by the computer in different scales and in different combinations as needed for day-to-day decisionmaking.

Photo credit: American Consulting Engineers Council

Computer-aided design and drafting (CADD) program speed the work of infrastructure planners designers, and structural planners. CADD programs can be used to create dimensional drawings, such as street plans, and nondimensional drawings, such as architectural renderings.

Related systems, computer-aided design and drafting (CADD) programs, also produce graphical displays, but are primarily used to create dimensional drawings, such as street plans and profiles, and nondimensional drawings, such as architectural renderings. CADD systems have links for database attributes, such as those of a GIS.

Automated mapping/facilities mapping (AM/FM) systems, also related to GIS systems, evolved from the need for numerous mapping products within local agencies. The needs include parcel maps at different scales, park and planning maps, tax assessment maps, real estate maps, water and sewer department maps, and street and bridge department maps. These systems have proven useful for operational decisions, inquiry response, land development planning decisions, resource planning decisions, management decisions, and policy decisionmaking. GIS, AM/FM, and CADD differ in user interface, discipline-specific procedures and terminology, data models, and applications; however, they share the same fundamental technology and the same enabling technologies, computer graphics, and database management

Computer graphics systems linked to AM/FM systems enable survey data to be processed at a speed comparable to electronic data collection. State-of-the-art computer mapping systems offer great flexibility in the

expertise cannot be replaced in every complex decisionmaking context.[21]

Computer Vision

Machine or computer vision refers to the automated analysis of visual images and can provide a reliable method for analyzing images in real time. For example, in a current highway application, video cameras are linked to computers that analyze the images to generate traffic flow and congestion information, which then serves as input for signal timing algorithms.

Research is currently being conducted to look at the applications of machine vision to analyzing facility condition. Highway cracking, patching, and potholes are distress types best captured by visual devices, but developing an automated system to identify pavement problems presents significant challenges. A complete inventory of distresses for asphalt or concrete pavements may exceed 20 types; current automated systems rarely cover more than 5 or 6 types and must perform their tasks quickly and reliably. Once perfected, however, such systems will provide highway authorities with cost-effective,

[21] Arno Penzias, vice president of research, AT&T Bell Laboratories, unpublished lecture, American Iron and Steel Institute Annual Meeting, May 31, 1990.

way information is presented; a library of symbols can be developed. If survey crews assign the symbol name in the field relevant map symbols can be automatically placed as the graphics software processes the data.

GIS information that is common to most uses of a map can be located in layers within the same file; information used less frequently can be placed in separate files. For example, all information required for project site selection, such as existing facilities, property boundaries, services, elevation contours, and buildings, can be stored in separate layers and manipulated independently, yet viewed and analyzed as a single, comprehensive map.

GIS information includes spatial, or location, data and attribute data. Spatial data is based on a geographic coordinate system; items can include land parcel, area and district, facility, and natural features. Attribute data is traditional database information that can be referenced geographically, such as by addresses, and can include location by events, conditions, demographics, construction permits, or police reports. (For examples of data see table 5-A-l.)

Geographic information serves a broad constituency, because information about land parcels and geographically related data are needed regularly by many different agencies for a variety of purposes. Moreover, the ability to combine land-related attributes from many different sources is a vital support for many government and nongovernment activities. However, while raw data are usually available, they often cannot be used effectively in making complex decisions because of variations among agencies in data format, quality, and organization. For multipurpose systems, information stored in property record books, paper files, microfiche, maps, charts, or computer databases must be input into a GIS in a consistent form and updated regularly. These can be time-consuming and costly tasks. Nonetheless, GIS, linked to the appropriate computer tools for specific purposes, will become a valued aid in many public works offices. With the installation of a computerized data system, the database can be shared and duplication of effort can be minimized, if organizational issues, such as system access authorization, data use, quality control, and validation of the automated record are addressed.

Table **5-A-1-Selected Geographic Information System Data Capabilities**

Planimetric and topographic features:	Area/district features:
Property parcel features	Current land use
Zoning boundaries	City boundaries
Stormwater drainage facilities	Neighborhoods
Water facilities	Planned land-use areas
Sanitary sewer facilities	zoning
Traffic control facilities	Planning/policy areas
Geodetic control	Tax rate areas
Reference grid	School service areas
Soils	Traffic analysis zones
Flood plains	Fire/rescue areas
All area/district map layers	sheriff ballwick areas
Census geography	Lgislatlve districts
Road network	Councilman districts
Road, water, and sewer master plans	School board districts
Depth to groundwater	Zip code areas
Facility features:	sanitary inspection districts
Parks	Solidwaste collection dlstrlcts
Solid and hazardous waste disposal sites	Sewer service areas
Sludge disposal sites	Stormwater service areas
Public transit routes	Natural features:
Snow emergency routes	Noise contours
Historical sites	Environmentally critical areas

SOURCE: Office of Technology Assessment, 1991,

objective, repeatable assessments of pavement condition.[22] See chapter 3, box 3-B and chapter 4, box **4-C** for other examples of public works uses of this technique.

Robotics and Automation

While the use of mechanized equipment to apply large forces or lift heavy loads in public works construction and maintenance is widespread, more advanced forms of automation are still largely in the R&D stage. The sophisticated sensing and electronics needed for autonomous operation in the public works environment have been installed in some test vehicles. For example, a multipurpose vehicle for a variety of road maintenance tasks is under development in France. Its intended uses include mowing grass around curbs, sowing, ditch excavation, road marking and cleaning, surface cutting, brushwood cleaning, and salt dispensing. Other machines are being developed for such tasks as curb and gutter construction, road surface patching, bridge cable/beam inspection, and paint removal/surface preparation. A system to help repair runways by removing rubble, filling cracks, and performing nondestructive testing is under development at the University of Florida and the Tyndale Air Force Base.[23]

[22] ***Haris*** Koutsopoulos, "Automated Interpretation of Pavement Distress Da@' ***Construction,*** newsletter of the Center for Construction Research and Educatiom Massachusetts Institute of Technology, winter 1989, p, 10.

[23] Miroslaw Skibniewski **and** Chris Hendrickson, Carnegie-MelonUniversity, "Automation and Robotics for Road Construction and Maintenance," unpublished paper, n.d., pp. 3-5.

Simulation Models

Simulation models have been developed over the years by public works officials to examine various aspects of flow and movement patterns.

Transportation

Planning models attempt to model consumer route and mode choice to assist planners in road and transit development plans. Road traffic models examine traffic patterns at intersections, traffic flows in networks, and aggregate system performance to provide information about traffic delays, bottlenecks, and aggregate vehicle performance. Researchers from the Federal Highway Administration (FHWA), State DOTS, and universities have developed numerous models; current efforts focus on models that process real-time information about traffic demand and use it to determine signal timing plans. The *Automated Traffic Surveillance and Control System (ATSAC) in Los* Angeles is based on the Urban Traffic Control System developed by FHWA. (For additional information, see chapter 3.)

The Federal Aviation Administration (FAA) makes use of a number of models to provide analytic and management information. *SIMMOD* is a detailed model that tracks individual travel times, delays, and fuel burn for a given airport, as well as airspace and traffic configuration. It is useful for measuring the delays at a specific location caused by airspace or procedural changes, but is difficult to use for systemwide analyses, as capacity must be estimated by trial-and-error.[24]

NASPAC provides delay and utilization statistics for entire networks based on simulation and queuing models, incorporating the national airspace and airways structure, and selected airports, arrival and departure fixes, and weather conditions.[25] Best suited for strategic analyses, NASPAC can estimate the benefits across the system of a new airport, such as **that in** Denver, Colorado, now under construction, or identify which elements of the air traffic system are limiting factors. However, since the model uses average traffic demand data, based on published airline schedules, it cannot analyze the transient behavior that characterizes daily operations.

Environmental Models

Simulation models are important to environmental studies for examining the way contaminants are dispersed in the various media and determining the impact of contaminants on groundwater, for example. Numerous models have been developed by the U.S. Environmental Protection Agency (EPA) and other agencies to assist in regulatory and decisionmaking activities.[26] The Bureau of Reclamation is developing a model that combines artificial intelligence, policy analysis, systems analysis, and risk analysis to yield a tool for river basin planning, operations, and management.[27] River basin planning in the Western States involves environmental concerns as well as irrigation, hydropower, and water rights considerations, and such a model can be of considerable help to decisionmakers at all levels of government.

Communications and Positioning Systems

Communications and positioning technologies are essential elements of traffic management and control and remote infrastructure monitoring. Public works managers and transportation users rely on communications, navigation, and surveillance systems, some developed and supplied by the Federal Government and others by private providers. Comparable technologies to locate and identify vehicles and craft, and to relay traffic instructions and other information, are now practical for each transport mode. See chapter 4, box 4-C for a related use in environmental public works.

[24] U.S. Congress, Office of Technology Assessment, Safe *Skies for Tomorrow: Aviation Safety in a Competitive Environment,* OTA-SET-381 (Washington DC: U.S. Government Printing Office, July 1988), p. 136.

[25] Federal Aviation Administration, "Plan for Research, Engineering, and Development-Volume II: Project Descriptions," Conference Review Draft #4, Sept. 21, 1989, p. 49.

[26] See, for example, the following OTA reports: *Protecting the* Nation's *Groundwater From Contamination,* vol. I, PB 85-154 219/AS (Springfield, VA: National Technical Information Service, 1985); *Use of Models for Water Resources Management, Planning, and Policy,* PB 83-103655 (Springfield, VA: National Technical Information Service, 1983); and *Catching Our Breath: Next Steps for Reducing Urban Ozone, OTA-O-412 (Washington* DC: U.S. Government Printing Office, July 1989).

[27] U.S. Department of the Interior, Bureau of Reclamation, "Advanced Decision Support Systems," Progress Report, June 30, 1989.

Signal Systems

Signals transmitted over various portions of the electromagnetic spectrum form the basis of the many types of navigation and surveillance systems, which generally depend on one- or two-way communications. The increasing power, reliability, and cost-effectiveness of microprocessing technology have made advanced communications and positioning functions available to a wide range of users.

Systems that support information transfer are considered to be communications technologies. High-frequency radio and visual signals are commonly used in line-of-sight communications for transportation vehicles, while waveguides, such as cables and fiber optics, are used to link ground facilities. The low-frequency radio spectrum permits over-the-horizon communications; however, interference and low data transfer rates pose problems.

Navigation technologies include radio signal systems that provide bearing, distance, or other reference to fixed transmitters. Widely used in aviation and maritime navigation, these are now finding increased application in surface transportation. Inertial navigation and dead reckoning systems compute vehicle position relative to an initial fixed location based on vehicle heading, speed, and time en route, also without communication links. However, small measurement errors can accumulate, causing problems over long distances.

Surveillance includes determining the position and other characteristics of a remote vehicle, usually through communications technologies, and in civilian transportation, cooperative vehicle-based systems and procedures are often used. For example, air traffic control radar information is augmented by automatic transponder replies from aircraft, which strengthen the signal returning to the radar, identify the aircraft, and provide other data. Position reports from vehicles transmitted to a monitoring facility is another type of cooperative surveillance, and is commonly used by commercial operators in all transport modes.

Satellites

Satellite-based systems offer the greatest potential for enhancing worldwide communications, navigation, and surveillance, because they have the key advantage of altitude. Operating thousands of miles above the Earth, satellites have direct line-of-sight over entire continents, permitting the higher frequencies of the radio spectrum to be used for communications and positioning. Satellites can support and augment existing communications and positioning systems, and serve as passive communications relays, as reference positions for navigation, or as interrogation and monitoring devices for surveillance. Although satellites are expensive to install and operate, a few satellites can replace an extensive ground-based infrastructure. However, potential users must consider ways to ensure that satellite systems can be reliably maintained and replaced.

Three decades of telecommunications industry experience and increasingly affordable mobile receivers and transmitters have enabled industry and public traffic managers to use communications satellites as linchpins in traffic surveillance and control. For example, truck companies have found satellite-based services to be cost-effective, because drivers on long haul routes do not have to stop en route to telephone their locations to dispatchers. FAA is considering using automatic dependent surveillance (ADS) for air traffic control over remote areas without radar coverage. Under ADS, onboard navigation systems would relay the aircraft's identification and position via satellite to a central monitoring facility to display screens similar to current radar-based ones.

The United States and the Soviet Union are each deploying constellations of satellites, which, although funded for military purposes, will allow civilian receivers to determine their positions to accuracies of around 100 meters.[28] The U.S. Global Positioning System (GPS) is expected to be available for worldwide navigation in late 1993. Each satellite serves as position reference by broadcasting its location and a precise time signal, and a receiver calculates its position by measuring the time delay of signals sent from three or more satellites. FAA is investigating whether a single navigation device using both GPS and Soviet satellite signals could provide greater redundancy and precision.

A different approach for obtaining position information is by radio-determination satellite systems,

[28] Military users will have access to encrypted signals unavailable to civilian users, permitting positioning accuracies roughly on an order of magnitude greater than civilian systems.

which unlike GPS requires that each participating vehicle transmit as well as receive. Signals sent from the vehicle must be relayed by at least two satellites to a central location, where the vehicle's location is computed by noting the time difference in the signals.

Automatic Vehicle Identification (AVI)

AVI systems commonly use vehicle radio- or microwave-based transponders, which can be "read" by fixed or mobile equipment. The readers can be placed along a route or at a facility where information needs to be exchanged or billing needs to take place, such as bridge or toll road entrances and exits (see chapter 3, box 3-E for further information), weigh stations, and ports of entry. FAA regulations require commercial carriers and all aircraft flying near the busiest airports to be equipped with radar transponders, which can transmit aircraft identification and altitude to ground controllers. Additional AVI technologies include optical and infrared systems, inductive loop systems, and surface acoustic wave systems.

Long-Range Radionavigation

Long-range radionavigation systems, LORAN and OMEGA, provided by the Federal Government and originally designed for marine operations, permit navigation in remote locations. OMEGA's coverage is worldwide; LORAN's is up to 1,000 miles. Positions are determined by measuring the difference in signals from precisely synchronized transmitters, using time difference for LORAN and phase difference for OMEGA. Low-cost/low-weight microprocessors can automatically perform these measurements, making widespread use possible. LORAN reception is presently concentrated in coastal areas, but FAA is providing funds to the Coast Guard to install four additional LORAN stations for complete coverage across the continental United States.[29] Combined with an automatic dependent surveillance link, LORAN and OMEGA allow enhanced low-altitude and remote-site traffic monitoring.[30]

Photo credit: PortAuthority of New York and New Jersey

Automatic vehicle identification and billing systems could significantly lessen traffic delays at toll faclities.

Automatic Meter Reading

Various communications technologies are being used to develop automatic meter reading systems (see box 5-B) for utilities that set rates on the basis of usage. System customers are provided with a meter and a device that collects information from the meter, packages it into a data stream, and sends it to a central location, where the data are received and stored in a computer. Systems can be developed for water, sewage, and other utilities, and the opportunity for computerized operational management may be the biggest advantage of such systems.[31]

Field Construction Technologies

The tasks necessary to complete a capital facility after a final design has been chosen comprise the field construction process. Although construction usually refers to building anew project, methods and techniques for rehabilitating existing infrastructure are equally, or perhaps more, important to today's public works officials. Nonetheless, engineering education and most related R&D emphasize con-

[29] U.S. Department of Transportation, Federal Aviation Administration, *National Airspace System Plan: Facilities, Equipment, Associated Development and Other Capital Needs* (Washington, DC: September 1989), p. IV-58.

[30] U.S. Department of Transportation, Federal Aviation Administration, "Federal Aviation Administration Plan for Research, Engineering, and Development" vol. II, draft manuscript, September 1989, p. 258.

[31] Donald Schlenger, United Water Resources, personal communication, 1990.

Box 5-B—Automatic Meter Reading Systems

Meters are used by utilities to measure consumption of their product water, gas, or electricity. A utility metering system usually consists of meters and local devices to collect information from the meter, package it into a data stream, and send it to a central computer. In contrast, traditional metering systems use collection personnel to read meters individually at the point of service. Automatic meter reading (AMR) systems can eliminate the extra work and costs involved in ''lock-outs,' estimates, call backs, and premature cancellations and can shorten read-to-bill turnaround,

The development of integrated circuitry and the restructuring of the Nation's telephone system now enable AMR systems to use telephone lines or a radio transmitter to send consumption data to the utility's computer system. An AMR system can be configured in one of several ways, including: 1) telephone dial-inbound which uses an electronic meter interface unit (MIU) on the customer's premises through the telephone company's test equipment without ringing the customer's telephone; 2) telephone dial-outboundin which the MIU dials the utility's computer and transmits the latest meter reading, usually at a preset time; 3) a cable TV-based system in which the utility communicates with individual MIUs over the cable to obtain the meter reading; and 4) a radio system in which the MIU transmits to a utility receiver. In a variation of the radio system, the utility queries the MIU for information. About 50 percent of the existing systems are telephone systems although these are restricted by court rulings relating to AT&T; cable systems area very small part of existing and potential systems.

AMR systems are part of a larger field, termed "computerized operations management." In addition, since most customers are served by more than a single utility, the information collection and transmission components needed by each utility could be integrated in a single metering system. Major issues must be resolved, however, including:

- who installs and maintains the equipment;
- telephone line use limitations and radio frequency use limitations;
- the way regulations affect or restrict utility activities; and
- standardization of the electronic equipment for compatibility of communications signals and data interchange and transmission issues.[1]

[1]Typical of the standards is the High Level Data Link Control model of the International Standards Organization that is designcd to facilitate synchronous code transparent transfer of user data. Japan has adopted its standarddata exchange format for automatic meter reading.

struction of new facilities rather than the special problems involved in rehabilitation.[32]

Construction activities require considerable planning and organization, as well as management of materials, personnel, and time. Many of these early processes are crucial to design and management, and take place primarily in an office. These and other phases of construction projects have been greatly aided by advances in computer hardware and software, new materials, and technologies related to structural design, corrosion protection, and robotics. Virtually all the construction technologies discussed here have already found some applications in public works.

Trench less Construction Technologies

Trenchless excavation construction (TEC) refers to installing of water supply, sewer pipes, or any other structural components, below grade without digging an open trench. Trenchless construction avoids much of the disruption and traffic delay associated with digging up streets, sidewalks, and yards and eliminates the need to excavate around other utility equipment and tunnels, particularly in dense urban areas.[33] It differs from construction of large diameter tunnels primarily in size--TEC openings range from 2 inches to 12 feet and permit the installation of pipes to transport fluids, while tunnels are much larger and transport vehicles. Table

[32]American Society of Civil Engineers, Task Committee on Water Supply Rehabilitation Systems, ***Water Supply System Rehabilitation,*** Thomas ***M.*** Walski (ed.) (New York, NY: American Society of Civil Engineers, 1987), p. 1.

[33]Natioal ResearchCouncil, U.S. National Committee on Tunneling Technology, ***Micro- andSmall-Diameter Tunneling*** (Washington,DC: National Academy Press, 1989).

Table 5-3—Types of Trenchless Construction and Rehabilitation Technologies

Type	Variations	Comments
Trenchless construction technologies:		
Horizontal earth boring	Boreholes can be produced by augering, drilling, ramming, and water jets.	Does not require workers in the borehole; some equipment is laser-guided and remote-controlled.
Pipe jacking	Excavation processes vary from manual to highly sophisticated tunnel boring machines; pipe can be prefabricated concrete, steel, or fiberglass.	Requires workers inside the pipe during the excavation and/or spoil removal process.
Utility tunneling	Excavation methods may be identical to pipe jacking methods; most widely used lining systems are tunnel liner plates, steel ribs with wood lagging, and wood box tunneling.	Smaller than transportation tunnels.
Rehabilitation technologies:		
Cured in place lining	Curing process includes inserting a resin impregnated hose into an existing pipe; liner materials include polyester felt, woven glass/ felt, and woven polyester; liner is cured by heat or ultraviolet light.	Requires that cuts be made in the liner for lateral connections.
Sliplining	Existing pipe is lined with a new pipe, possibly polyolefin, with spirally wound profiled pipe, or with pipe that reaches its final shape and size after insertion into the original pipe and an expansion process.	Joining pipe sections is critical; grouting between liners and original pipe maybe needed.
Spraying	Cementitious or polymeric coating reinforced with steel is sprayed onto the interior walls of pipe; cementitious coatings are limited to man-entry sewers.	Sources of water infiltration must be removed before lining is applied; can utilize manual spray equipment or remote-controlled spray equipment.

SOURCES: For construction technologies—D.T. Isley, Department of Civil Engineering, Louisiana Teeh University, "Trenchless Excavation Technologies (TEC) Methods: A Classification System and an Evaluation," unpublished paper, Second Annual Alumni Appreciation Seminar, Ruston, LA, Nov. 3, 1989. For rehabilitation technologies-K. Reed, *The Development of a Framework for the Evacuation of Sewer Renovation Systems,* Report No. 539 (Huntingdon Valley, PA: Water and Wastewater Technologies, October 1989).

5-3 summarizes the primary trenchless construction and renovation technologies.

Trenchless construction R&D has focused on smaller structures-generally less than 42 inches in diameter-because this size range includes the majority of piping networks used for water supply, petroleum product, and sanitary and storm sewer systems. Rapid development of new techniques and innovations in traditional methods underscore the importance of having installers, designers, and regulatory agencies be familiar with TEC capabilities. Installation of TEC systems requires a high degree of accuracy and increases the need for monitoring and control systems, because if trenchless construction is done incorrectly, it can be more destructive than trenching work.[34] Contractors have been slow to adopt these techniques because of the complexity of installation and because they prefer simple methods that provide fewer chances for technical problems.[35] Supporting technologies that can speed the application of TEC methods include active guidance systems, improved cutting equipment to handle large cobbles and boulders, and obstruction sensing equipment.[36]

Tunnels

Tunneling consists of excavating a hole in the ground and supporting the hole as the tunnel advances, if necessary. Conventional tunneling includes a systematized drill and blast cycle for excavating and tunnel support by timbering, masonry arches, or steel ribs. Tunnel boring machines (TBMs), introduced in the United States in 1954, provide a continuous excavation process that is fast and relatively inexpensive, although use of TBMs is largely restricted to ground with predictable, constant geology.

The New Austrian Tunneling Method (NATM), one of the most recent innovations, was developed

[34] D.T. Iseley, Department of Civil Engineering, Louisiana Tech University, "Trenchless Technology: Alternative Solutions to Complicated Underground Utility Network Problems," seminar notes, Second Annual Alumni Appreciation Seminar, Ruston, LA, Nov. 3, 1989.

[35] James B. Gardner, "Trenchless Technology: A Quiet Revolution," *The National Utility Contractor, vol. 12, No. 12* (Arlington, VA: National Utilities Contractors Association, December 1988), p. 18.

[36] National Research Council, op. cit., footnote 33, pp. 20-21.

in the 1950s for construction of road and water tunnels in the Alps. The technique met the demands of extremely variable geology and the need for flexible construction methods to meet changing ground conditions. NATM includes drill-and-blast excavation; extensive use of shotcrete, a light coat of concrete sprayed on the tunnel walls to seal the newly exposed rock from the atmosphere and to support unstable rock; extensive instrumentation to measure ground deformation; and frequent use of waterproofing membranes. NATM also requires contracting arrangements that permit decisions on construction methods and the extent and timing of structural support systems to be made jointly by the engineering and contracting staff as excavation progresses. While NATM saves money on materials because it uses no shield and less lining, the savings realized by the sheer speed of TBM excavation may offset the extra material costs of conventional tunnel linings.

A flexible, waterproof, asphalt-based material recently developed in Japan offers potential as a backfill material for tunnels, particularly in earthquake-prone areas. Consisting of an asphalt emulsion, cement, and a water-absorbing polymer, the components are liquid at ambient temperature and can be pumped, but form a waterproof gel when mixed. This material has lower strength but higher ductility than other materials used as tunnel backfill. The ductility is important because it allows the material to cushion the shock from earthquakes. Because the material is more viscous than standard backfill material, it can fill the space between tunnel segments and the surrounding rock more completely and make the tunnel more waterproof.[37]

Soil Improvements and stabilization

Earth can be strengthened and stabilized by steel reinforcing bands that are used to form a cohesive wall or embankment from sand, gravel, and other fill material. Other reinforcement techniques include fibro-compaction, compaction grouting, dynamic compaction, and wick drains.

Soil nailing, or drilling a hole into a slope and filling it with a steel rod and grout, usually concrete,[38] is an alternative method for constructing retaining walls for construction projects. Although the technique has been used in other countries for nearly 20 years, U.S. experience has been limited. A design manual under preparation for FHWA will provide specific design information and allow more widespread use of soil nailing for highway projects.

Jet grouting is a versatile technique for underpinning existing foundations, but other applications are evolving as the technique becomes better known. Grout slurry is pumped under high pressure down a drill pipe 2 to 3 inches in diameter and forced out of lateral jets at high velocity. The grout shatters the surrounding earth, mixes with it, and dries, after the removal of the drill pipe, to form a column up to 48 inches in diameter of grouted soil. The soil and jetting conditions determine the physical properties of the column.[39] Jet grouting has also been used as temporary shoring for open cut and shaft excavation, to construct tie-backs for anchoring reinforced concrete retaining walls, and to construct nails for soil nailing.

Dredging Technology and Capabilities

There are two basic methods of dredging—mechanical and hydraulic-and the particular application depends on sediment type, water depth, sea conditions, and the location and proximity of the disposal area. Mechanical dredges employ buckets, grapples, or other containers to cut and scoop material and transport it to the surface; they are generally less efficient for U.S. waterway conditions than hydraulic dredges, which work like vacuum cleaners. The pump/suction elements of hydraulic dredges are often coupled with mechanical devices to loosen material from the bottom.

Improvements in automation and instrumentation, rather than changes in fundamental dredging equipment and techniques, offer the best potential for reducing excavation costs for channel maintenance and construction in the near term. Short-term dredging contracts, the vast majority of U.S. work, favor use of older, less-sophisticated equipment and discourage new investment and R&D.[40] The last wholesale introduction of new private dredge equip-

[37] Akihiro Moriyoshi et rd., ''A Composite Construction Material That Solidi.ties in Water, " *Nature,* vol. 344, Mar. 15, 1990, pp. 230-232.

[38] Reinhard Gnilsen, ''Soil Nailing Debate,'' *Civil Engineering,* vol. *58, No. 8,* August 1988, P. 61.

[39] Paul Pettit and Clayton Wooden, ''Jet Grouting: The Pace Quickens,'' *Civil Engineering,* vol. *58, No. 8,* August 1988, p. 65.

[40] National Research Council, op. cit., footnote 33, p. 113.

ment followed the retirement of the Corps' hopper dredges in the late 1970s.

Rail Track Construction and Rehabilitation

Track maintenance has been highly mechanized with complete rail-mounted machines capable of total track rehabilitation in one operation. These sophisticated technologies are, in general, used by the more affluent railroads; smaller railroads tend to use more traditional manual maintenance methods.[41] For example, one class I railroad is testing a mechanized tie renewal system designed to replace 400 ties per hour. The system carries its own ties, spikes, anchors, and plates, and consists of several units, each responsible for a different part of the tie renewal process (rail anchor removal, spike pulling, tie removal, tie insertion, and tamping). It travels along the track at roughly **0.5 mile** per hour as it renews the ties, reducing the labor and track occupancy time normally needed for tie renewal.[42] New equipment designs have also been introduced for automated ballast tamping operations, ballast cleaning, rail laying, and aligning and gaging.[43]

Materials and Corrosion

Concrete and steel will continue to be primary construction materials for infrastructure for quite some time. Recent research has identified new additives, coatings, and uses for these materials to improve their durability and resistance to operating stress. Corrosion has plagued all elements of infrastructure for decades, and many technologies exist to combat this problem at both the design and maintenance levels. However, convincing State and local officials to invest limited funds in preventive methods is difficult.

Concrete

Concrete is one of the most widely used construction materials in the United States; it is found in public works structures ranging from bridge decks to railroad ties, highways to runways, and structural supports to water pipes and storm drains. The principal advantages of concrete include the availability of component materials throughout the country, its low cost, workability at time of installation, and durability. Concrete is a strong, workable material, made up of aggregate, cement, water, and controlled amounts of entrained air. Sand, gravel, and crushed stone are the most commonly used aggregates; clay, shale, slate, and slag are more lightweight, but less frequently used. The lightweight aggregates can reduce initial costs and produce better acoustic and thermal insulation than stone aggregate. The trade-off is some loss in structural strength. Concrete can be recycled, but the process is difficult, because the old pavement must be crushed to retrieve the aggregate.[44]

Cement is the "glue" that binds the aggregate together. The one most commonly used in construction is Portland cement, a dry powder, consisting of silica, alumina, lime, and iron oxide, which react chemically when water is added to form a glue-like binder. Any excess water not used by the chemical reaction improves the workability of the cement and aggregate mixture. However, excess water increases the porosity of the concrete, which in turn reduces its strength, and engineers and construction workers must choose between strength and workability.[45]

In addition to the basic ingredients, various additives to concrete mixtures can achieve certain properties. Air entraining admixtures increase the amount of air in the concrete material, increasing the concrete's resistance to the cracking associated with freezing and thawing. Accelerators, such as calcium chloride,[46] sodium chloride, sodium sulfate, sodium hydroxide, sodium sulfite, potassium sulfate, and potassium hydroxide can speed up the hydration process to make the concrete set faster, but this may reduce the materials' effective lifetime. Organic materials, such as sugar and lignosulfonates, act as retarders to slow the hydration process. Under certain conditions, increasing the time required for

41 Federal Railroad Administration, informational document, n.d.

42 "Continuous Action Tie Removal/Insertion," *Progressive Railroading*, November 1989, pp. 43-44.

43 Federal Railroad Administration op. cit., footnote 41.

44 Hal Friedland, Aviation Consultants, personal communication, Nov. 8, 1989.

45 U.S. Congress, Office of Technology Assessment, *Advanced Materials by Design*, OTA-E-351 (Washington, DC: U.S. Government Printing Office, June 1988), pp. 48-49.

46 While calcium chloride is the most common accelerator employed by the construction industry, excessive use can cause serious corrosion of steel-reinforced rods. See corrosion section in this chapter.

Photo credit: American Public Works Association

Concrete's low cost, durability, and workability at the time of installation make it one of the most widely used construction materials.

the concrete to set can produce concrete that can maintain its strength for longer periods of time.

Concrete is considerably stronger under compression than under tension and works well for structures such as gravity dams, footings, and heavy foundations. To compensate for its low tensile strength, concrete is generally reinforced with steel. Because it changes volume at different temperatures and moisture levels, concrete is subject to cracking. Joints between slabs of concrete can accommodate volume changes, but often allow moisture to seep in, which eventually causes further damage. Proper design and maintenance can minimize these problems.

Brittleness is another disadvantage of concrete, which is able to bend only slightly to absorb stress and may crack as a result. Researchers are studying the chemical reactions of cements in order to improve the strength and durability of concrete. Some aggregates contain silica in a form that reacts with sodium or potassium in cement, absorbing moisture and expanding to crack the concrete.

Because of the many advantages of concrete, the construction industry continues to use it regularly. Government and university researchers are working to overcome its limitations. (See table 5-4 for further information.)

Asphalt

Asphalt is an inexpensive material, processed from petroleum byproducts, and used primarily as a cementing and waterproofing agent. Although asphalt's public works applications include lining cards and reservoirs, waterproofing and facing dams and dikes, and coating pipes, more than 70 percent of asphalt produced in the United States is used as a cementing material for asphaltic concrete (AC), for paving roads and highways. Hot asphalt is mixed with hot graded stone aggregate. The mixture is spread over a gravel base and subbase and rolled, while still hot, to produce the desired density and smoothness.[47]

The problems associated with AC pavements include rutting, stripping, fatigue cracking, thermal cracking, and aging, and may result from improper installation and maintenance and unexpected traffic wear. AC pavement's ability to withstand heavy loads is a function of both its design and the strength of the subbase. It can be designed to support the same loads as concrete pavement, but care must be taken when it is laid. The Strategic Highway Research Program (SHRP) (see chapter 6 for details) will monitor over 800 sections of pavement over the next 15 years to compare performance with design in order to improve the design method. These evaluations of design methods are important because engineers rely heavily on the performance histories of concrete composed of specific aggregates under certain environmental conditions.[48]

Resurfacing an AC pavement is relatively simple; the top inch of the pavement is scraped off and remixed; then anew layer is added on top of the old. The remix method gives an excellent seal between the old surface and new layers and serves as a form of instant recycling. If surface cracking is too severe, a fiber mat impregnated with asphalt material can be laid over the old surface; when the new layer is placed on top, the mat distributes stress around the cracks of the old pavement, preventing them from affecting the new layer.

Current research is focusing on ways to improve performance of AC pavement. SHRP is studying the chemistry of the asphalt binder so as to develop guidelines for State and local engineers to follow

[47] *McGraw Hill Encyclopedia of Science & Technology* (New York, NY: McGraw Hill Publishing, 1987), vol. 2, @I ed., pp. 111-112.
[48] John Broomfield, Strategic Highway Research Program, personal communication, June 21, 1990.

Table 5-4--Concrete Types Used in Infrastructure

Type	Characteristics	Uses/comments
Steel reinforced concrete	Steel reinforcing bars are implanted into concrete for increased tensile strength.	Pavement, buildings, dams, parking decks.
Prestressed concrete	High-strength steel wire is stretched inside a concrete member prior to hardening process; increases tensile strength.	Bridges and buildings where heavy weights must be supported.
Post tensioned concrete	High-strength wires are stretched after the concrete has hardened to increase tensile strength.	Bridges and buildings where weight must be supported.
Blended cements; cement substitutes	Current substitutes are used to reduce overall cost while increasing strength and reducing permeability of concrete; depends on local availability of substitutes.	Reduces costs.
Blended cements; fast setting or high early strength	Additives are used to achieve faster curing times or yield higher early strength.	Permits quicker use of finished product; more costly. Long-term performance of some mixtures needs to be evaluated.
Fiber reinforced concrete	Small, discontinuous fibers are added (steel, glass, carbon, nylon, polyethylene, and polypropylene) to concrete mixture.	Adds impact resistance and ductility to the concrete.
Roller compacted concrete	Concrete using less cement and lower quality aggregate is rolled after put in place.	Dam construction and low-speed heavy-weight vehicle pavements; problems can occur due to poor binding between layers and random uncontrolled cracking.
Polymer concrete	Polymers are added to aggregates.	Sets quickly and has low permeability; costs are high.

SOURCE: Office of Technology Assessment, 1991.

Photo credit: American Society of Civil Engineers

Resurfacing an asphaltic concrete pavement is a relatively simple procedure. The top inch of the pavement is scraped off and remixed; then anew layer is added on top of the old.

when building a road, runway, or parking lot. These specifications will describe performance results for both the asphalt binder and the aggregate selected and will take into account variations in weather and temperature.[49] Private sector research to develop more durable, and more crack-resistant AC products includes experimentation with a sulfur modifier, which lowers cost, reduces the amount of petroleum needed to produce asphalt, and makes the pavement less susceptible to temperature variations.[50]

Steel

Steel's great strength, elasticity, durability, and ductility make it a valuable material for public works, where it is used in bridges, building structures, storage tanks, and pipelines. However, steel's vulnerability to corrosion requires that coatings or other protective techniques be used. Galvanized and polymeric-coated steel, which represent two types of corrosion protection, are widely used for culverts, bridge spans, retaining walls, revetments, and underground piping.

Any exposed steel surface will develop a protective oxide layer in the presence of moisture and oxygen, which isolates it from the environment and retards corrosion.[51] However, if conditions are hostile enough, this protective layer is not sufficient,

[49] Ed Harrigan, asphalt program manager, Strategic Highway Research Program, personal communication Dec. 7, 1989.

[50] Ibid.

[51] N. Dennis Burke and James Bushman, *Corrosion and Cathodic Protection of Steel Reinforced Concrete Bridge Decks*, FHWA-IP-88-007 (Washington, DC: Federal Highway Administration, 1988).

and once the steel structure is corroded, the alternatives are costly—shoring up the structure or replacing the affected members. Currently, the best way to protect a new steel structure in a highly corrosive environment is to coat it with some type of material, usually paint. A cathodic protection system can be used if the steel is in an electrolyte such as soil or water.

Weathering steel forms a hard, protective, oxide coating that prevents additional rust. Under the right combination of moisture, sunlight, and fresh air, it stands up to corrosive environments better than conventional steel.[52] However, if weathering steel is not used properly, the formation of the protective rust film stops, and normal corrosion proceeds instead of slowing to a negligible rate once the oxide layer is formed.[53] Prolonged exposure to deicing salt and water, such as might occur in bridges in cold climates or marine environments, is very harmful to weathering steel. FHWA has developed guidelines to aid local officials in designing structures using weathering steel.[54]

Geotextiles

Geotextiles, woven or nonwoven fabrics, are made of long chains of polymeric filaments or yams formed into a stable network. Geotextiles became widely available in 1975, when 3 million square yards were sold. Because the fabrics are inert to commonly encountered chemicals, sales of 400 million square yards were expected in 1990, driven by demand for geotextiles for industrial hazardous waste landfills. Infrastructure needs have also spurred the geotextile industry, and forecasters see an annual growth rate for infrastructure applications of 5 to 10 percent in the near future.[55] Geotextiles have a wide variety of uses in infrastructure maintenance, rehabilitation, and new construction for drainage; erosion control; materials separation; soil reinforcement; and blocking moisture seepage. For example, when used on a road running through a swampy area, geotextiles can help reinforce the surrounding banks and prevent soil erosion.

Despite their utility, these relatively new products have problems that need to be resolved before this technology gains full acceptance. Uniform quality standards are lacking, and geotextile manufactures currently set their own strength and durability standards. Techniques for working with geotextiles are not commonly taught in engineering schools, and the engineering community is consequently reluctant to use geotextiles, because trial-and-error methods have often failed. FHWA, the American Association of State Highway and Transportation Officials, the Associated General Contractors, and manufacturing industry representatives plan to form a task force to establish performance standards for silt fences, drainage, erosion, separation, and paving fabric. Other groups working on standards include the California DOT, the Army Corps of Engineers, and the U.S. Forest Service.[56]

Plastics

Recent advances in plastics, primarily in the area of polyvinyl chloride (PVC) pipe manufacturing have benefited public works infrastructure. PVC pipes had long been banned from most wastewater projects, because the pipes did not conform to standards set by the American Society for Testing and Materials for compression resistance, tensile strength, and other loading factors. Manufacturers of PVC piping assert the pipes can now meet the standards for pipes up to 60 inches in diameter, large enough for most water and wastewater applications.[57] PVC piping can attain the same strength as standard metal or masonry piping, but is more resistant to corrosion in hostile environments such as acidic soils or exposure to stray currents and is generally lighter, making it easier to handle

Advanced Composites

Advanced composites have been used in the aerospace industry for years with great success, but little advanced composite technology has been transferred to infrastructure needs. The main hurdle is a fragmented construction industry, with few

[52] Rita Robison, "Weathering Steel: Industry's *Stepchild," Civil Engineering,* vol. 58, No. 10, October 1988, p. 42.

[53] Broomfield, op. cit., footnote 48.

[54] Ibid.

[55] Jerry Dimaggio, senior geotechnical engineer, Federal Highway Administration, personal communication Nov. *9, 1989.*

[56] Michael Lawson, "Geosynthetics Winning New Respect," ***Engineering News Record,*** vol. 223, No. 17, Oct. 26, 1989, pp. 36-38.

[57] U.S. Congress, Office of Technology Assessment, "Construction and Materials Research and Development for the Nation's Public Works," staff paper, June 1987, sec. 7, pp. 4-5.

incentives to innovate or move away from traditional materials, such as concrete and steel. Other obstacles include high initial costs and lack of manufacturing equipment, uniform design codes, data on long-term performance, and understanding of advanced composites by public works designers and engineers and construction and maintenance officials. Moreover, composites often degrade on exposure to water, oxygen, and light, leading to changes in color, size, mechanical properties, and occasionally to crazing or propagation. The rates of degradation can be significantly reduced by using expensive additives that are justifiable for high-performance aircraft, but much less so for public construction projects.

Advanced composites have many advantages over traditional building materials. Most are more durable, lighter, and less costly to maintain, and can form strong interlocking bonds without rivets or welds. Composites are not affected by corrosion and do not require much inspection during the design life. Many deliver the same strength as traditional materials, but at much lower weight, a potentially large advantage for the design of heavy structures, such as bridges. The largest load that must be supported by a long span bridge is the dead weight of the bridge itself, rather than the traffic on the bridge deck. Therefore, lightweight advanced composites can save money by reducing the amount of material required to support both the dead weight and a given traffic density, or the same amount of material can support much heavier traffic.[58]

In England, a 7-year advanced bridge project led to the construction of a 250-ton, corrosion-resistant, glass fiber bridge, with decks that latch together. Japan is also researching infrastructure applications for advanced composites; a 4{ story office building in downtown Tokyo contains ,0,000 wall segments made of pitch fibers.[59] '

Maintenance: Protecting Against Corrosion

Corrosion of infrastructure components costs billions of dollars (one major study estimated that costs total about 4 percent of the Nation's GNP annually) in repair, replacement, and lost productivity; approximately 15 percent of these costs are avoidable with current technology.[60] Corrosion most often affects metal structures, such as bridges, concrete reinforcing bars, and pipelines, and even problems invisible to the casual observer can lead to structural failure, lost lives, the loss of investment, and damage to the environment. As the average age of facilities and structures continues to rise, corrosion problems will inevitably worsen, although expenses can be minimized if proven technologies and techniques that account for corrosion in all phases of construction (design, installation or fabrication, maintenance, and repair) are utilized.

A natural phenomenon, corrosion is an electrochemical process through which metals are oxidized in aggressive environments, such as moist salt air in a marine environment,[61] wastewater in pipelines or wastewater treatment plants,[62] soils in contact with buried structures or pipelines,[63] or where a structure is subjected to pickup and discharge of stray currents from such sources as direct current rail systems.[64] Material selection, use of coating systems, consideration for corrosion in the design of a facility, and cathodic protection are options for controlling corrosion. It is important that engineers and other design professionals be aware of the many available corrosion control techniques and of the benefits of incorporating them into initial designs to extend the service life of structures.

Corrosion of reinforcing steel in buried, submerged, and atmospherically exposed concrete structures including bridge decks and substructures, piping for water and wastewater, water treatment

[58] U.S. Congress, Office of Technology Assessment, *Advanced Materials by Design: New Structural Materials Technology,* OTA-E-351 (Washington, DC: U.S. Government Printing Office, June 1988), pp. 87-88.

[59] "Can New Technologies Save Our Public Works?" *Civil Engineering,* vol. 59, No. 12, December 1989, pp. 26-28.

[60] National Bureau of Standards, *Economic Effects of Metallic Corrosion in the United States: A Report to Congress by the National Bureau of Standards, NBS Special* Publication 511-1 (Washington DC: 1985). Costs are extrapolated from a 1975 study by the National Bureau of Standards.

[61] R.J. Kessler and R.G. Powers, "Conductive Rubber as an Impressed Current Anode for Cathodic Protection of Steel Reinforced Concrete," *Corrosion/89* (Houston, TX: National Association of Corrosion Engineers, April 1989).

[62] J.L. Villalobos, "Corrosion of Reinforcing Steel by Hydrogen Sulfide Induced Corrosion in Wastewater Facilities," *Corrosion/90* (Houston, TX: National Association of Corrosion Engineers, April 1990).

[63] K.C. Garrity et al., "Corrosion Control Design Considerations for a New Well Water Line," *Materials Performance,* August 1989.

[64] A.W. Peabody, Control *of Pipeline Corrosion* (Houston, TX: National Association of Corrosion Engineers, 1967).

Photo credit: American Society of Civil Engineers

Corrosion of public works infrastructure costs several billions of dollars annually for repair, replacement, and lost productivity.

facilities, and parking garages has become a significant problem in the United States for many types of public works facilities.[65] Concrete is porous, and acts like a sponge in the presence of water or other liquids. It normally provides a protective environment for reinforcing steel, because its chemical constituents and highly alkaline nature help create a protective film on the surface of the steel. However, if the water contains chloride ions and these penetrate to the surface of the reinforcing steel, the protective film will be disrupted and corrosion of the reinforcing steel will begin.[66] As corrosion of the reinforcing steel progresses, rust products which have a larger volume than that of the original steel will accumulate around the corroding area. This eventually causes cracking and spalling of the concrete due to forces that can exceed 5,000 pounds per square inch. Corrosion may also occur when the protective film does not develop uniformly, as may happen when calcium chloride is added to concrete during mixing to accelerate the set of the concrete.

Photo credit: Marsha Fenn, OTA Sfaff

Using properly protected steel bars for concrete provides defense against corrosion.

Protection

Techniques to protect concrete structures against chloride contamination include high-quality, dense concrete, epoxy-coated reinforcing bars, liners, and corrosion inhibitors added to concrete mixtures (see table 5-5 for details). Regardless of the choice of protective method, ongoing maintenance is essential and replacement may eventually be necessary .[67]

Maintenance and Rehabilitation

The principal technologies now available for corrosion prevention during rehabilitation are cathodic protection, waterproof overlays, epoxy sealers, and local patching. Once concrete has been contaminated with chloride ions, engineers have several options depending on how long the repairs must last and how much money can be spent (see table 5-6).[68] For example, if a bridge has a functional life of only 3 to 5 more years before replacement, a quick fix method is most cost-effective.

Cathodic protection, used by the Navy for more than 50 years to protect the integrity of ship components, provides longer term safety. Cathodic protection is not now widely used on bridge decks, because placing a new layer of concrete can also be

[65] Office of Technology Assessment and National Association of Corrosion Engineers, Materials Technology and Infrastructure Decisionmaking Workshop, unpublished remarks, Oct. 14, 1989,

[66] M.L. Allan and B.W. Cherry, ''Mechanical Simulation of Corrosion Induced Cracking in Reinforced Concrete,' *Corrosion/89* (Houston, TX: National Association of Corrosion Engineers, April 1989).

[67] John Broomfield, Strategic Highway Research Program, personal communication Nov. 30, 1989.

[68] National Association of Corrosion Engineers, "Steel Reinforced Concrete Structures Corrosion Control Considerations," unpublished report, November 1989.

Table 5-5-Corrosion Reduction Techniques

Method	Characteristics	Comments
High-quality dense concrete	Less permeable than ordinary concrete; reduces the likelihood of chloride ions contaminating steel reinforcement.	Increases weight and production costs; traditional protection method in high-risk environments.
Epoxy-coated reinforcing bars (rebars)	Protective sleeve prevents corrosion even in presence of chloride ions.	Now widely used for bridges in United States and Canada; requires careful handling during construction.
Penetrating sealers	Thin layer of sealer is applied to surface to reduce ion penetration.	Frequently used on roads and highways.
Waterproof overlays	Layer is bituminous, covered with layer of asphalt.	Used successfully in European countries.
Corrosion inhibitors	Admixtures to concrete mixture.	New technology; test results are inconclusive.

SOURCE: Office of Technology Assessment, based on Federal Highway Administration, "Time-to-Corrosion of Reinforcing Steel in Concrete Slabs," FHWA-RD-88-165, unpublished report, September 1988.

Table 5-6-Rehabilitation Techniques for Corroded Bridge Decks and Substructures

Method	Characteristics	Comments
Cathodic protection	Current passed through the steel reinforcing bar stops the electrochemical corrosion activity.	Current must continue or corrosion can begin again.
Waterproofing membranes	Pavements and bridge decks resurfaced with asphaltic-type concrete.	Membrane can crack soon after installation.
Epoxy sealers	Surface sealed with epoxy or other polymer products to prevent more chlorides from entering or to change internal moisture content.	Effective in short term; sealer often needs to be replaced.
Patching	Deteriorated concrete replaced.	Not effective in the long term unless all the chloride-contaminated concrete is removed.
Conductive polymer concrete	Bridge decks and structural supports overlaid with sprayable conductive concrete to prevent electrochemical corrosion.	Still under development; experimental testing shows promise.

SOURCE: Office of Technologv Assessment. based on Federal Highwav Administration. "Sprayable Electrically Conductive Polymer Concrete Coatings," FHWA-RD-85-102~ unpublished report, July 1987.

successful in preventing corrosion. However, cathodic protection is a preferable method of protecting contaminated concrete substructures, because the removal of a significant layer of contaminated concrete in preparation for an overlay could result in structural collapse. Missouri, one of the few States to turn to extensive cathodic protection for bridges, did so because its bridges had relatively thin layers of support, and the degree of corrosion made State DOT officials concerned about their structural integrity.

Coatings

Because it is simple and cost-effective, paint is the most common coating for preventing corrosion. However, environmental concerns have created new complications for public works officials and for the paint industry. Regulations governing lead contamination require measures to ensure that lead does not escape into the atmosphere during paint removal and that paint debris is disposed of safely. In North Carolina, DOT officials have turned to sandblasting off old paint and then using the sand-lead mixture in asphalt pavement.[69] States that do not find such alternatives face hazardous waste disposal problems.

The air pollution caused by volatile organic compounds (VOCs) in paints also poses an environmental dilemma. VOCs are hydrocarbon-based solvents that evaporate during application, drying, and curing and create lower atmospheric ozone in the presence of nitrogen when catalyzed by sunlight. While paints without VOCs have been developed, they do not yet adhere as well or last as long.

Some 224,000 steel bridges in the national inventory need protection from corrosion. Officials responsible for their maintenance must find ways to protect them with coatings that conform to new environmental regulations.[70] In some cases, local

[69] William G. Krizan, "Regulators Putting the Lid on Paint," *Engineering News Record,* vol. *223, No. 14,* Oct. *5,1989,* pp. 30-33.

[70] Ibid.

officials have found it cheaper to replace a bridge than to strip the paint for coating replacement.[71] Since costs for R&D to develop new materials are prohibitively high for State and local agencies, FHWA is doing research on protective coatings for steel as well as how to dispose of contaminated, removed paint.[72]

Water and Wastewater Facilities

The pipe systems for water and wastewater facilities are particularly subject to corrosion. Acidic and moist soil attacks the outside of the pipe, while materials in the water or the wastewater corrode from the inside. Stray currents from such sources as nearby high-voltage mass transit power supplies, or grounding systems from electrical distribution systems, and oil and gas pipelines, also cause corrosion.

Three available methods protect pipes from the effects of corrosion: material selection, coating selection, and cathodic protection. Advances in materials and coatings have done much to mitigate against corrosion and prolong the useful lives of pipes, making the additional initial investment well worthwhile. However, the most effective method to protect a water/wastewater distribution system is cathodic protection. Gas and oil pipelines are required by law to have cathodic protection, because leaks caused by corrosion can lead to explosions. In contrast, penalties are rarely assessed for a water or wastewater leak, giving local agencies little incentive for protecting their piping systems. Yet a simple protection system can extend the life of a piping network indefinitely, and since corrosive materials in effluent from wastewater facilities are common, corrosion protection considerations should be a routine part of planning a pipe network.[73]

Technology Management

The complex and fragmented process for Federal, State, and local public works decisionmaking, the requirements for community participation in large projects, environmental impact statements, and complicated permit processes make public works project timetables extraordinarily lengthy. Numerous organizations and interest groups committed to preserving the status quo affect technology choice, and legal, social, economic, and political considerations usually outweigh technology-related factors. It is hard to imagine a decisionmaking framework less adaptable to change and to innovation. Politics often determine what gets built, by whom, and how, and somehow elected and appointed decisionmakers must find an appropriate balance among competing needs and technology alternatives.

Designing the Project

Every large construction project goes through similar stages before completion, with preliminary design activity beginning even before a decision is taken to start construction. Project design, which has a major impact on the final outcome, can be carried out by agency staff or by a design consultant. In either case, designers pay close attention to existing design standards and previous projects to ensure the success of the project and to reduce the financial, political, and professional risks involved with the project. Neither agency engineers nor design firms have an incentive to introduce new technologies unless directed to do so by the owner, and many public officials are not interested in being the first owner of a new technology.[74] Thus, technologies developed offshore are not easily introduced into the United States because designers are not familiar with them, operating experience is often under different conditions, and handbooks and manuals describing their implementation and use are not readily available.[75]

After a design is completed and accepted, bid documents are prepared, which include the project design, specifications for materials, parts, and equipment, and contract provisions. Designers rely on engineering standards and specifications to prevent unexpected failures, and since the design determines what the contractor will construct, opportunities for introducing promising new methods or technologies are limited. Flexibility in certifying what is acceptable to meet specifications, such as allowing proprietary and sole source technologies, might spur the

71 Don Fohs, chief of materials, Federal Highway Administration, personal communication Nov. 28, 1989.

72 Ibid.

73 National Association of Corrosion Engineers, "Water and Wastewater Corrosion Considerations Offered by the National Association of Corrosion Engineers," unpublished paper, November 1989.

74 Rudolf Nothenburg, chief administrative officer, City and County of San Francisco, personal communication, Feb. 10, 1989.

75 Victor Elias, private consultant, personal communication, May 2, 1990.

use of innovative technology.[76] Legal restrictions often prevent a designer and contractor from working together to develop a better or less costly project.

Long-term maintenance requirements of new designs must be considered, since an improved design may reduce capital costs but require additional inspection and maintenance efforts. Because responsibility for design, construction, operations, and maintenance is divided in most organizations, opportunities during design for improving operations are often unknown to, or overlooked by, designers. Maintenance managers are not always consulted in the development of specifications for a facility or equipment for which they will be responsible, even though their suggestions can result in cost savings.[77]

One possible improvement to the process is holding a competition for preliminary designs; this would allow evaluation before detailed development of the preferred design and weighing of alternatives on a basis of more than low cost.[78] Although examining alternative designs can bring long-term savings, the costs of funding more than one design may be hard for public officials to justify. Costs are incurred early in the process, benefits are accrued only in the future, and there is no guarantee that the benefits will be as estimated. Projects can be procured through a design-build contract (see below), but in some States this approach is not considered protective of the public interest, and legal restrictions prohibit it for public projects.[79]

Design on the basis of system performance is another way to develop less costly designs. Good performance specifications require a thorough understanding of the problem and the technological ways to solve that problem.[80] Even when officials have such understanding, evaluating alternative designs to meet performance objectives is difficult, because comparisons are based on a range of criteria that have different definitions and measures. Evaluating designs that include new or innovative technologies is also difficult, particularly if operating experience is lacking. Despite these complications, performance-based design competitions can open the path for innovative problem solving.

Value engineering (VE) is a very specific cost control methodology for examining a design on the basis of its functional purpose and capital, operating, and maintenance costs, so as to identify cost items unnecessary for the proposed function of the facility. EPA mandates VE for projects greater than $10 million and currently reports an $18 return per dollar spent on VE.[81] Some design firms perform an independent in-house VE of all their design projects.[82] Some DOT programs, especially in the Urban Mass Transportation Administration, also require VE for capital grant-funded facilities.

Procurement Options

Most public works projects are purchased under a system of competitive bidding that offers those who are qualified an opportunity to prepare a bid or proposal. Procurement procedures and regulations have been developed over time to ensure fairness and accountability and to protect the large sums of public money involved. Some procurement regulations, such as Buy America and minority set-asides, have been established to achieve specific economic and social goals, but they also can affect technology choice.

Selection on the basis of lowest cost or 'low-bid' is most common for public works projects, even though the lowest bid price rarely accounts for quality, performance over time, and maintenance. Contractors compete against one another in the bidding process, and often the winner subsequently competes with the locality to further minimize costs and maximize profit. However, choices on the basis of lowest initial cost ignore options that could have higher quality and long-term economy. Since operating and maintenance costs are not the same for different designs, a purchase decision that ignores

[76] Russell Vakharia, Congressional Research Service, ''Productivity in Public Works Construction: Options for Improvement" report 88-97, Jan. 29, 1988.

[77] Robert Contino, ''Employee Participation: The Blue Collar Edge," *Public Works*, June *198'7,* pp. 81-82.

[78] Vakharia, op. cit., footnote 76.

[79] H. Gerald Schwartz, vice president, Sverdrup Corp., personal communication, May 4, 1990.

[80] Thomas Richardson chief, Engineering Development Division, U.S. Army Engineering Waterways Experiment Station, remarks at the OTA Workshop on Transportation Infrastructure Technologies, July 25, 1989.

[81] William Jakubic, private consultant, personal communication, Apr. 30, 1990.

[82] Thomas Moran, U.S. Environmental Protection Agency, personal communication, May 4, 1990.

them can result in high expenses in the future. Some public officials, while recognizing the difficulties of administering alternative procurement approaches, characterize low-bid procurement as "penny wise and pound foolish."[83]

One alternative to low-bid procurement is based on life-cycle cost, which takes into account capital, operations, and maintenance costs of equipment or facilities over their expected life. Bidders must work closely with the purchasing agency to fully understand the performance needs of the owner. A disadvantage of life-cycle cost procurement is that promising technologies seldom have life-cycle cost data to support the analysis, and uncertainty over future cost prevents wider use.

Federal agencies have successfully used alternative methods of procurement for construction, particularly when time was limited or the project was complex, unusual, and initially difficult to define.[84] These nontraditional methods include:

- cost-reimbursable contracts that permit payment of allowable costs plus a fee or profit that is fixed or variable based on performance;
- competitive negotiations that involve face-to-face negotiations with a number of potential contractors;
- a two-step bid process, with evaluation of technical proposals followed by submission and evaluation of cost proposals;
- concurrent design-build, which allows the start of the construction phase before the design is completed; and
- turnkey construction, in which a firm assumes the responsibility for design and construction and hands the keys over to the owner upon completion. In a variation of the turnkey approach, the contractor would also have responsibility for operations and maintenance.

Each of these approaches involves additional contract administration effort; and legal, administrative, or political considerations can make them difficult to implement.[85]

The design-build approach in which a single firm is awarded the contract to design and build a facility has been used successfully for private construction projects. Combining the design and construction steps with a contract to operate and maintain is another possibility, one that is currently being used for the Channel Tunnel project linking England and France. The contractor won the right to develop the tunnel at its own expense and the concession to operate the tunnel until 2042 with freedom to set tolls.[86] Variations of this approach are possible for other revenue generating projects where private financing is available, although approval by a legislative body is often required.

Standards and Specifications

Design standards help the designer achieve a safe and reliable design and serve to protect the owner's investment from inferior products.[87] The process for establishing standards and specifications is lengthy, and once developed, standards are difficult to change. Thus while providing substantial protection to the owner, they limit the opportunity for introducing product improvements. Standards can range from theory-based, structural design standards to mandated water quality standards for treating municipal wastewater. They are usually conservative in nature and include a safety factor that is a reminder that our understanding of risks, materials, and designs is not always complete;[88] as just one example, EPA regulations have been described as requiring wastewater to be treated so that it is cleaner than the receiving stream without addressing the need to protect the stream from other pollution sources.[89]

[83] Henry W. Wedaa, vice chairman, South Coast Air Quality Management District, remarks at the OTA Workshop on Transportation Infrastructure Technologies, July 25, 1989.

[84] Federal Construction Council Consulting Committee on Procurement policy, *Experiences of Federal Agencies With Nontraditional Methods of Acquiring Real Property*, Technical Report No. 83 (Washington, DC: National Academy Press, 1986).

[85] Vakharia, op. cit., footnote 76.

[86] "Managing a Megaproject," *Civil Engineering*, vol. 59, No. 6, June 1989, p. 45.

[87] Michael Krouse, "Workshop Report-Engineering Standards Versus Risk Analysis," *Risk-Based Decision Making in Water Resources*, Yacov Y. Haines and Eugene Z. Stakhiv (eds.) (New York, NY: American Society of Civil Engineers, November 1985).

[88] Forrest Wilson, "Doctors for Building," *Technology Review*, vol. 89, No. 4, May/June 1986, p. 49.

[89] Whit Van Cott, commissioner of water, Toledo, Ohio, remarks at the OTA workshop on Environmental Technologies, Sept. 14, 1989, p. 64.

Construction contracts include many specifications and provisions that go beyond the actual project design. They include general provisions regarding legal issues such as liquidated damages, project change orders, terms of performance, and methods and schedule of payment; special provisions dealing with system or equipment verification, quality assurance, and contractor deliverables; and technical provisions that describe all the specifications that must be met.

Risk and Liability

Each new technology is surrounded by risk due to uncertainty. The risk is multifaceted and includes:

- technical risk (will the system do what it is designed to do?);
- health risk (will it control disease as effectively as other technologies?);
- safety risk (will it reduce injury and death?);
- financial risk (will the investment be justified?);
- political risk (will the technology provide desirable results?); and
- liability risk (will the potential for failure be financially bearable?).

Public decisionmakers are reluctant to purchase new technology; their basic decision guideline is that technology should be proven in the field or in revenue service before being considered for their jurisdiction. While it maybe an exaggeration to say that administrative agencies ". . . anguish over new technology and the possible effects on society . . ."[90] it is true that public works are not ". . . well-suited for trial-and-error management; the cumulative operating experience is not long enough to provide a good database on what the risks are.''[91] However, if opportunities for introducing new technologies are limited by various risks, the value of seeking better methods for testing and evaluating new technologies is great.

Risk-sharing arrangements, which recognize that no one party can afford to accept all the risk, represent one way to overcome bias against new technology. Risk sharers can include all levels of government that would benefit from successful application, local investors and developers who could gain financially, and manufacturers and contractors who anticipate future sales contracts. The need to spread the risk in the United States results from governmental unwillingness to establish a recognized authority to test and approve new technologies.[92] Efforts such as EPA's Innovative and Alternative Technology Program (see box 5-C) were designed to provide an increased Federal match to localities for construction grants.[93] Demonstration projects that help bridge the gap between a developed technology and Ml-scale implementation in an operating environment are an effective way to encourage the use of advanced technologies.

Repair and Rehabilitation

Although numerous studies have documented the value of good maintenance practices, maintenance funds are highly vulnerable to budget cuts.[94] Easy to overlook and defer and with little or no political constituency, maintenance has been compared to visiting the dentist because, ''. . . it's painful and costly . . . and it doesn't get done unless it is absolutely necessary or catastrophic.''[95] Because maintenance budgets are limited, small repairs are often made with low-grade materials to eliminate an immediate problem and to delay a more costly, longer lasting repair.

Inventories, inspections, and evaluation are all needed to avoid costly repairs and rehabilitation. A recent study of New York's bridges stressed the importance of preventive maintenance, recognizing that if maintenance is stopped, even for short periods, deterioration accelerates.[96] The study also concluded that although modem methods are helpful, some of the best steps are the simplest. Cleaning,

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[90] Peter Huber, ''Don't Innovate: It's Dangerous,'' *Civil Engineering*, vol. *58, No. 4,* April 1988, p. 6.

[91] Walter Diewald, ''Risk Analysis and Public Works Decision-Making,'' Engineering *Applications of Risk Analysis*, F.A. Elia, Jr., and A. Moghissi (eds.) (New York, NY: The American Society of Mechanical Engineers, 1988), pp. 39-43.

[92] National Council on public Works Improvement, *Fragile Foundations: A Report on the Nation's Public Works,* Final Report to the President and the Congress (Washington, DC: February 1988), p. 128.

[93] American Public Works Association, ''Structuring Demonstration Projects of New Technologies,'' *Proceedings, Aug. 3*, 1987, p. 7.

[94] Apogee Research, Inc., ''Maintaining Good Maintenance,'' technical memorandum prepared for the National Council on Public Works Improvement Sept. 30, 1987.

[95] Van Cott, Op. cit., footnote 89.

[96] ''Fixing What Ain't Broke,'' *Civil Engineering,* vol. *59, No. 9,* September 1989, p. 69.

Box 5-C—The Environmental Protection Agency's Alternative and Innovative Technology Program

Americans' zest for innovation and the drive to build a better mousetrap fades rapidly when it comes to public works. The history of the Environmental Protection Agency's (EPA) efforts to promote nontraditional technologies for wastewater treatment highlights the conservatism of State and local officials' attitudes toward public works innovation.

Disturbed that the construction grant program established by the Clean Water Act of 1972 was funding predominantly large regional facilities using conventional technologies, Congress authorized the Innovative and Alternative Technology (1/A) Program in 1977 to absorb the financial risks of local experiments with nontraditional system design and construction. If a community used an EPA-approved alternative treatment or innovative technology, EPA covered an extra 20 percent (or 75 percent) of project costs, even if they were as much as 15 percent higher than conventional methods. Communities that chose new technologies were eligible for 100 percent grants to corrector replace systems that failed. States were required to set aside 4 percent of their total Federal construction grant allocations to fund the required bonuses for new technologies.

While providing a proving ground for experimental technology was a prime program goal, only 600 out of the 2,700 I/A-funded projects meet EPA's definition of innovative--using developed, but not fully proven technologies.[1] This category includes, for example, new aeration and mixing processes and innovative kinds of clarifiers and disinfection for wastewater treatment, and aerobic and/or anaerobic digestion of sludge. The vast majority of I/A projects use more orthodox methods EPA classifies as alternative; these include land treatment of wastewater and sludge, aquifer recharge, and methane recovery—well known, if not widely used, techniques that are low cost and emphasize environmental preservation and energy conservation. Despite the relatively low participation in innovative projects, EPA reports that the acceptance of ultraviolet disinfection as an alternative to chlorination and technical improvements in sequencing batch reactors for small communities are direct results of I/A-funded projects.[2]

Most I/A grants have gone for alternative projects in capital-short, small communities more interested in money and low-cost operations than cutting-edge technology. Over two-thirds of I/A projects serve communities with populations under 10,000, many of which would have had low priority for Federal or State funding outside the I/A program.[3] Between 1979 and 1985, over one-half of the States failed to appropriate all their State I/A set-aside, foregoing millions in Federal funds.[4]

Funding for I/A projects ended in 1990 when the Construction Grant Program expired. Innovative wastewater treatment projects are eligible for State Revolving Fund loans, but for most communities, loan repayment is likely to be a further disincentive to innovation and risk-taking.

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[1] u.s. Environmental Protection Agency, Office of **Water,** ***Effectiveness of the Innovative and Alternative Wastewater Treatment Technology Program (Washington DC:*** September 1989), p. 66.

[2] Ibid., p. 67.

[3] Ibid., p. 64.

[4] Ibid., p. 45,

painting, patching, and sealing need to be performed regularly.

Proprietary Technologies

When the private sector develops a better mousetrap, the rights to it are important because of the competitive advantage they bring. Selling the improved mousetrap to the public sector may be difficult, because public authorities want to protect themselves against price changes or supply problems associated with proprietary technologies.[97] Furthermore, the private sector may have to forego some proprietary rights on a product purchased by the public sector, thereby sacrificing its competitive position. Sole source procurement is possible where a one-of-a-kind product is available, but procedures built into the procurement system to protect against favoritism make sole sourcing difficult.

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[97] Vakharia, op. cit., footnote 76, p. ***21.***

Personnel Training, Education, and Recruitment

As promising as many new technologies appear, they cannot be used properly without trained managers and technicians, and there is much evidence that the public works field is losing its well-trained people to the private sector and to retirement much faster than they are being replaced. Many new technologies require new skills; in some cases jobs must be redefined or job assignments combined, so that qualified people can be hired at a competitive salary.[98] Some public works departments are providing special training for entry-level employees to help them qualify for jobs and for additional technical training.[99] The current need for repair and rehabilitation in public works increases the severity of these problems, because very little engineering training and education focuses on emerging methods or technologies.

Small systems have particular difficulty in finding trained personnel to operate and maintain the complex treatment systems necessary to meet current EPA standards. The National Rural Water Association with funding from EPA has developed a circuit rider program (see chapter 4, box 4-E) to alleviate some of the problems created by the lack of trained personnel, but more help is needed. Qualified circuit riders soon leave the program for more money and greater opportunity in larger systems. Thus while it is important to develop special technologies for small systems, helping find the people to staff them is even more crucial.

Improved training and education are necessary for many reasons. If procurement procedures are changed to allow promising technologies to be introduced more quickly, public works staffs must be capable of adjusting to the improvements. Procurement decisions based on performance standards, for example, will require abilities that are not now generally available. As one expert puts it, "We cannot have performance specifications if all we have are a bunch of contract monitors."[100] Nontraditional procurement procedures will also require more contract administration and greater coordination between the technical and administrative staffs of public agencies.[101]

The construction industry and its labor unions have recognized the need for additional well-trained personnel and have initiated a national training program, spending about $400 million last year alone.[102] DOT's university centers, too, are focusing on attracting students to stay in the civil engineering field in public works. (See chapter 6 for further details.)

Conclusions

Although many innovative technologies are available to help infrastructure managers use staff more productively and improve system operation and maintenance, institutional, management, and financial constraints prevent their adoption by most public works organizations. Moreover, since many of these originated in fields other than infrastructure, successfully applying them to public works requires additional analysis, development, and field testing and evaluation. Yet, despite a multitude of Federal technology transfer programs, efforts to implement cross-cutting technologies with application across a range of public works have no institutional home.

Acceptance and use of new technologies is closely tied to legal requirements and management and procurement policies that inhibit consideration of alternatives without an extensive record of operational experience. Although caution is necessary when public funds are used, Federal leadership would be invaluable in developing appropriate safeguards and evaluation procedures that allow a broader set of technology alternatives to be considered.

[98] U.S. Congress, Office of Technology Assessment, *Making Things Better: Competing in Manufacturing*, summary (Washington, DC: US. Government Printing Office, February 1990), p. 22.

[99] Carolyn H. Olsen, commissioner, Atlanta Department of Water and Pollution Control, personal communication, Feb. 7, 1990.

[100] Thomas Richardson, chief, Engineering Development Division, U.S. Army Engineering Waterways Experiment Station, remarks at the OTA Workshop on Transportation Infrastructure Technologies, July 25, 1989.

[101] Federal Construction Council Consulting Committee on Procurement Policy, *Experiences of Federal Agencies With Nontraditional Methods of Acquiring Real Property*, Technical Report No. 83 (Washington DC: National Academy Press, 1986).

[102] C. James Spellane, The Kamber Group, personal communications, May 10 1990.

Promising Technologies

Computers for scheduling work tasks, monitoring equipment use, ordering and tracking supplies, tracking staff requirements, organizing and tracking documents, and performing many other routine functions in public works projects have brought enormous benefits. Public works organizations are most likely to be using computers; the degree to which other electronic or advanced decisionmaking tools are used depends on the skill levels of personnel and the agency's financial resources.

Communications and Decision Tools

Advances in solid-state electronic technology have fueled the development of low-cost reliable tools to assist public works managers in assessing their systems. These sensing and measuring devices, especially when coupled with information management systems, can provide extensive infrastructure condition and performance data for many decisionmaking and management tasks. They can also reduce long-term maintenance costs by helping managers to identify problems when they are less costly to correct and to set maintenance priorities when funding is tight. However, budget processes make it difficult for public works officials to purchase items designed to reduce future expenditures or those not directly related to current needs, and most current Federal grant categories preclude use for this sort of equipment.

Computer-based inventory and decision support systems provide efficient means of storing and accessing infrastructure condition and performance data. Expert systems and artificia1 intelligence programs show promise as training and engineering tools. Computer systems coupled with appropriate technical skills and decisionmaking tools can help public works authorities faced with expanding inventories of facilities and limited operating budgets operate more productively and efficiently.

Advances in communications and positioning technologies may make large-scale traffic management and control, common today in aviation, practical for other modes of transportation. Surface traffic flow gains on the order of 10 percent are possible, and in congested areas this might result in large reductions in delay. Off-the-shelf urban traffic signal control systems can reduce delay by up to 10 to 20 percent.

Construction and Materials

Considerable research is under way on materials for highway construction to yield longer life and lower maintenance costs. Improved methods and techniques for construction and preventive maintenance are as important as materials to prevent premature failure. Construction methods that do not physically disrupt normal operations and minimize the tra.file delays of traditional methods of construction are available for wider use in public works. Such methods are particularly cost-effective in congested areas and for heavily used facilities, and are also important for repair and rehabilitation projects.

Advanced tunneling technologies provide opportunities for lower cost construction for transportation and water projects. Combined with electronic guidance and monitoring equipment these technologies can make completing such projects easier and less costly.

Techniques such as soil nailing and jet grouting and using geotextiles make it easier to utilize existing soils and terrain conditions, lowering construction costs. Such techniques also can be used for cost-effective repairs and rehabilitation and deserve further exploration and development.

Although their initial cost is higher, advanced materials, such as polymers and composites, can yield higher strength, longer life, and improved durability to public works, making them good long-term investments. In addition, regular, preventive maintenance and using known techniques can save the costs and prevent many of the losses due to corrosion of infrastructure facilities and equipment.

Technology Management

Probably the greatest gains in public works productivity and efficiency will be made by focusing on changing management practices. Table 5-7 provides a summary of issues and alternatives.

Changes in the Federal Role

Federal policies could be shaped to encourage public officials to make greater use of procurement approaches that have proven successful for public projects. Using life-cycle costs and value engineering in making procurement decisions can help lower long-term costs without affecting project performance.

Table %7—Alternatives for Technology Management

Subject	Issues	Alternative
Project design	Engineers and designers have few incentives to introduce innovative technologies; designers and contractors are often legally prohibited from working together on public projects. Project designs direct contractors as to what to construct so they have no incentive to innovate except in construction techniques.	Design competitions, performance specifications, and value engineering furnish opportunities for innovative approaches.
Procurement	Low-bid procurement does not account for quality, performance over time, and future maintenance requirements. it encourages adherence to the status quo and stifles the opportunity for innovation.	Alternative procurement methods have proven successful in delivering higher quality products, often at a lower cost. Design-build procurement has been used to advantage in the private sector for many years.
Standards and specifications	Design standards are vaiuabie but they are difficult to change and hinder innovation. The scope of project specifications has expanded to include many provisions that address legal and administrative areas.	Streamlining design standards and contract specifications would be helpful. A materials testing laboratory could hasten new technology introduction.
Risk and liability	Public decisionmakers have little or no incentive to introduce a new technology; risk aversion is widespread in the public sector. industry is highly protective of proprietary technology.	Risk-sharing arrangements are necessary for the public sector to embrace new technology. Demonstration projects can encourage innovative technologies. Funding tied to performance may provide an additional incentive.
Repair and rehabilitation	Poor and deferred maintenance are known to lead to premature failures and deterioration of capital facilities, and yet decisionmakers often discount the long-term value of good maintenance,	inventories, condition assessment data, and preventive maintenance programs together with capital funding that is tied to these can force appropriate actions.
Personnel training, education, and recruitment	New technologies require new technical skills and too few engineers are entering the field to meet the need. improved training and education is needed so that innovative technologies can be put into use quickly and effectively.	Efforts to educate and train engineers and technicians that include the engineering profession, universities, consultants, and unions need private and public support to address the severe staff shortages.

SOURCE: Office of Technology Assessment, 1991.

Acceptance of new technologies requires a sharing of the financial and technical risks among designers, manufacturers or builders, and government agencies that finance and operate these technologies. Projects designed to evaluate, refine, and demonstrate innovative technologies in an operating environment would help promote new technology and provide a basis for determining their value. Such demonstration projects will require considerable public-private cooperation, and Congress could consider focusing a few R&D programs on promising technology areas and encouraging public-private arrangements.

The establishment of an authoritative institution for testing and approving new technologies would help avoid some of the current problems associated with risk and liability. Such an institution will require considerable support from the Federal Government (see chapter 6 for a discussion of the National Institute of Standards and Technology). An independent, national testing laboratory and national technology demonstration program **sponsored by the Federal Government could encourage researchers and facilitate the introduction of new products and technology.**

Even though preventive maintenance is an important component in protecting the investment in capital facilities, the value of maintenance is often discounted when the competition for limited budgets increases. Congress could consider ways to recognize deferred maintenance as a cost item and to hold the capital grant recipients accountable for premature deterioration of facilities and equipment due to improper and deferred maintenance.

Personnel Training, Education, and Recruitment

The complexity of much new technology places high demands on the technicians, operators, and maintenance personnel involved. The need for additional training of such personnel and their managers is very great if new technology is to be used effectively. Consultants, manufacturers, professional organizations, unions, and universities all can help provide training. Mentor programs that provide help to small systems would be particularly helpful.

The average age of infrastructure managers increases, and the numbers of young graduates in relevant fields to take the place of the retiring infrastructure work force are insufficient. The United States faces a serious shortage of qualified personnel to operate public works. Directing additional funds to programs that support university **research in transportation and environmental infrastructure could attract students back to transportation and civil engineering and alleviate the worsening shortage of qualified engineers to design, build, operate, manage, and maintain infrastructure systems. Congress could address the need for more engineers and for engineering curricula that includes attention to maintenance and rehabilitation.**

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.

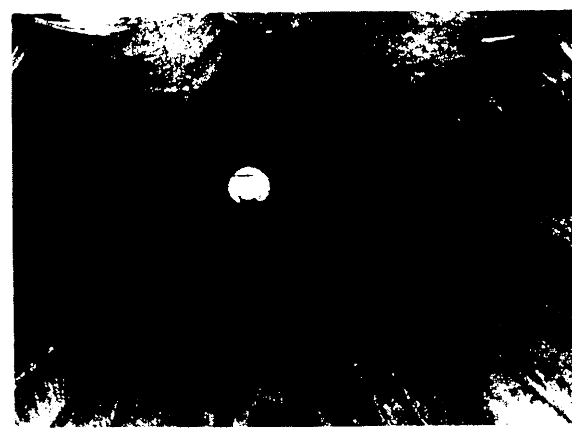


Photo credit: American Consulting Engineers Council

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 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.

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.

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.

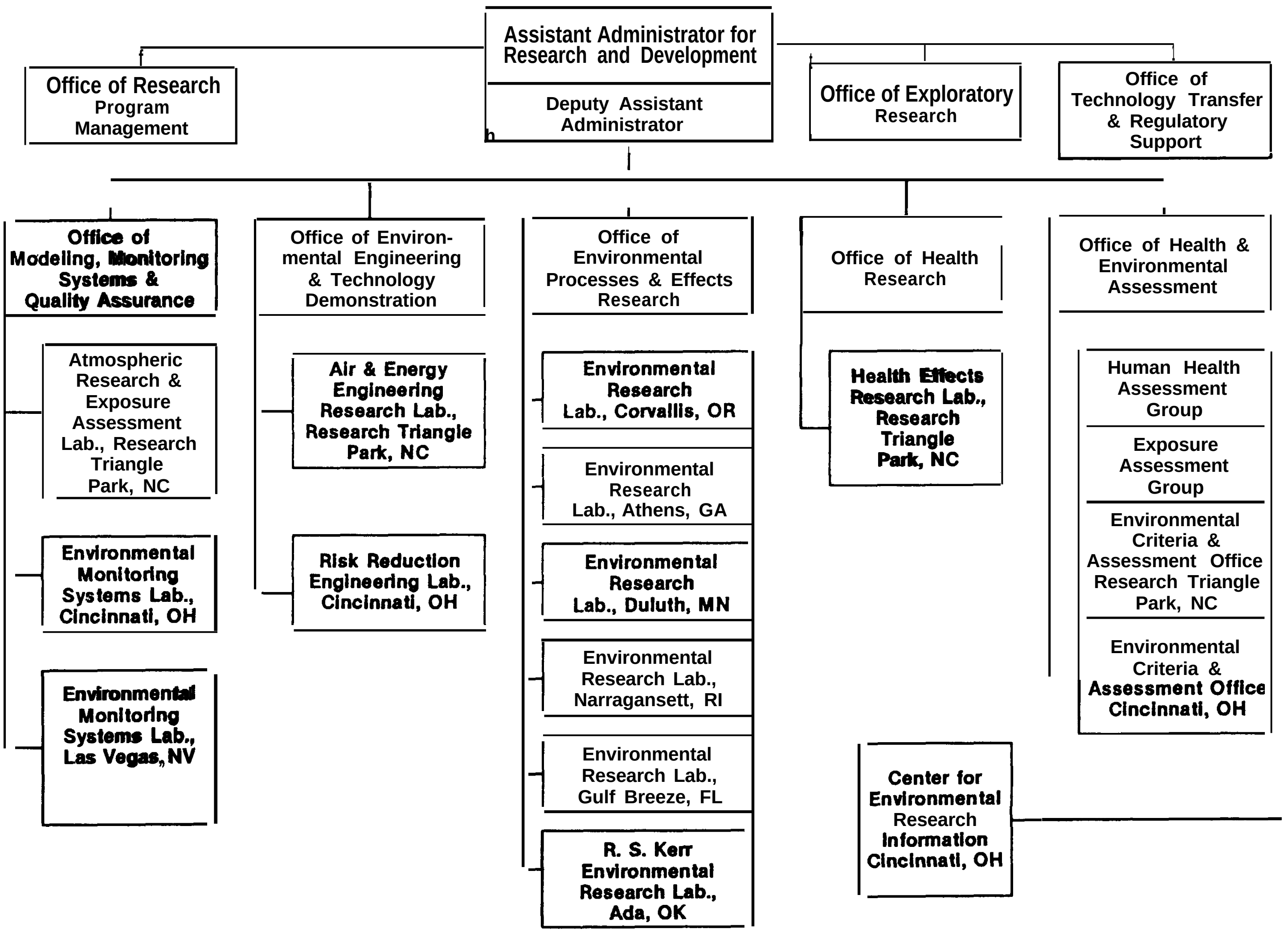
The Office of Environmental Processes and Effects Research administers six Environmental Research Laboratories that focus on marine and inland aquatic ecosystems. The laboratories are located in Oregon, Minnesota, Florida, Oklahoma, Georgia, and Rhode Island.

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 Administratlon	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]

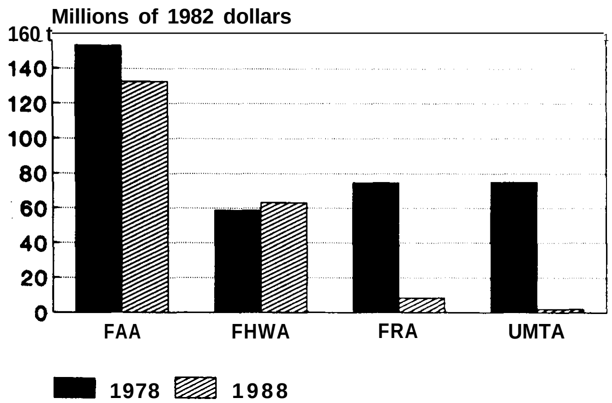
For a number of years DOT has used universities as outside R&D resources. About 71 percent of all Federal research funds for universities take the form of grants to individuals for specific research projects.[13] DOT invested $31.3 million in such contracts in fiscal year 1988,[14] with FAA allocating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

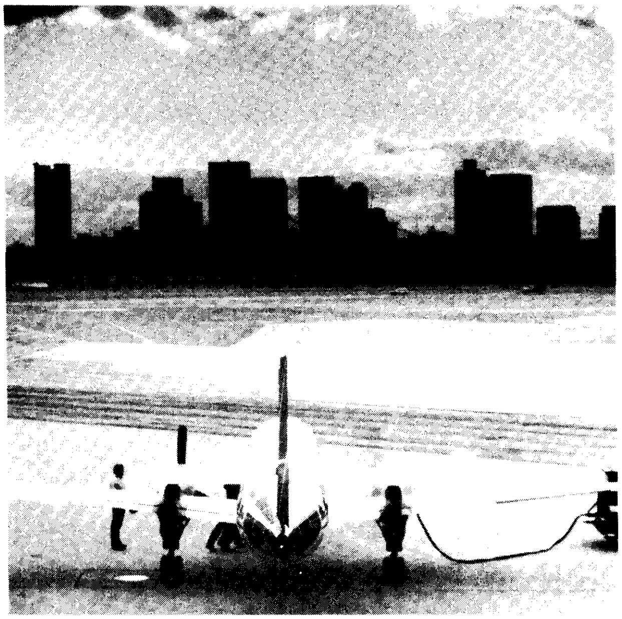


Photo credit: Federal Aviation Administration

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]

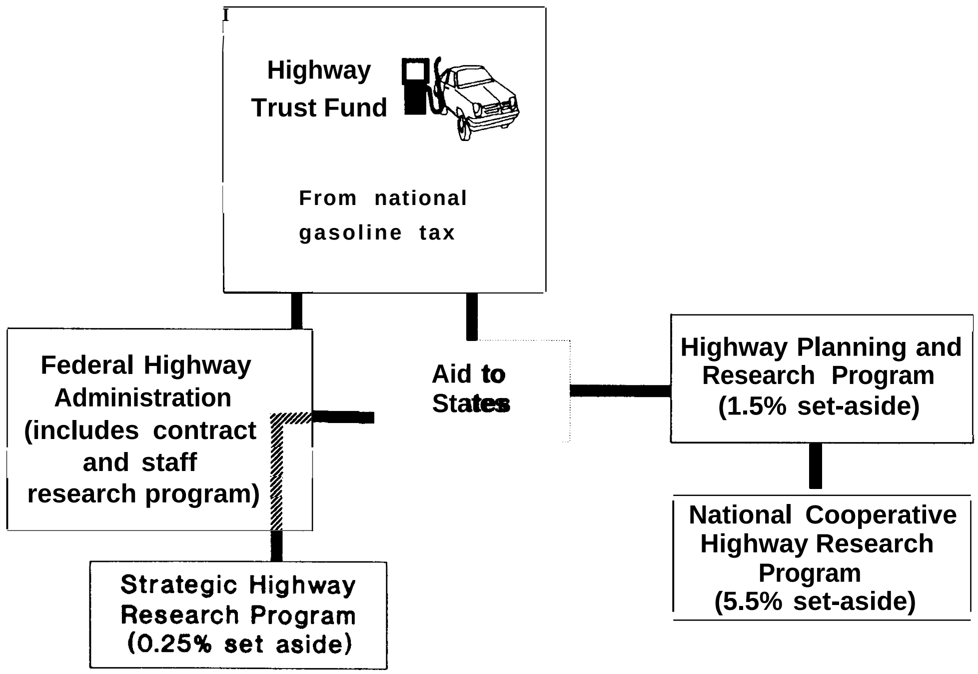
SHRP was established to examine gaps in current knowledge and the lack of coordinated R&D, and to target short-term, high-payoff technologies and issues. Congress included in Public Law 100-17 the release of $150 million from the Highway Trust

[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.

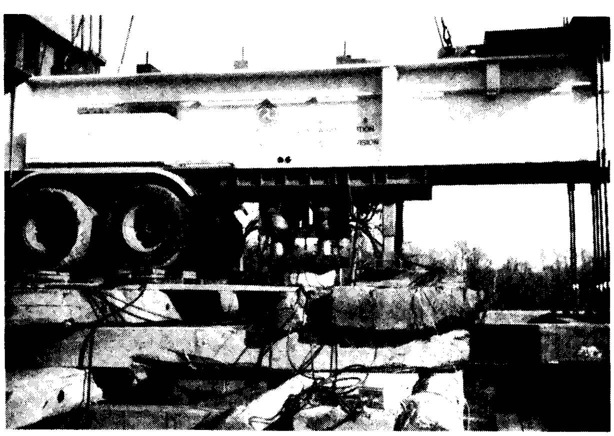


Photo credit: American Consulting Engineers Council

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 underinvestment 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 and Development Program (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 ear-marked 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

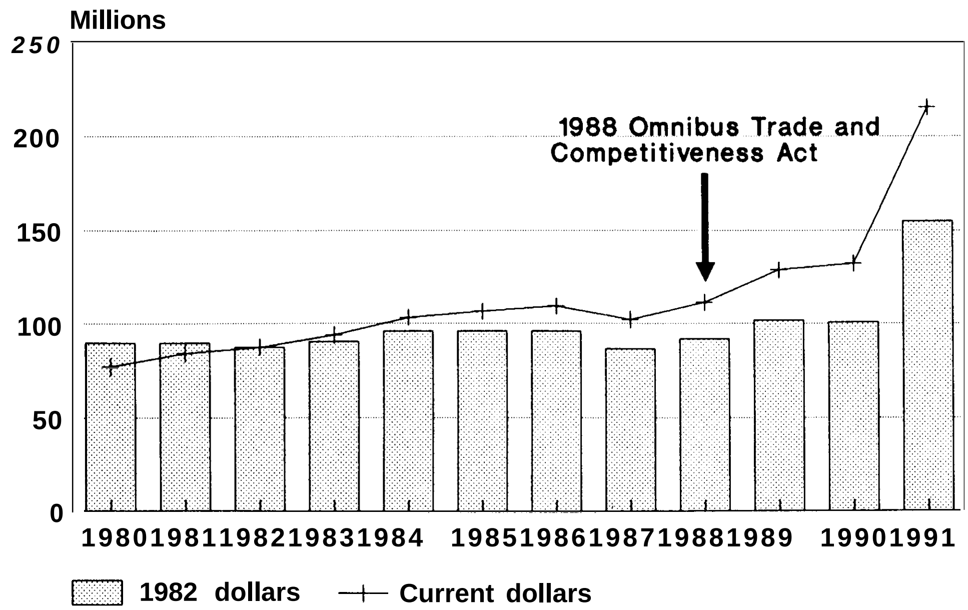
The Center for Building Technology of the National Institute of Standards and Technology has developed advanced methods for detecting flaws in concrete structures such as those in this runway.

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.

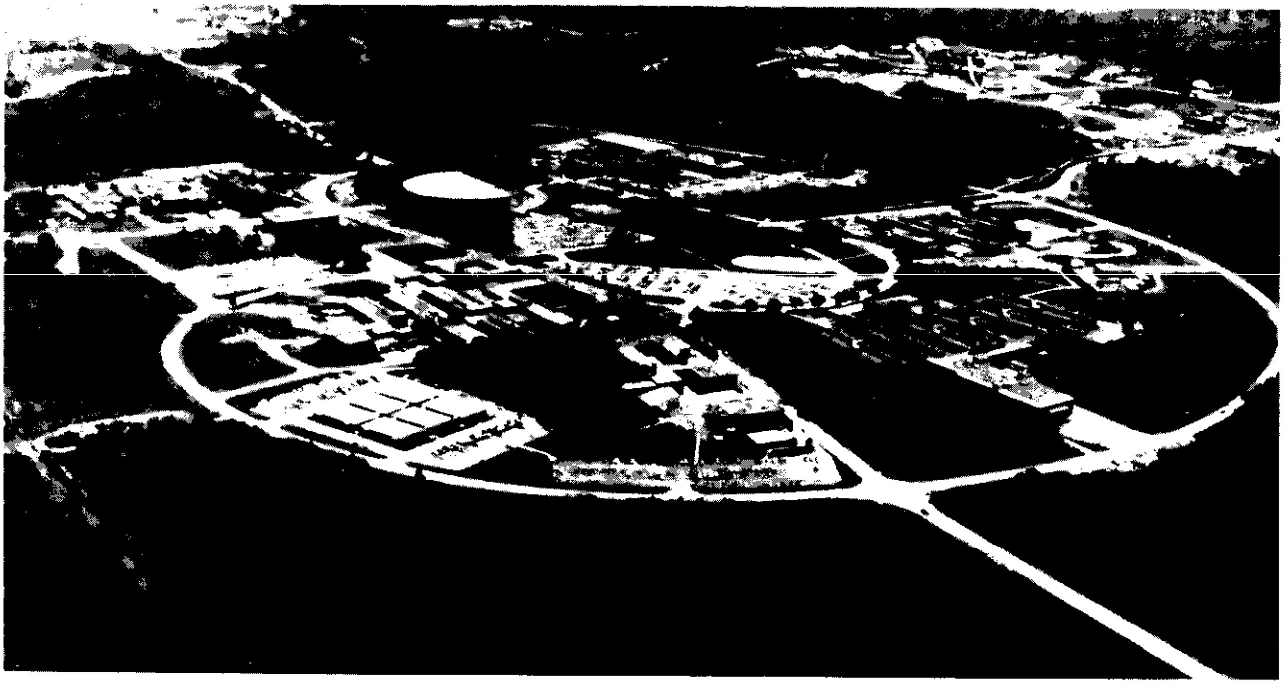


Photo credit: Argonne National Laboratory

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

[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, TechnoIogy, 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 censoria, 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

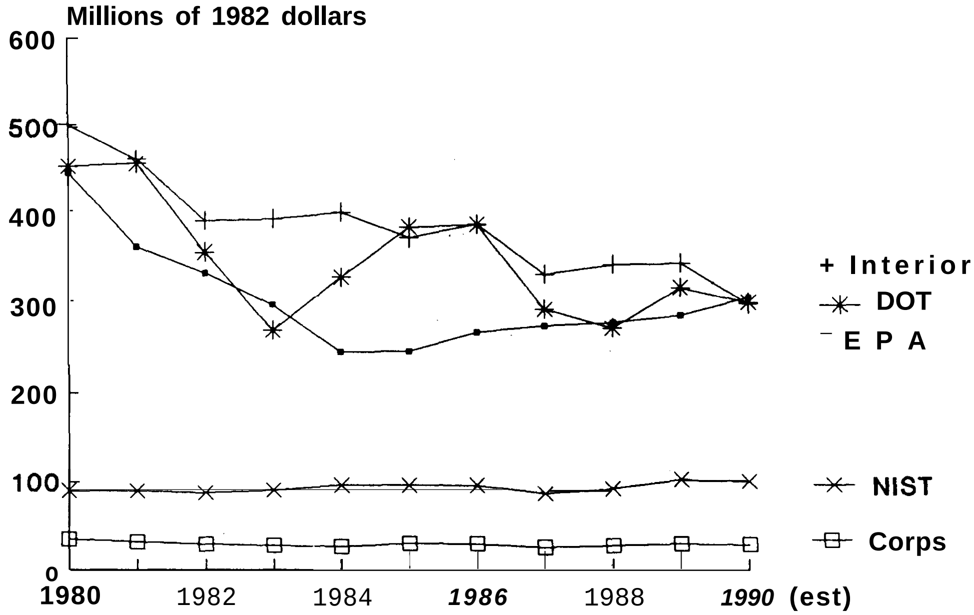
EPA's R&D is task-oriented due to the Agency's congressional mandate, its administrative structure, the immediate need for support of regulations, and limited funds.[64] The research now under way on broad environmental issues is focused on how to meet regulations, with little attention to identifying 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.

APPENDIXES

APPENDIX A
Fiscal Capacity and Effort Measures

Fiscal capacity is a concept developed by the U.S. Advisory Commission on Intergovernmental Relations (ACIR) to measure the relative revenue-raising abilities of States and their local governments, including taxes and nontax revenues, such as user charges. ACIR defines fiscal capacity as the relative amount of revenue States would raise if they used a "representative" tax and revenue system, consisting of national average tax rates and charges applied to 26 commonly used tax and revenue bases. Therefore, State capacities vary because of differ ing tax base characteristics, such as property values, sales tax receipts, and mineral production. For example, the effect of lower energy prices would adversely affect the fiscal capacity of those States that rely on energy-related taxes and user charges to raise a significant share of State revenue. The method developed by ACIR is only one of several methods to measure fiscal capacity, and some believe an analysis based on per-capita income, though much simpler, is equally useful.

ACIR also measures fiscal effort, or relative tax burdens, across States. (See table A-1 for State capacity and effort indexes and rankings.) Revenue effort is defined by ACIR as the burden that each State places on each revenue base relative to the national average.

Because the ACIR analysis is based on 1988 data changes have undoubtedly occurred in the index, but the general trends and relationships remain valid.

Table A-1—State Fiscal Capacity and Effort, 1988

	Fiscal Capacity[a]		Fiscal effort[a]			Fiscal Capacity[a]		Fiscal effort[a]	
	Index (100=U.S. average)	Rank	Index (100=U.S. average)	Rank		Index (100=U.S. average)	Rank	Index (100=U.S. average)	Rank
Alabama	77	46	95	31	Montana	84	40	102	18
Alaska	255	1	122	3	Nebraska	89	34	106	12
Arizona	97	22	97	29	Nevada	129	4	75	50
Arkansas	74	50	86	48	New Hampshire	123	7	66	51
California	115	10	98	27	New Jersey	126	6	95	34
Colorado	106	14	94	36	New Mexico	88	35	103	17
Connecticut	142	2	83	49	New York	110	13	141	1
Delaware	120	8	94	37	North Carolina	89	33	91	39
District of Columbia	126	5	137	2	North Dakota	85	38	107	11
Florida	103	17	87	46	Ohio	92	28	98	25
Georgia	93	27	98	26	Oklahoma	87	37	95	33
Hawaii	111	11	111	8	Oregon	91	29	104	16
Idaho	76	49	98	24	Pennsylvania	95	25	93	38
Illinois	100	19	95	35	Rhode Island	100	20	99	23
Indiana	88	36	96	30	South Carolina	78	44	102	20
Iowa	84	41	118	4	South Dakota	78	45	95	32
Kansas	91	30	104	15	Tennessee	84	42	89	42
Kentucky	80	43	89	43	Texas	95	26	89	45
Louisiana	84	39	97	28	Utah	76	47	109	9
Maine	97	23	99	22	Vermont	102	18	100	21
Maryland	111	12	102	19	Virginia	104	15	90	40
Massachusetts	131	3	89	44	Washington	98	21	105	13
Michigan	96	24	112	7	West Virginia	76	48	90	41
Minnesota	103	16	117	5	Wisconsin	90	31	117	6
Mississippi	65	51	108	10	Wyoming	118	9	105	14
Missouri	89	32	86	47					

[a] Based on State and local tax bases and other revenue sources, such as user charges, relative to the national average.

SOURCE: Advisory Commission on Intergovernmental Relations, 1988 *State Fiscal Capacity and Effort* (Washington, DC: 1990), p. 33.

APPENDIX B

List of Acronyms

AAR —Association of American Railroads
AASHTO —American Association of State Highway and Transportation Officials
AC —asphaltic concrete
ACIR —Advisory Commission on Intergovernmental Relations
ACTA —Alameda CorridorTransportation Authority (California)
ADS —automatic dependent surveillance
AERA —automated en route air traffic control
AGT —Automated Guideway Transit
AM/FM —automated mapping/facilities mapping
AMR —automatic meter reading
ASCE —American Society of Civil Engineers
ATC —air traffic control
ATM —Advanced Traffic Management
ATSAC —AutomatedTraffic Surveillance and Control
AVI —automatic vehicle identification
AVL —advanced vehicle location
AVM —advanced vehicle monitoring
BuRec —Bureau of Reclamation
CADD —computer-aided design and drafting
CBT —Center for Building Technology
CERL —Construction Engineering Research Laboratory
CFCS —chlorofluorocarbons
CFCF —Central Flow Control Facility
CFR —crash, fire, and rescue (services)
CIP —capital improvement plan
CNG —compressed natural gas
corps —U.S. Army corps **of Engineers**
CPAR —Construction Productivity Advancement Research program
CRREL —Cold Regions Research and Engineering Laboratory
CSO —combined sewer overflow
CUFT —Center for Utilization of Federal Technology
DCA —Department of Community Affairs (-Florida)
DCD —Department of Community Development (Washington State)
DCS —Distributed Control System
DOT —Department of Transportation
DoD —Department of Defense
EPA —U.S. Environmental Protection Agency
ESPs —electrostatic precipitators
FAA —Federal Aviation Administration
FHWA —Federal Highway Administration
FLC —Federal Laboratory Consortium
FmHA —Farmers Home Administration
FRA —Federal Railroad Administration
GA —general aviation
GIS —Geographic Information System
GOCO —Government Owned Contractor Operated
GPS —Global Positioning System
HEW —Department of Health, Education, and Welfare
HF —high frequency
HOV —high-occupancy vehicle
HP&R —Highway Planning and Research
HSGT —High Speed Ground Transportation (Act)
I/A —Innovative and Alternative Technology
ICAO —International Civil Aviation Organization
ICC —Interstate Commerce Commission
ICTF —Intermodal Container Transfer Facility (California)
IDAP —Infrastructure Development Assistance Program
IFR —instrument flight rules
ILS —instrument landing system
IVHS —Intelligent Vehicle/Highway System
IWTF —Inland Waterways Trust Fund ‘
JAL —Japanese National Airlines
JNR —Japanese National Railway
LFD —load factor design
LLWAS —low-level windshear alert system
LRFD —load and resistance factor desire
MARAD —Maritime Administration
MCL —maximum contaminant level
MGD —million gallons per day
MIU —meter interface unit
MIT —Massachusetts Institute of Technology
MLS —microwave landing system
MSW —municipal solid waste
MTU —master terminal unit
NAS —National Airspace System
NATM —New Austrian Tunneling Method
NCHRP —National Cooperative Highway Research Program
NCP —Nationally Coordinated Program
NDE —nondestructive evaluation
NEPA —National Environmental Policy Act
NHTSA —National Highway Traffic Safety Administration
NPDES —National Pollutant Discharge Elimination System
NPS —nonpoint source
NRWA —National Rural Water Association
NTSB —National Transportation Safety Board
NWS —National Weather Service
OER —Office of Exploratory Research
OMB —Office of Management and Budget
PACE —Program for Airport Capacity Efficiency (Massachusetts)
PCBs —polychlorinated biphenyls
PCI —Pavement Condition Index
POE —point of entry

POTW —publicly owned treatment works
POU —point of use
PRT —Personal Rapid Transit
PVC —polyvinyl chloride
PWTF —Public Works Trust Fund (Washington State)
R&D —research and development
RCRA —Resource Conservation and Recovery Act
RDF —refuse derived fuel
RO —reverse osmosis
RSPA —Research and Special Programs Administration
RTRI —Railway Technical Research Institute (Japan)
SCADA —Supervisory Control and Data Acquisition
SDWA —Safe Drinking Water Act
SHRP —Strategic Highway Research program
SOCs —soluble organic compounds
SRF —State Revolving Loan Fund
STAA —Surface Transportation Assistance Act
STCs —Science and Technology Centers
SWTR —surface water treatment regulations
TBM —tunnel boring machine
TEC —trenchless excavation construction
THMs —trihalomethanes
TRB —Transportation Research Board
TSC —Transportation Systems Center
UMTA —Urban Mass Transit Authority
URI —University Research Initiatives
VE —value engineering
VFR —visual flight rules
VOCs —volatile organic compounds
WES —Waterways Experiment Station
WIM —weigh-in-motion

APPENDIX C

Workshop Participants and Other Reviewers and Contributors

State and Local Infrastructure Management and Financing Workshop, July 7, 7989

Burton Stallwood, *Workshop Chair*
Town Administrator
Lincoln, RI

John Amberger
Executive Director
Southeast Michigan Council of Governments

Mary Boergers
Delegate
Maryland House of Delegates

Wayne Collins
County Engineer
Maricopa County Highway Department
Phoenix, AZ

Settle Dockery
Development Director
York Properties

John Gunyou
Finance Officer
City of Minneapolis, MN

John Horsley
Commissioner
Kitsap County, WA

Anthony Kane
Associate Administrator
Federal Highway Administration

Morgan Kinghorn
Deputy Assistant Administrator
U.S. Environmental Protection Agency

Byron Koste
President
Westinghouse Communities

Ian MacGillivray
Director, Planning Research
Iowa Department of Transportation

Donald Morse
Secretary/Treasurer
Kentucky Infrastructure Authority

Heywood T. Sanders
Associate Professor
Trinity University

H. Gerard Schwartz
Vice President
Sverdrup Corp.

Mary Simone
Mayor
RockSprings, Tx

Ron Wagenmann
Town Manager
Upper Merion Township, PA

Workshop on Transportation and Infrastructure Technologies: Slow Motion Progress in a Fast Forward World, July 25, 1989

John J. Fearnsides, *Workshop Chair*
Vice President
The Mitre Corp.

William H. Allen
Vice President
Parsons Brinckerhoff Quade & Douglas, Inc.

Carol Bellamy
Principal
Morgan Stanley & Co., Inc.

Harry Cooke
President
National Waterways Conference, Inc.

Chris Hendrickson
Professor
Carnegie-Mellon University

Gill Hicks
Manager of Transportation Planning
Port of Long Beach

Richard R. John
Deputy Director
Transportation Systems Center

Damian J. Kulash
Executive Director
Strategic Highway Research program

Richard Marchi
Director of Aviation, Planning and Development
Massport

Mel Olsen
Vice President for Capacity Planning
American Airlines

Robert E. Parsons
Director, Program on Advanced Technology
for the Highway
University of California-Richmond

Craig Philip
Vice President, Intermodal Division
Southern Pacific Railroad

Thomas Richardson
Chief, Engineering Development Division
Coastal Engineering Research Center
U.S. Army Engineering Waterways Experiment Station

Albert J. Sobey
Consultant

Vern Wagar
President
National Association of County Engineers

Henry W. Wedaa
Vice Chairman
South Coast Air Quality Management District

Workshop on Environmental /infrastructure Technologies: *Finding the Balance Between Performance and Regulation, September 14, 1989*

Al Aim, Workshop Chair
Senior Vice President and Director
Science Application International Corp.

John Convery
Deputy Director
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency

Patrick Gilligan
Manager
Brookings-Deuel Water System

Neil Grigg
Director
Water Resources Research Institute

Joseph Kavanaugh
Senior Process Engineer
CH2M Hill

Trudie Lay
Small Systems Program Manager
American Water Works Association

G. Wade Miller
President
Wade Miller Associates, Inc.

Henry M. Peskin
President
Edgevale Associates, Inc.

William Ross
Vice President
Roy F. Weston Co.

H. Gerard Schwartz
Vice President
Sverdrup Corp.

Edgar Smith
Civil Engineering Research Laboratory
U.S. Army Corps of Engineers

Whit Van Cott
Commissioner of Water
Toledo, OH

Hendrik Willems
Director, Washington Liaison Office for Engineering and Research
U.S. Department of the Interior

Charles Larry Wilson
Deputy Director
Arkansas Department of Pollution Control and Ecology

Materials Technology and Infrastructure Decisionmaking Workshop, *October* 5, 1989

Robert Baboian
Principal Fellow
Texas Instruments, Inc.

Stanley Barkin
Associate Director
National Materials Advisory Board

George F. Braun
Director, Engineering and Housing Support Center
The Society of American Military Engineers

John P. Broomfield
Technical Contract Manager for Concrete and Structures
Strategic Highway Research program

Victor Chaker
Corrosion Research and Materials Engineer
Port Authority of New York and New Jersey

Edward Escalante
Metallurgist
National Institute of Standards and Technology

Milon Essoglioli
Director, Research and Development
Naval Facility Engineering Command

John J. Gaudette
Assistant Executive Director
Program and Capital Development
Chicago Regional Transportation Authority

Hazel Gluck
President
Public Policy Advisors, Inc.

Robert E. Green
Director, Center for Nondestructive Evaluation
The Johns Hopkins University

Betsy Houston
Executive Director
Federation of Materials Societies

Jerome Kruger
Professor
Materials Science and Engineering
The Johns Hopkins University

Carl E. Locke, Jr.
Dean, School of Engineering
University of Kansas

Stanley V. Margolin
President
Network Consulting, Inc.

Eugene DeMichele
Director, Technical Services
Water Pollution Control Federation

Dale Miller
Director, Membership and Public Affairs
National Association of Corrosion Engineers

Tomoki Oka
Manager, Research Engineer
National Institute of Standards and Technology

Luis Ortega
Chief Architect
Civil Engineering Division
U.S. Coast Guard

Thomas J. Pasko, Jr.
Director, Office of Engineering and Highway Operations
Research and Development
Federal Highway Administration

Rayne G. Poussard
Manager, Public Affairs
United Parcel Service

Rick Ricker
Group Leader, Corrosion Group
National Institute of Standards and Technology

Murray A. Schwartz
Program Manager for Materials
U.S. Bureau of Mines

Carl Sciple
Assistant Director of Engineering for Construction
Massachusetts Port Authority

Richard H. Sullivan
Associate Executive Director
American Public Works Association

Gilbert M. Ugiansky
President
Cortest Engineering Services, Inc.

Y. Paul Virmani
Research Chemist
Federal Highway Administration

Donald M. Waters
Vice President
PSG Corrosion Engineering, Inc.

Harold H. Weber
Director of Industrial Programs
The Sulphur Institute

John D. Wood
Professor
Lehigh University

Other Reviewers and contributors

Blake Anderson
Orange County Sanitation Districts

L. George Antle
U.S. Army Corps of Engineers

Amy Baker
Florida Department of Community Affairs

R. Darryl Banks
Department of Environmental Conservation

Robert Bastian
U.S. Environmental Protection Agency

David Berg
U.S. Environmental Protection Agency

Robert K. Best
California Department of Transportation

Ray Beurket
American Public Works Association

Rosina Bierbaum
Office of Technology Assessment

Peter Blair
Office of Technology Assessment

Rebecca Brady
National Conference of State Legislatures

John P. Broomfield
Strategic Highway Research Program

Joseph F. Canny
U.S. Department of Transportation

William Carpenter
Martin Marietta Energy Applications, Inc.

Elliott chamberlain
Sverdrup Corp.

Frank Cihak
American Public Transit Association

Robert Clark
U.S. Environmental Protection Agency

Claudia Copeland
Congressional Research Service

Charilyn Cowan
National Governors' Association

Rich Davis
Southern California Rapid Transit District

Michael Deich
Congressional Budget Office

Eugene DeMichele
Water Pollution Control Federation

Neil N. Diehl
Ingram Barge Co.

Arlene L. Dietz
Us. Army corps of Engineers

Gordon English
Queens University, Canada

Norman D. Falk
University of New Mexico

Malachy Fallon
Standard & Poor Corp.

John Fischer
Congressional Research Service

Brian Frennea
Inland Rivers, Ports and Terminals, Inc.

Robert Friedman
Office of Technology Assessment

Geoffrey Frohnsdorff
U.S. Department of Commerce

Jerry Garman
U.S. Environmental Protection Agency

Rich Grady
Intergraph Corp.

Campbell Graeub
Transportation Research Board

James B. Groff
National Association of Water Companies

Ruth Hewitt
Ionia, Michigan Chamber of Commerce

Robert M. Hill
SRI International

John Hornbeck
Congressional Research Service

M. Leon Hyatt
Bureau of Reclamation

Thomas Iseley
Louisiana Tech University

Larry Jenney
Transportation Research Board

Peter Johnson
Office of Technology Assessment

Dan Jones
Office of the Mayor
Houston, TX

Joseph Kavanaugh
CH2M Hill

John Kelly
Oregon Department of Land Conservation
and Development

Elaine King
Transportation Research Board

Ken Kirke
Association of Metropolitan Sewerage Agencies

James Kreissl
U.S. Environmental Protection Agency

Richard Kuchenreither
Black & Veatch Engineers

Lester P. Lamm
Highway Users Federation

Thomas D. Larson
U.S. Department of Transportation

Jerry F. Lavelle
Tri-City Regional Port District

Howard Levenson
Office of Technology Assessment

Sue Lior
Roy F. Weston, Inc.

Steven Lockwood
Federal Highway Administration

James Manwaring
American Water Works Association

Wayne Marchant
U.S. Department of the Interior

Kathleen Marcucci
Lehigh University

Francis Mayo
Florence, Kentucky

Kenneth Mead
U.S. General Accounting Office

Dale Miller
National Association of Corrosion Engineers

Elizabeth Miner
U.S. Environmental Protection Agency

Arrigo Mongini
U.S. Department of Transportation

Jeffrey Mom
Urban Mass Transportation Administration

Karen Morehouse
U.S. Environmental Protection Agency

Mike Mulbarger
Cambridge, Massachusetts

Robert Niblock
Office of Technology Assessment

Don Niehus
U.S. Environmental Protection Agency

Reed Nielsen
Bechtel National, Inc.

Kent A. Olsen
Fluor Daniel, Inc.

Robert B. Oswald, Jr.
U.S. Army Corps of Engineers

Constantine N. Papadakis
University of Cincinnati

Lee Pasarew
U.S. Environmental Protection Agency

Thomas J. Pasko, Jr.
Federal Highway Administration

Michael Phillips
Office of Technology Assessment

Beth Pinkston
Congressional Budget Office

Richard Powell
American President Lines

Yvonne Pufahl
U.S. General Accounting Office

Karen Rasmussen
California Trucking Association

William Reilly
Transportation Research Board

John Reith
American Trucking Associations

Victor Rezendes
U.S. General Accounting Office

Rip Rice
Rice International Consulting Enterprises

Gary T. Ritter
Transportation Systems Center

Judith Rohrer
U.S. Environmental protection Agency

Donald Rote
Argonne National Laboratory

David Sanford, Jr.
U.S. Army corps of Engineers

David Schnare
U.S. Environmental Protection Agency

Neil D. Schuster
International Bridge, Tunnel and Turnpike Association

Sarah J. Siwek
Southcoast Air Quality Management District

Dennis R. Smith
Us. Army corps of Engineers

Ken Strom
Dames & Moore

Stephen J. Thompson
Congressional Research Service

John Trax
National Rural Water Association

Thomas Wehri
U.S. Department of Agriculture

Jacqueline Williams-Bridger
U.S. General Accounting Office

Carl Williams
California Department of Transportation

Roger Wolff
U.S. Department of the Interior

Leslie Wollack
National League of Cities

Richard N. Wright
U.S. Department of Commerce

Darwin Wright
U.S. Environmental Protection Agency

David York
Florida Department of Environmental Regulation

Michael Zywokarte
Federal Aviation Administration

Contractor Reports

Copies of contractor reports done for this project are available through the U.S. Department of Commerce, National Technical Information Service (NTIS), Springfield, VA 22161, (703) 4874650.

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