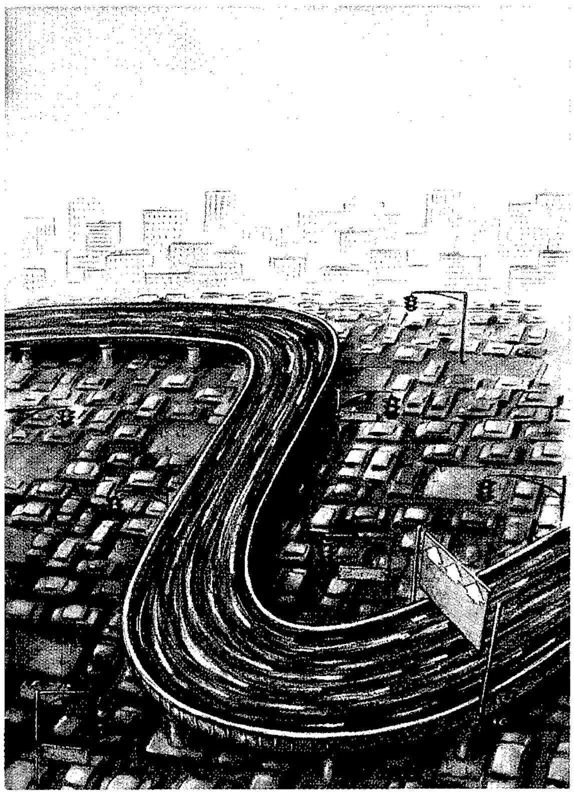
SURFACE TRANSPORTATION

PB99-160574



RESEARCH AND TECHNOLOGY ASSESSMENT

MAY 1999

About the National Science and Technology Council

President Clinton established the National Science and Technology Council (NSTC) by Executive Order on November 23, 1993. This cabinet-level council is the principal means for the President to coordinate science, space, and technology policies across the Federal Government. NSTC acts as a "virtual" agency for science and technology (S&T). The President chairs the NSTC. Membership consists of the Vice President, Assistant to the President for Science and Technology, Cabinet Secretaries and Agency Heads with significant science and technology responsibilities, and other White House officials.

Through the NSTC, Federal departments and agencies work cooperatively to ensure that Federal science and technology investments support national goals. NSTC Committees prepare R&D strategies that are coordinated across the Federal government to form a comprehensive investment package.

Call 202-456-6100 to obtain additional information regarding the NSTC.

Prepared by

United States Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
Transportation Strategic Planning and Analysis Office
55 Broadway
Cambridge, Massachusetts 02142-1093

Technical Report Documentation Page

1. Report No. DOT-T-99-22	2. Government Accession No. PB99-160574	3. Recipient's Catalog No.
4. Title and Subtitle SURFACE TRANSPORTATION: RESEARCH AND TECHNOLOGY ASSESSMENT		5. Report Date
		6. Performing Organizational Code
7. Author(s)		8. Performing Organization Report No.
9. Performing Organization Name and Address U. S. Department of Transportation Research and Special Programs Administration Volpe National Transportation Systems Center Kendall Square Cambridge, MA 02142		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Science and Technology Council Executive Office of the President Washington, DC		13. Type of Report and Period Covered May 1999
		14. Sponsoring Agency Code **DOT/RSPA**

15. Supplementary Notes
Released in cooperation with the U.S. Department of Transportation's Technology Sharing Program

16. Abstract
This report focuses on the role of the U.S. Department of Transportation as a partner in national interagency R&D and technology application efforts relating to advanced materials and technologies for improved infrastructure maintenance, rehabilitation, and renewal. An opening section summarizes the current condition and performance of major sectors in the Nation's surface transportation system. The report then categorizes technologies that are likely to improve transport system infrastructure functions and describes DOT Programs which supports them. Major programs are introduced which are designed to facilitate development and dissemination of technology applications to those organizations. Observations on programs which facilitate technology transfer are offered in conclusion. Research for this report included a review of recent literature and interviews with the developers and users of infrastructure technologies, from both the public and private sectors.

17. Key Words surface transportation; technology; infrastructure	18. Distribution Statement **Availability is unlimited. Document is being released for sale to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161**

19. Security Classif. (of this report) **Unclassified**	20. Security Classif. (of this page) **Unclassified**	21. No. of Pages 64	22. Price

Form DOT F 1700.7 (8-72) Per FORM PRO/Delrina 04/04/94 Reproduction of completed page authorized

Surface Transportation Research and Technology Assessment

May 1999

TABLE OF CONTENTS

Executive Summary iii

Introduction 1

1. Surface Transportation System Baseline Condition and Performance 4

2. DOT Research Programs and Promising Technologies 13

3. Technology Innovation and Dissemination Programs 27

4. Progress Made under ISTEA and Lessons Learned 39

5. Findings and Conclusions 44

Appendix A: Acronyms A-1

Appendix B: Estimate of R&T Funding of Physical Infrastructure Maintenance, Monitoring, and Renewal, FY 1998 ..... B-1

LIST OF FIGURES

Figure 1: The U.S. Transportation Infrastructure, 1995 1

Figure 2: Pavement Condition of U.S. Highways 5

Figure 3: Deficient Bridges in the National Inventory (1996) 5

Figure 4: Freight Tonnage Rail, Truck, and Total 6

Figure 5: Major Intermodal Rail and Maritime Terminals 9

LIST OF TABLES

Table 1: Department of Transportation R&D Funding FY 1997-1999 13

Table 2: Surface Transportation R&T Assessment
DOT Technology Innovation Programs 38

Executive Summary

Because more resources than ever before have been poured into surface transportation maintenance and reconstruction over the last six years, the United States has kept pace with its infrastructure maintenance needs. However, within the next ten to fifteen years, the number of crucial surface connections and arteries needing major renewal will swell, posing a challenge for officials charged with their stewardship. The task for these officials is to hold costs within the allocated resources, while keeping surface arteries open and functioning efficiently, not only during routine maintenance, but also during major renewal. Complicating matters further, recent data show that traffic congestion, always aggravated by maintenance activities, plagues more metropolitan areas now than it did just two years ago. Fortunately, powerful new technologies, materials, equipment, and methodologies are being explored that can help transportation professionals make infrastructure improvements better, cheaper, and faster. Unfortunately, however, despite concentrated efforts to speed the process, new technologies often penetrate the fragmented surface transport infrastructure marketplace only slowly.

This document reviews Federal research and technology (R&T) programs aimed at preservation of the surface transportation physical infrastructure through monitoring, maintenance, and rapid renewal. Relevant programs for all modes of transportation were examined, including the airport and port infrastructure that serve as critical connections to the primary surface transportation modes - highway, rail, and transit. This intermodal approach was essential to assure that the study considered the system impacts on surface transportation infrastructure – the ways that change in freight tonnage at ports affects road and railroad access requirements, for example. Key findings include the following:

- U.S. DOT research and technology programs for FY 1998 totaled about $1 billion. Of this amount, more than $900 million targeted the safety and efficiency of operations. Less than $100 million of DOT's 1998 R&T budget was dedicated to surface transportation infrastructure preservation.[1]

- Almost all DOT R&T programs that target infrastructure preservation are housed in the Federal Highway Administration (FHWA). FHWA devotes about 35 percent of its total R&T resources to this purpose.

- Many modal R&T programs use similar types of sensing, positioning, computer, and communications technologies to monitor or control operations and increasing throughput. The goal is to make operations safer and more efficient or faster. Many of these same technologies could be adapted to be very useful for infrastructure monitoring.

[1] Physical infrastructure security was not included in the scope of this study.

- Cross-modal efforts to leverage the synergies of such core technologies to improve intermodal operations are beginning in DOT; similar cross-modal applications should be considered for infrastructure preservation and renewal.

- Major technological advances have been made in two key areas for physical infrastructure preservation:

  1. The development of stronger, lighter, and more durable materials, useful for maintenance, renewal and life cycle cost reduction; and
  2. The development of remote sensing and non-destructive evaluation tools and related positioning and communications technologies. These are essential for condition monitoring and maintenance and rapid renewal scheduling and management.

- Wider adoption by State and local government agencies and industry of these new technologies and the management techniques they can support could save billions of dollars over the next few decades.

- Technology transfer programs aimed at deploying new technologies in the field have had some success for highway applications. Experts agree that R&T programs leading to technology innovations must be backed by validated performance results, strong incentives and technology champions. Only then will States be more likely to adopt the technologies and incorporate them as best practices.

Although this report provides an initial look at US DOT R&T programs for surface transportation infrastructure preservation, the findings point to several important additional policy questions that the Department should consider. These include:

- **Should more R&T resources be focused on surface transportation infrastructure preservation?** It can be argued that less than ten percent of the Agency R&T total is too small an amount relative to the crucial economic importance of a smoothly functioning physical surface transport system.

- **How much of the total R&T funding should be devoted to technology transfer and deployment and how are cross-modal applications best encouraged?** Since years of effort to improve the process have produced only modest success, wider use of structured incentives through project funding streams might be encouraged.

- **How should a DOT-wide focal point for the cross cutting, intermodal benefits of physical infrastructure preservation R&T be structured?** A major role would be bridging the significant gaps between the FHWA's efforts and the needs of the other modes for durable, high service, low maintenance surface transportation connections.

- **How should DOT ensure that environmental and safety issues related to system preservation are included in the research?** Environmental and safety issues are included in two of the Department's five strategic goals: safety, mobility, economic growth and trade, human and natural environment, and national security. No one of the goals should be diminished in the process of striving toward an individual goal.

- **What is the most effective way to channel incentives to deployments aimed at meeting intermodal needs?** This is an especially thorny issue, because ownership of intermodal linkages is often divided between the public and private sectors, and conflicting goals make partnerships challenging.

- **What benchmarks are appropriate for assessing the value and cost-effectiveness of R&T programs for infrastructure preservation and for guiding investment?** Because long-term infrastructure performance and accurate life-cycle cost savings are not known for many years, setting appropriate performance targets for infrastructure R&T is not easy.

Introduction

As the turn of the Century approaches, the United States is at the end of almost fifty years of building and expanding its surface transportation infrastructure, particularly the national highway system. During those years, older elements of the infrastructure such as the rail system and port connections have been pruned and reshaped. Much of this surface infrastructure, even those segments that were built or modernized relatively recently, has aged, with significant portions nearing (indeed, often exceeding) their original design lives. Thus, the infrastructure requires regular maintenance and extensive renewal to ensure preservation of the level of service that enables the Nation to meet its strategic goals of safety, mobility, and economic competitiveness. Simultaneously, freight volumes and passenger travel over the surface network have grown steadily, spurred by brisk domestic and international trade, a healthy economy, and logistics technologies that have made travel and shipping more efficient. This trend is projected to continue.

Much of the Nation's far-flung transportation network (see Figure 1) is aging and costly to maintain, and suffers periodic service disruptions for repairs or reconstruction. Since businesses today depend on just-in-time deliveries to keep inventory costs low, surface artery closures for maintenance or reconstruction cause costly delays in meeting tight

<u>Surface</u>

• Highways and roads	3.9 million miles
• Highway Bridges	581,862
• Airports	5,400 public use, including 29 large hubs
• Intercity rail	170,000 miles
• Urban rapid rail	9,582 miles

<u>Linking</u>

• Petroleum and natural gas pipelines	190,000 miles
• Navigable waterways	26,000 miles
• 600 ports, and 10,000 waterfront facilities (82 percent privately owned)	

Figure 1. The U.S. Transportation Infrastructure, 1995

Source: *Condition and Performance: 1997, Status of the Nation's Surface Transportation System, Report to Congress*, U.S. Department of Transportation, Federal Highway Administration and Federal Transit Administration, p. 7; and *Transportation Statistics Annual Report 1997*, U.S. Department of Transportation, Bureau of Transportation Statistics, pp. 4-5.

shipping schedules. Good performance from the Nation's physical infrastructure is equally important to transportation system users, general taxpayers, and the Government. Moreover, the performance depends on segments of surface infrastructure that are privately owned and maintained, such as railroad tracks, as well as those owned and maintained by public entities, such as most roads and bridges.

Regardless of ownership, efficient, cost-effective tools and techniques are needed for monitoring the condition of the infrastructure; for programming and carrying out timely, efficient, cost-effective maintenance; and for rapid renewal. Yet, the methods, tools, and materials used for the construction and maintenance of vehicles and transportation infrastructure tend to change very slowly. This often is because infrastructure decision-makers choose to minimize the initial investment or want to limit the risk of possible unforeseen future consequences from using relatively untried technologies. Moreover, because the U.S. infrastructure renewal markets generally are localized and limited, industry is not motivated to perform advanced R&D. In this market context, low profit margins must be anticipated for innovative products.

Recognizing these factors, an Infrastructure Renewal Subcommittee of the National Science and Technology Council (NSTC) Interagency Coordinating Committee on Transportation R&D was charged with developing a strategic R&D plan for transportation. The plan was completed and published in 1997, and one of the goals outlined in the plan was to focus R&D programs on technology partnerships for monitoring, maintenance, and rapid renewal of the physical infrastructure.[1] The intent is to encourage all Federal agencies to explore uses of new materials and associated technologies for infrastructure renewal engineering. Infrastructure renewal is a core element of the Administration's Technology Policy, as well as of the 1997 DOT *Strategic Plan.*

This report focuses on the role of the U.S. Department of Transportation as a partner in national interagency R&D and technology application efforts relating to advanced materials and technologies for improved infrastructure maintenance, rehabilitation, and renewal. Relevant programs for surface transportation infrastructure in the Federal Aviation Administration (FAA), Federal Highway Administration (FHWA), Federal Rail Administration (FRA), Federal Transit Administration (FTA), Maritime Administration (MARAD), Coast Guard (USCG), National Highway Traffic Safety Administration (NHTSA), and Research and Special Programs Administration (RSPA) were reviewed. Every effort was made to take a 'systems' view of surface transportation, to ensure that intermodal concerns were addressed.

---

[1] National Science and Technology Council, Committee on Transportation Research and Development, Intermodal Transportation Science and Technology Strategy Team, *Transportation Science and Technology Strategy*, September 1997, p. 17.

Chapter 1 of this report summarizes the current condition and performance of the major sectors of the Nation's surface transportation system. A complete listing of acronyms used in this report is provided in Appendix A. Chapter 2 categorizes the technologies that are likely to improve transport system infrastructure functions and describes DOT programs supporting them. Chapter 3 introduces the major programs designed to facilitate development and dissemination of technology applications to those organizations with responsibility for surface transport physical infrastructure. Chapter 4 offers some observations on programs for facilitating technology transfer, and criteria for success. Finally, Chapter 5 presents findings and conclusions. Research for this report included a review of recent literature and interviews with the developers and users of infrastructure technologies, from both the public and private sectors.

Chapter 1

Surface Transportation System Baseline Condition and Performance

The well being and vitality of the surface transportation infrastructure are essential to the safety, mobility, and economic prosperity of the Nation. In direct expenditures alone, transportation-related activities account for about 11 percent of the U.S. Gross Domestic Product. The underpinnings for these activities, transportation infrastructure systems, must be restored, renewed, preserved, and strengthened on a regular basis while they continue to serve the ever-growing and changing transportation needs of our Nation. To assess the role that technological innovations could play in making stewardship of the surface infrastructure system more efficient and cost-effective, potential applications of new technology must be evaluated against a system condition and performance baseline. This chapter reviews the condition and performance issues related to surface transportation infrastructure maintenance and renewal specific to roads, railroads, and transit, and the related links to airports and ports and waterways. Although the focus of this report is a systems look at surface transportation R&T programs, transportation statistics and research agendas are developed, managed, and published modally. Therefore, modal descriptions and information are necessary, with a return to a systems perspective as appropriate and useful.

Roads and Bridges

According to the FHWA, the average condition of pavement continues to improve. However, more than six percent of all pavement is in need of immediate repair; an additional thirteen percent will require attention within five years to avoid being rated in poor condition (see Figure 2).

While the condition of the nation's bridges also continues to improve, approximately 27 percent, or about 93,000, bridges are classified as deficient. Functional deficiencies, such as being too narrow, are slightly more prevalent than structural deficiencies, such as design load limitations (see Figure 3).

The Federal Highway Administration estimates that maintaining current physical conditions on existing roadways and bridges without raising costs to the users of the system would require an investment of about $29 billion annually: $23.5 billion for highways and $5.6 billion for bridges. Capacity-related improvements to keep congestion near current levels call for another $17 billion annually.[2] In 1995, only about $17.5 billion of the $35 billion in total capital expenditures on public roadway infrastructure (excluding local roads

---

[2] U.S. Department of Transportation, *1997 Condition and Performance*, p. 55.

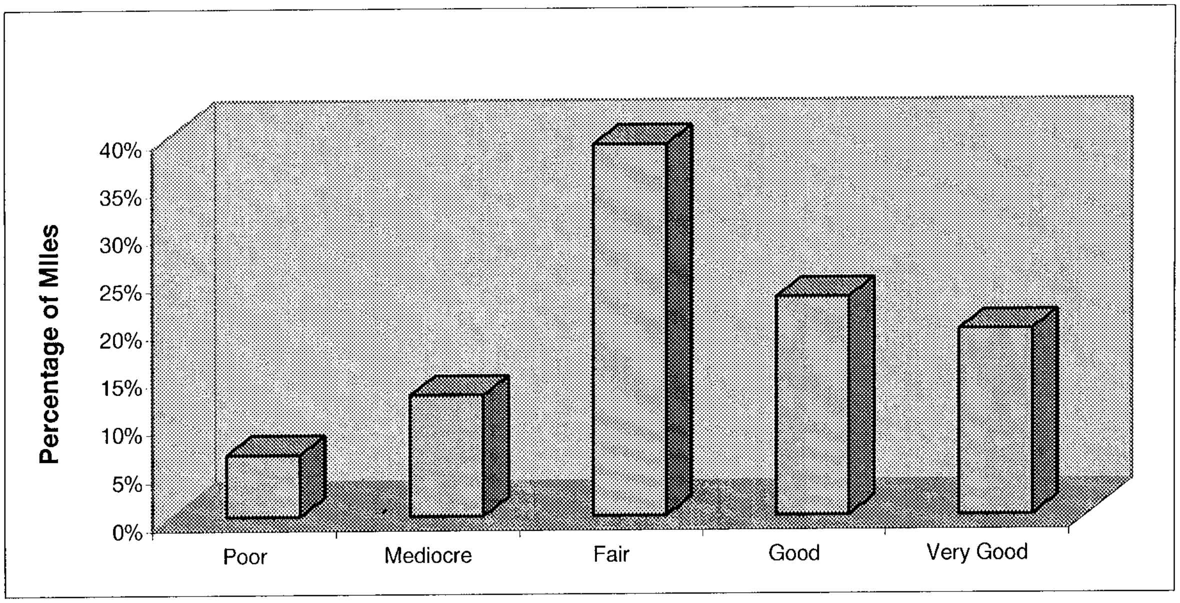


Figure 2. Pavement Condition of U.S. Highways

Source: U.S. Department of Transportation, *1997 Condition and Performance*, p. 26.

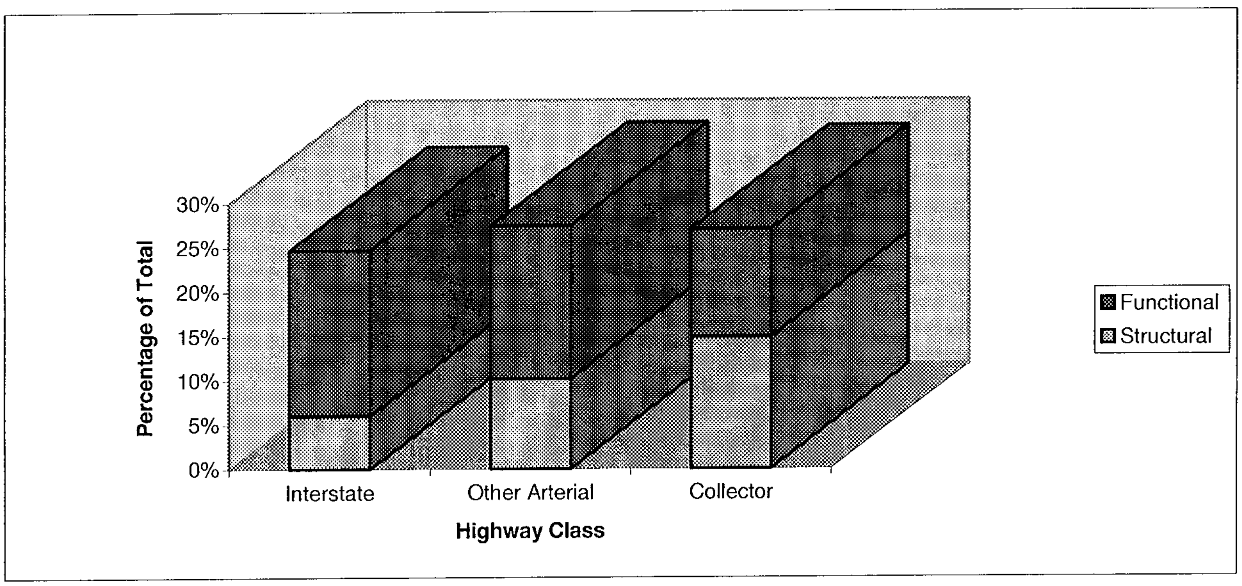


Figure 3. Deficient Bridges in the National Inventory (1996)

Source: U.S. Department of Transportation, *1997 Condition and Performance*, pp. 28-29.

and streets) went toward preserving or upgrading existing facilities to meet current design standards. Of the remainder, $8.9 billion in capital investment was directed toward improved capacity, $5.4 billion was invested in new roads and bridges, and $3.2 billion was invested in other improvements such as safety features, traffic control systems, and noise barriers.[3] In addition to capital investments, $44.8 billion was spent on non-capital expenditures, including $24.5 billion for maintenance.[4]

As encouraged by the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, states and localities have increased the emphasis on system preservation, maintenance, and operations. In constant dollars, spending for highway maintenance and operations (including research and administration) grew at twice the rate of total highway spending from 1960 to 1993. This trend is expected to continue as the massive highway construction associated with building the Interstate Highway System draws to a close. However, highway infrastructure needs are expected to grow over the coming decade, with both freight and passenger travel continuing to climb. Figure 4 shows the growth trend in U.S. freight tonnage for railroads and trucks, and the total for all modes.

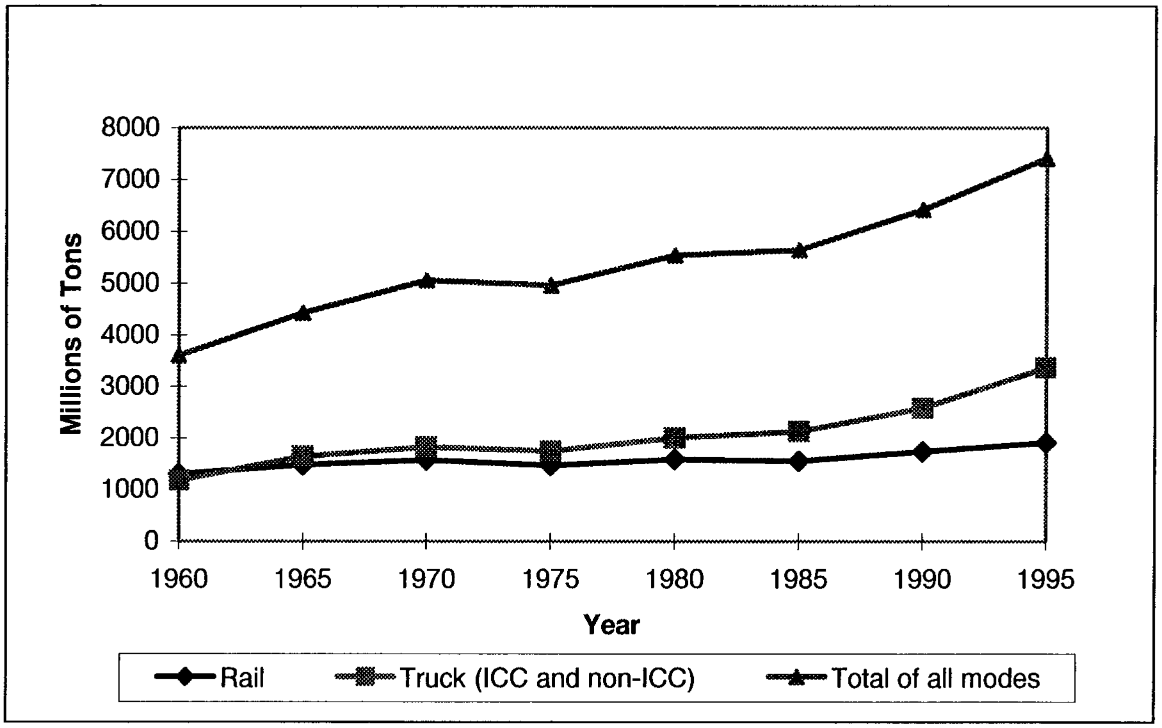


Figure 4. Freight Tonnage Rail, Truck, and Total

Source: The Eno Transportation Foundation, Inc., *Transportation in America: Historical Compendium, 1939-1995*, 1997, p. 19.

[3] *Ibid.*, pp. 45-46. About $80 billion would be required to materially improve conditions to achieve optimum economic efficiency.
[4] *Ibid.*

As traffic on the Nation's network of roads and streets increases, the most heavily traveled segments become overloaded, severely degrading operational performance. Since 1985, traffic on urban Interstate highways has grown steadily at an average rate of 2.4 percent per year. The result is that congestion within segments of the highway network is increasing. Between 1990 and 1995, the portion of peak-hour urban Interstate highway travel occurring under congested conditions rose from about 50 percent (1990-92) to about 52 percent (1993-95). Congested roadways indicate the need for technologies and techniques to monitor infrastructure condition and determine remaining service life, and for rapid reconstruction and renewal processes that minimize their contribution to congestion.

Transit

The U.S. transit system consists of 537 public transit operators in 316 urbanized areas.[7] Urban mass transit use is concentrated in large cities with both bus and rail service, including metropolitan New York City (the largest single mass transit market), Los Angeles, San Francisco, Chicago, Washington DC, Philadelphia, and Boston. In 1995, the national transit system included the following:

- 43,577 buses with 17.0 billion passenger-miles;
- 8,725 rapid rail and light rail vehicles with 11.4 billion passenger-miles;
- 4,413 commuter rail vehicles with 8.2 billion passenger-miles;
- 68 ferries with 243 million passenger-miles; and
- 12,825 demand response vehicles with 397 million passenger-miles.[8]

Local governments dominate the operation and maintenance of public transit systems, as well as funding some construction, but state governments are playing an increasing role in transit system support. Federal outlays by the FTA include grants to States and local agencies for the construction, acquisition, and improvement of mass transportation facilities and equipment, and for the payment of operating expenses. The FTA Grants Program provides funding to transit agencies for both buses and infrastructure. States can also draw on Congestion Mitigation and Air Quality (CMAQ) funding for environment-related improvements, as well as other Surface Transportation program (STP) flexible funds for certain transit activities. Since 1988, FTA has provided capital grants to transit agencies for purchase of over 2,000 alternative-fuel buses operating on ethanol, methanol, liquefied gas, and compressed natural gas. In addition, FTA provides research funding. Other current infrastructure improvements are driven by the need to meet requirements mandated by the Americans with Disabilities Act, such as the upgrade or installation of gates, signage, and station monitors. Some funding also is directed towards the physical security of transportation facilities and their patrons.

---

[7] U.S. Department of Transportation, 1997 *Condition and Performance*, p. 7.
[8] U.S. Department of Transportation, *Transportation Statistics Annual Report* (TSAR) 1997, p. 5.

In addition, investments are being made with Federal assistance in modernizing older facilities. Even the relatively new systems, such as the Washington (DC) Metro system and the Bay Area Rapid Transit system (BART), are approximately twenty years old. As these systems age, they require increasingly large maintenance programs to maintain an acceptable reliability and safety level. Federal aid targeting system modernization and renewal has paid off in improved infrastructure conditions. For transit and commuter rail infrastructure, the condition of power stations, systems, bridges and tunnels, and maintenance improved between 1984 and 1995. In 1995, 73 percent of elevated structures were judged to be fair to good condition, and 73 percent of track and 61 percent of stations were in good to excellent condition.[9] A survey of urban bus maintenance facilities in 1995 found that 74 percent were in good or excellent condition, also a significant improvement over previous assessments. However, all these structures will need continued investments to sustain acceptable performance.

Railroads [10]

The U.S. railroad industry has been transformed significantly since the enactment of the Staggers Rail Act of 1980. The changes that have occurred in the railroad industry over the past two decades (and continue still) have been as radical as any that have taken place during the industry's 175-year history. By gaining the flexibility to negotiate rates and choose routes, the industry has been able to respond more effectively to market demands. The outcome has been the emergence of a small number of larger, more profitable carriers carrying more freight tonnage and passengers, as well as providing more freight-miles and passenger-miles. This has been accomplished with fewer employees, terminals, track miles, railcars, and locomotives. Revenues for Class I railroads in 1995 totaled $32.3 billion, and they carried a total of 1.7 billion ton miles of cargo. This is an increase 42 percent from 1980. Profitability was at an all-time high.

In 1995, the nation's railroad infrastructure consisted of about 170,000 miles of track owned and maintained by freight railroads and Amtrak. Figure 5 shows the locations of major intermodal rail and maritime terminals having significant annual lift capacity or container throughput. Activities at these terminals have major impacts on other surface transport infrastructure connecting links.

The average tonnage hauled per train also has increased from 2,144 tons in 1980 to 2,849 tons in 1995. This trend has affected the need for track maintenance, for which industry expenditures have been rising moderately over the past ten years. In 1995, Class I railroads spent $3.3 billion on track maintenance, representing 12 percent of their total operating expenditures.

[9] U.S. Department of Transportation, 1997 *Condition and Performance*, p. 38.

[10] Information on railroads is from *National Transportation Statistics (NTS) 1997*, U.S. Department of Transportation, Bureau of Transportation Statistics, pp. 237-238; and *TSAR 1997*, pp. 4, 8.

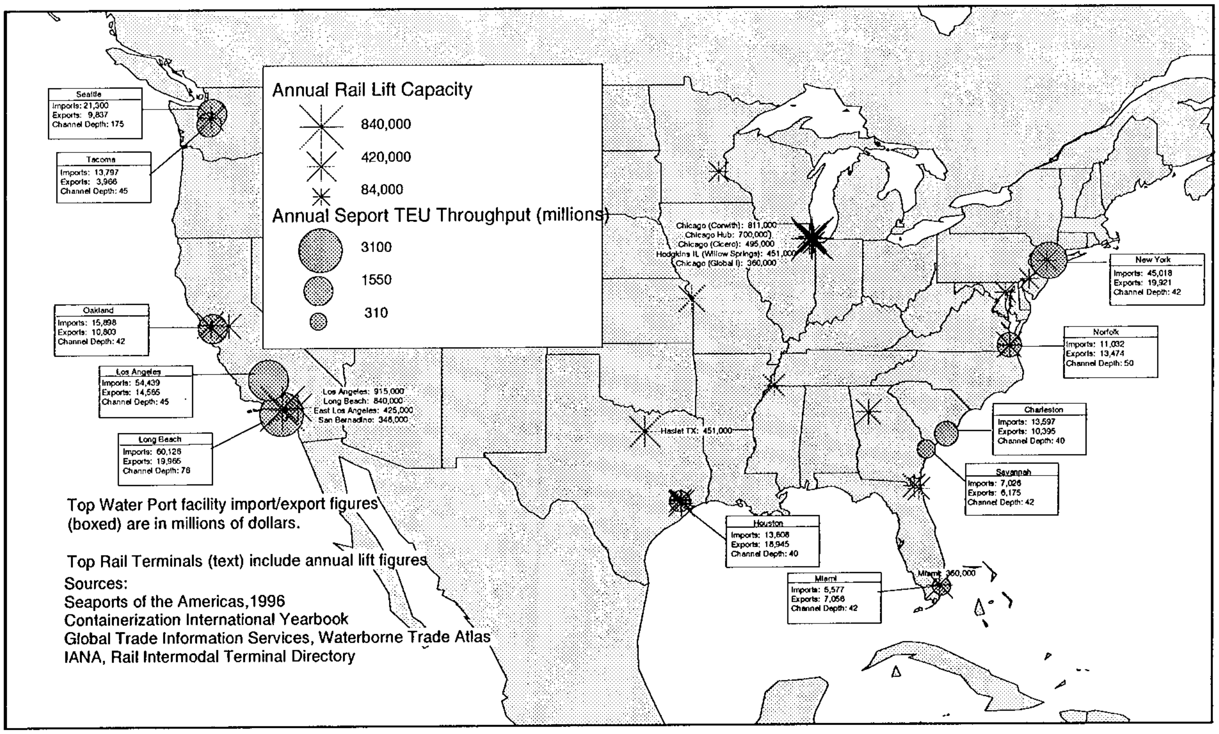


Figure 5. Major Intermodal Rail and Maritime Terminals

Amtrak is the nation's only intercity passenger railroad. With the exception of a few high-density corridors (particularly in the northeastern United States, Los Angeles, and Chicago), freight railroads own the tracks and infrastructure used by Amtrak and commuter railroads. Amtrak carried 20.7 million passengers and produced 5.5 billion passenger miles on intercity routes in 1995, for revenues of $1.5 billion. Amtrak operates many of the Nation's commuter railroad services for transit agencies. Commuter rail traffic has been the most rapidly growing segment of the railroad industry, with the number of passenger trips increasing by 27 percent over the past ten years.

Railroad and grade crossing fatalities declined significantly from 1960 through 1995, with fatalities down by nearly 40 percent and grade crossing accidents down by nearly 60 percent. Human factors and track defects are considered to be the most significant causes of these accidents; 35 percent of accidents are attributable to human factors, while track defects account for 34 percent of the accidents. Equipment defects and other factors are responsible for the remainder.

The last ten years have brought increases in infrastructure investment, steady growth in international trade, and mounting demand for timely delivery of freight. These trends have forced changes in railroad operating characteristics that may affect the durability of the existing track structure, including the following:

- Higher axle loads, resulting from increases in the average gross weight per train due to changes in load types and new double-stack cars for hauling containers;
- Increased traffic density, due to growing domestic trade and intermodal freight demand;
- Higher locomotive speeds, to meet demands imposed by competitive pressures and just-in-time requirements;
- Aging, because the risk of track defects relating to bridge failure or material degradation increases as the infrastructure ages; and
- Reduced maintenance labor capacity - as one indicator of maintenance labor capacity, the number of maintenance workers per track mile, has been declining steadily.[11]

Ports and Waterways

Ports are big business. The nation's maritime facilities include 26,000 miles of navigable inland rivers and intra-coastal waterways, and 3,740 port facilities. In 1995, a total of 1.1 billion tons of domestic freight was transported through the U.S. waterways. Roughly 60 percent of the domestic waterborne trade moved on inland rivers and canals, 30 percent on coastal waterways; and another 10 percent on the Great Lakes. The value of waterborne international exports and imports traded in international commerce in 1995 totaled $620.4 billion, with the greatest concentration at the ports of Long Beach, Los Angeles, and New York/New Jersey. All goods move to ports by surface transportation; thus, improvements in ports and waterways inevitably create more landside traffic, affecting already congested highways and freight rail connections.

Indeed, at the most active ports, demand for railroad and roadway access currently is increasing due to growing container movements, larger vessels, and bigger trucks. Container throughput, which measures the capacity of the marine infrastructure, has risen by nearly 200 percent over the past fifteen years in the continental United States, from approximately six million 20-foot equivalent unit (TEUs) in 1980 to just under 17.7 million TEUs in 1995. Also in recent years, container vessels have increased in size from 3,900 TEU containers to more than 5,000 TEUs, and "megaships" of greater than 6,000 TEUs are being deployed in world trade. Corresponding increases in truck volume, axle size, weight, and turning radius requirements to move these heavier containers already are placing heavier demands on highways at seaports.

In addition, pavement and bridge damage from excessive container weight can be significant. A survey conducted several years ago indicated that approximately 40 percent

[11] GAO, *Rail Transportation: Federal Railroad Administration's New Approach to Railroad Safety*, GAO, Report to Congressional Requesters, July 1997, estimates that the number of workers per 100 miles of track declined by approximately 25 percent from 1976 to 1995.

of the exported containers and 25 percent of the imported containers moving through U.S. ports exceeded the FHWA limits for their respective container/chassis weight. Many ports are reluctant to enforce highway weight limits, fearing a loss of shipping business in this highly competitive industry.

Finally, responsibility for managing ports and waterways and performing maintenance and monitoring functions is shared by Federal, state, local, and private entities. Federal agencies involved in marine transportation include the U.S. Coast Guard, U.S. Army Corps of Engineers, National Oceanic and Atmospheric Administration (NOAA), Environmental Protection Agency (EPA), Department of Defense (DOD), and MARAD. Environmental considerations, including wetlands protection and coastal land use regulations, limit the ability of many ports to provide additional landside access.

Airports

The United States has over 5,400 public use airports providing the Nation with the infrastructure and services necessary for successful operation of the world's largest aviation system. In 1995, the air transportation system accommodated 5,567 passenger aircraft that flew a collective total of over 4.6 billion miles. Flying in those aircraft were more than 548 million enplaned passengers. In addition, 12.5 billion domestic ton-miles of freight were transported by air in 1995.[13]

Airport runways, taxiways, and aprons are discussed in this report, because the results of aviation-related pavement R&T programs are applicable to surface transportation infrastructure in other modes. The total investment in airport surface infrastructure currently exceeds $100 billion. In several respects, runway performance and condition are as critical to safe airport operations as air traffic control. First, runway operations can minimize the risks associated with weather. From 1980 to 1991, 130 aircraft accidents were directly attributed to runway overruns and veer-offs resulting from snow, ice, water, and rubber deposits on runways. In addition, pavement outages and downtime for maintenance and rehabilitation contribute to the costs associated with aviation system delays. Many research and technology efforts are directed toward reducing the impact of runway maintenance and other pavement outages on airport traffic operations, thereby reducing overall aviation system delays. In addition, the FAA airport research and technology program is seeking to improve runway traction and safety characteristics

To accommodate the next decade of anticipated strong growth in global aviation, the Federal government continues to make substantial investments in airport infrastructure, including airport pavements. In 1994, FAA planners approved some 1,500 applications

[13] U.S. Department of Transportation, *NTS 1997*, p. 212.

for airport runway projects to preserve, improve, and expand the over 650 million square yards of airport runway pavement. For the past several years, annual funding for airport surface infrastructure activities has been approximately $2 billion, with most of this funding directed toward the 67 largest airports.[14]

Summary

Federal funding and resources devoted to highway maintenance and operations by States and localities have increased to all-time highs, and the recent Transportation Equity Act for the 21st Century (TEA 21) of 1998 authorizes continued historic levels of spending. Despite these increases, however, there is room for improvement. Transit agencies face the dual challenge of renewing the oldest systems such as New York and Boston, and the simultaneous maturing of newer systems, like those in San Francisco and Washington DC. Commuter rail passenger growth has required expansion and modernization for many systems. Although progress has been made in reversing deterioration for the older facilities, continued renewal and some major reconstruction will be necessary over the coming decades for every transit system's infrastructure.

The Nation's port and railroad infrastructures also must modernize and renew while coping with increasing demand. The number of intermodal container movements is growing. In addition, there are significant increases in the size and configuration of the ships and trains carrying the containers and the trucks moving the containers to their final destinations. This creates more demand for landside access and intermodal facilities, particularly at the most active ports. The responsibility for maintaining and managing the maritime infrastructure is spread among multiple public and private sector entities. This greatly complicates making decisions about large infrastructure and surface access project financing and implementation.

Technology can and should play a pivotal role in meeting the demands for maintaining infrastructure in good working condition, providing better service, and keeping preservation and life-cycle costs as low as possible. However, for technology to be effective, the rate of adoption by those responsible for project implementation must accelerate. The following chapters identify key technologies and point to promising avenues leading in the direction of realizing their capabilities.

[14] Approximately half of this annual investment in surface infrastructure is provided through the FAA Airport Improvement Program's Grants-in-Aid to Airports, with the other half is provided by State and local governments and airport operators. Airport Improvement Program funding comes primarily from the aviation ticket tax, the receipts of which are deposited into the Airport and Aviation Trust Fund.

Chapter 2

DOT Research Programs and Promising Technologies

Materials, construction practices, and infrastructure use in the United States vary dramatically from region to region. However, regardless of regional location, the life span of surface transportation infrastructure is measured in multiple decades, and the impacts of major technology advances will be realized only over time. Thus, infrastructure facilities stay relatively constant, while the communities they serve and the demands placed on them change in major ways. In this context, a constellation of institutional factors must be favorable for new techniques and methods for maintaining and renewing an aging, relatively unchanged facility to be acceptable and successful. Moreover, because transportation innovations often result from advances in a wide range of scientific and engineering disciplines, support for broad-scale continuing research is necessary to provide a solid foundation for 21st century transportation technology. Recognizing this, the U.S. DOT is spending close to $1 billion dollars for R&D programs in recent years, allocated as shown in Table 1.

Table 1.
Department of Transportation R&D Funding
FY 1997-1999
(Dollars in Millions)

	FY 1997	**FY 1998**	**FY 1999 (Request)**
Federal Highway Administration	$495.6	$426.4 *	$462.4
Federal Railroad Administration	46.3	41.2	42.9
Federal Transit Administration	46.0	57.4	58.2
National Highway Traffic Safety Admin.	56.8	62.9	72.4
Other (e.g., FAA, MARAD, OST, RSPA, USCG)	282.1	270.9	258.0
Total	**$926.8**	**$858.8**	**$893.9**

- Includes funding of $226 million in FY 1998 for the ITS program.

Source: U.S. DOT Office of Budget and Programs

A cross-modal array of DOT and selected other Federal R&T programs were reviewed to identify technologies that were developed with their assistance and that potentially could address monitoring, maintaining, and renewal for surface transport infrastructure. The review focused on sensing, computer, and telecommunications technologies; advanced rapid construction methods; advanced materials; computer-based planning, modeling, and asset management tools; data systems; and non-destructive testing techniques. The underlying premise is that innovations in these areas would provide a solid basis for advancing the state-of-the-practice for infrastructure preservation and renewal to realize cost and durability advantages. For example, computer modeling and planning tools could analyze proposed changes in road and railroad connecting infrastructure to ensure that they will be able to handle future increases in intermodal container movements at international ports. Sensing, telecommunications, and computer technologies already in place for highway traffic management could be used for condition monitoring, thereby enabling cost-effective scheduling of maintenance and reconstruction.

Research and Technology Context

The review revealed that surface transportation research sponsored by U.S. DOT modal agencies addresses priority problems in accordance with each agency's official mission and the concerns of its respective constituents. The R&T problems addressed, indeed the majority of DOT R&T agendas, focus overwhelmingly on safe and efficient operations for all modes. FHWA, which in recent years has received about one-half of the Department's R&D funding, is the only DOT branch that has devoted substantial research resources to stewardship of the physical transportation surface infrastructure. FHWA supports research into durable materials that require less maintenance; non-destructive bridge and pavement evaluation technologies; and data collection and analysis from which preferred pavement maintenance and rehabilitation strategies can be derived. These items are critical to state Departments of Transportation, FHWA's constituents, which have primary responsibility for building and managing most of the interstate and other major national highway systems. The FHWA also promotes the development and implementation of bridge management systems (BMS) to assist in making cost-effective bridge replacement, maintenance, and rehabilitation decisions. About one-third of FHWA's total R&T budget, amounting to $77.2 million in FY 1998, is devoted to infrastructure preservation and renewal. (For a detailed breakout of FHWA's programs and funding support for that year, see Appendix B.)

In other modes, such as MARAD, FRA, and FAA, surface transportation infrastructure stewardship is not the primary agency mission and does not receive significant R&T resources.[16] At the FRA, for example, most R&T activities focus on railroad safety because that is the Agency's foremost responsibility. Furthermore, most railroad infrastructure is owned by private sector freight companies, which operate largely without Federal funding. Indeed, only one FRA research program — bridge monitoring, funded at about $200,000 in FY 1998 — was identified as being aimed at infrastructure preservation.[17] The majority of the FAA's substantial R&T program funding supports safety-related research and technologies for air traffic control modernization, which is largely a renewal of the FAA operational infrastructure. That Agency recently has supported its Airport Pavement Research Program at an annual level of $5 million.

Despite understandably different modal missions, goals, and constituencies, DOT R&T programs, including those focused on operations, already explore many technologies that are adaptable for infrastructure preservation. The remainder of this chapter describes a cross-section of DOT modal research programs to illustrate the technology opportunities available for other applications already supported within the Department.

Technologies Adaptable to Monitoring

Sensing, locating, and communications technology applications tied to computers and databases increasingly are being used in all modes to improve operations. In some cases, especially for highways and transit, these applications come under the heading of Intelligent Transportation Systems (ITS). Intelligent Transportation Systems involve the effective application of advances in communications, navigation, sensor, and information processing technologies to transportation. These technologies in some form are being implemented in all modes, but a strong Federal role in ITS for highways and transit was authorized in ISTEA, which provided an annual DOT budget of approximately $200 million for ITS research and demonstration activities. Support for ITS is continued by the TEA 21 reauthorization.

Within DOT, the ITS Joint Program Office (JPO) is responsible for Department-wide coordination and planning of ITS activities. The JPO is located in the FHWA; other DOT organizations that are active in ITS are the FTA, NHTSA, FRA, RSPA and the Office of the Secretary.

Following are examples of DOT-sponsored ITS and related technology R&T programs that could be adapted for infrastructure monitoring:

---

[16] While infrastructure stewardship is an important FTA mission, infrastructure renewal and rehabilitation has not recently been a top priority for FTA R&T. The majority of FTA's grant recipients operate only bus systems, and do not maintain their own infrastructure. Those transit agencies maintaining their own rail infrastructure receive significant capital funding from FTA's fixed guideway investment program for renewal of rolling stock and facilities.

[17] Federal Railroad Administration, Office of Research and Development, April 1998.

Highways and Transit: Several sensor-based ITS applications are contributing to improved roadway operations and routine maintenance. For example, a network of "smart structures" — roadways, bridges, and tunnels embedded with sensors — may be implemented to support Advanced Traveler Information Systems (ATIS). Such systems provide the traveling public with real-time information on weather and road/railroad conditions for specific locations so that they can make more informed transportation choices.

A different application of these systems aids State DOTs. More than $2 billion is spent annually on winter road and railroad maintenance in North America, including significant wasted effort in anticipation of storms that fail to materialize. With better forecasts of inclement weather, agencies have found that they can improve their productivity and performance through more effective allocation of labor and equipment. Detailed information about icing and wet conditions from sensors embedded in rights of way can be used for assessing roadway and railroad conditions and dispatching plows, as well as for guiding the appropriate application of sand, salt, and de-icing chemicals. This saves money and reduces the infrastructure corrosion associated with these substances. The FHWA has identified twenty-four sensor-related weather projects, including Road Weather Information Systems (RWIS), in twenty-one States.[18] Five States (North and South Dakota, Colorado, Nevada and Washington) are developing statewide RWIS using both weather and roadway sensors. Pavement sensor systems using infrared sensors are being developed for maintenance trucks (Indiana and Vermont) as well as for embedded roadway condition monitoring sensors (New York). Most of the remaining weather-related applications monitor the impact of fog and storm conditions on driver visibility.

A number of existing weather and roadway information/monitoring systems use wireless communications between sensors and remote processing units (RPUs), which transmit the collected data to a central management site. The potential gains for infrastructure condition monitoring using such systems are significant. In addition to reporting on surface conditions, embedded sensors could be used to monitor the internal physical condition of infrastructure components, facilitating the scheduling of maintenance and rehabilitation efforts. To do this successfully, the sensor system must be integrated with a data collection, processing, and analysis infrastructure, and combined with diagnostics and failure prediction models. Because such systems would be costly and would require specially trained staff to operate effectively, a benefit/cost calculation should be performed for each potential installation. Investment analyses for these multi-purpose monitoring systems are more likely to be most favorable for high-volume bridges and road segments in areas with frequently dangerous weather conditions. However, anticipated savings in reduced chemical usage and personnel overtime would quickly pay for these investments.

[18] Eileen Singleton, "Weather Synthesis Report," prepared for the FHWA Weather Workshop, June 17-18, 1997, *passim.*

Transportation and law enforcement agencies at the State and local levels, as well as the railroad industry, have relied for decades on a variety of telecommunications systems to support their operations and maintenance activities. These include both wireline (primarily telephone) and wireless systems, such as fixed base and mobile radio communications. The rapid evolution of information systems and telecommunications technologies in recent years, however, has significantly expanded both the quality and quantity of the available options. Many organizations are using these new, inexpensive, and reliable telecommunications services to enhance their effectiveness. Wireless communications and EDI protocols also are used to expedite intermodal cargo movements among ships, railroad freight cars, and trucks. Before automated systems were available, when cargo tracking was done manually, it often took the drayage carrier hours to pick up or drop off a load. Now that automated systems are available, the movement may be completed in fifteen minutes. The U.S. Customs Service has made such automated bill of lading and cargo tracking systems available to commercial users since 1993.

One of the most dramatic new trends is the use of complex, high-volume wireline networks for voice, video, and data transmission. With the introduction of cable and fiber optics to supplement the traditional copper wire configuration, the amount of data that can be carried on such a network has increased exponentially. Many jurisdictions are implementing their own long-distance wireline communications networks for public purposes, but the potential of these new technologies for infrastructure monitoring has not yet been tapped. Indeed, as shown in Box 1, many state networks were put in place for purposes other than transportation.

Rail: The FRA sponsors operational safety research that uses sensing and communication technologies. Railroad track inspection using automated inspection cars has enabled railroads to store track-related data in an active database to monitor track performance and quantify changes in track conditions between surveys. Global Positioning Systems (GPS) are used to transmit data for both analysis and control. Elements of the track defect detection program include the following:

- Automated Track Inspection Program (ATIP) - The FRA has developed a high-speed track geometry vehicle to detect track defects and non-uniformities due to train speeds, tonnage, weather, geographic conditions, and normal wear and tear. The FRA's Office of Safety operates the Track Geometry Survey Vehicle (T-10), which uses advanced electronic sensing and data processing, to obtain track measurements to be used to monitor compliance with the Federal Track Safety Standards (FTSS).

- Gage Restraint Management System (GRMS) - This system, developed for the FRA by the Volpe National Transportation Systems Center in partnership with the railroad industry, is an automated technology that measures the ability of track to maintain the proper distance between two rails under a variety of service load conditions.

Communications-based train control systems, the subject of FRA-sponsored research under the Positive Train Control (PTC) Program, could have significant implications for infrastructure monitoring and maintenance. The hard-wire signal systems are likely to be replaced with a system of on-board computers linked by digital data radio to control center computers. Pole lines carrying communications and signaling circuits, which are costly to maintain, are being replaced with microwaves, fiber optics, and integrated digital voice and data systems.

Concerns have been raised that broken rail detection capability would be lost as these systems supplant the current track and wayside-based signal circuits. However, recent industry-sponsored research has shown that track circuits are effective only in detecting broken rails that are completely separated when broken, as in rail pull-apart during cold winters due to excessive tensile stresses. Research also indicated that track circuits did not offer any warning in the case of partially broken rails, as may result from the growth of internal material defects due to fatigue. FRA believes that implementing positive train control does not necessarily justify the elimination of all track circuits. FRA is also funding the development of a prototype alternative locomotive-mounted device for detecting broken rails ahead of a moving train. Positive train control minimizes wayside equipment needs, and changes the established design, procurement, operation,
and maintenance practices. It can increase effective capacity; improve running time, asset utilization, and reliability; and enhance safety by reducing the risk of collisions.

Ports: Federally-sponsored maritime programs use sensors, radio frequency devices, wireless systems, radar, satellite-based communications, and software systems, the same types of technologies used by road traffic managers, to monitor and manage navigation and port operations. MARAD, in conjunction with industry, has two ongoing cooperative research programs using these technologies to facilitate cargo handling by ports. One of these programs, the Marine Terminal Automated Management System (MTAMS), represents a pioneering effort by MARAD and the port industry to develop an automated terminal control system that would enhance the accuracy and timeliness of information related to terminal operations. It is designed to provide an on-line inventory of containers, cargo, and chassis, and their respective locations. This inventory is updated by transactions entered at the five major operating nodes within a terminal: gate, yard office, window office, container control, and vessel planning.[19]

[19] One variation on such an automated system is the Maher Terminals' chassis-mounted container system (CMCS). This system is used to make equipment selection decisions, provide directions at strategic locations, monitor activity and report exceptions, control inventory and equipment usage, and provide current and historical data. Maher terminals use an on-line real-time terminal management computer system with major modules for terminal operations, manifest systems, equipment maintenance, chassis pool operations, off-terminal (inland) tracing, and financial reporting system.

Box 1
A Step toward Monitoring:
State and Local Telecommunications Activities

Montgomery County, MD has developed a master plan for *FiberNet.* This is a 550-mile broadband fiber optic network, which eventually will provide voice, data and video services to all county departments (including transportation, social services, consumer affairs, health, and administration, as well as the public schools and libraries) at an estimated cost of about $22 million. The Montgomery County DOT will use *FiberNet* to carry signals from the thousands of traffic signals, variable message signs, video surveillance cameras and other devices in the county Advanced Traffic Management System (ATMS).[20] Once installed, the network should have sufficient capability to carry signals from embedded sensors and other monitoring and maintenance-related devices in addition to the ATMS applications.

As in Montgomery County, nearly every major urban ITS program includes a metropolitan communications network to carry the vast quantity of video, voice, and data transmissions required of such installations. Typically, these networks consist of hundreds of miles of fiber optics and electronics equipment connecting thousands of deployed devices to central Traffic Management Centers. More advanced networks are being developed for the four 'Model Deployment' Intelligent Transportation Infrastructure sites (New York, San Antonio, Phoenix and Seattle) as well as for Atlanta, Boston, Cincinnati, Houston, and Minneapolis. A number of state agencies and turnpike authorities, in places as diverse as New York, Ohio, Maryland, and Missouri among others, are implementing similar systems or are proposing to use their highway rights-of-way to construct long-distance fiber optic lines. The excess capacity of these lines, after transportation needs are met, can generate additional revenue by being sold or rented to other users.

Once in place, a communications line — whether traditional copper, cable or fiber optic — along a roadway or railroad facilitates the placement of road/railroad condition and weather sensors and monitors at specific locations. Thus, a weather information or infrastructure condition monitoring system along a highway or railroad is much easier to install and operate in conjunction with an effective communications network along the corresponding right-of-way.

The Ports and Waterways Safety Act of 1972 (as amended) gave the Coast Guard the responsibility to construct, operate, and maintain a Vessel Traffic Services (VTS) System, a shore-based waterways management and communications system, at ports that need it for navigational safety. VTS combines the use of surveillance equipment (principally radar),

[20] *Montgomery County FiberNet Master Plan: The Montgomery County Information Highway for the Twenty-first Century*, March 1995, *passim.*

closed-circuit television, radio, and software for control of traffic in navigable waters. VTS helps to determine the presence of vessels in and around ports, and provides information to vessels on such matters as position, traffic flow, tides, weather, and port emergencies. One of the system's functions is to minimize the risk of grounding by providing oversight and guidance for vessel docking, thereby improving the utilization of existing berths. The U.S. Coast Guard has installed and operated VTS in eight major ports: New York, San Francisco, Houston-Galveston, Puget Sound, Valdez, Morgan City, Louisville, and Sault Saint Marie.[21]

Airports: The FAA is the principal sponsor of airport pavement research and technology initiatives. Based on input from airport operators, air carriers, and aviation associations, key runway pavement research priorities are identified and pursued through the FAA's Airport Pavement Technology Program. This program, which received over $5 million in FY 1997, is coordinated at the FAA Technical Center, in Atlantic City, NJ.[22]

For many years, airport pavement research and technology has benefited from advances in the much larger field of highway research, as well as from Department of Defense research supporting military aircraft and airfields. However, the weight of the next generation of large civil aircraft may well exceed that of military aircraft. Due to their proposed weight and landing gear configuration, these aircraft will have unique effects on runway pavement. The FAA has initiated pavement monitoring and maintenance efforts to address these impacts. As one example, to better understand the behavior of airport pavements under operational conditions, the FAA initiated the Airport Pavement Instrumentation Project in 1992 at the new Denver International Airport (which was under construction at the time). Through an interagency agreement with the Army Corps of Engineers' Waterway Experiment Station, various sensors were embedded in sections of one runway. Data from these sensors are collected and stored in an FAA database and are accessible through an FAA (AAR-410) web server.

Technologies Adaptable for Maintenance and Rapid Renewal

Technical advances in the defense and consumer sectors have produced a rich inventory of advanced materials and associated structural concepts, tools, and techniques for their use. Examples include high-performance concrete, new steel alloys, innovative composite materials and adhesives, imaginative structural concepts, computer-aided design techniques, automated construction and maintenance tools, and new approaches to corrosion protection and control. Ongoing research in these areas supports the application of these features to the transportation infrastructure. These applications may include demonstrations of effectiveness, suitability for rapid component placement, long-term durability, reduced need for maintenance, and the reduction of costs to a competitive level.

---

[21] GAO, *Marine Safety: Coast Guard Should Address Alternatives as It Proceeds With VTS-2000*, Report to Congressional Requesters, April 1996.

[22] Other public and private entities also engage in runway pavement research and technology efforts; with few exceptions, these efforts are funded by, guided by, or in other ways connected to the FAA's runway pavement research activities.

High-performance construction materials include high-performance concrete (HPC), which has compressive strength of 10,000 pounds per square inch (psi), in contrast to the 5,000 psi of conventional concrete. HPC is also durable and resistant to corrosion and environmental deterioration. Such materials can reduce the cost of new bridge construction by 10 percent, representing potential cost savings of up to $100 million per year if half of the new bridges built in the United States use HPC.

Similarly, high performance steel (HPS) is considerably stronger than conventional structural steel, on the order of 70,000 kilograms per square inch (ksi) compared to 50,000 ksi strength. This higher strength can accommodate greater traffic loads by decreasing the structural "dead" load (the weight of the bridge itself) that must be supported.

New composite materials and high-strength aluminum offer similar performance improvement options. Research focused on the development and refinement of composite materials has demonstrated that although such materials are more costly than concrete or steel, their lighter weight and high strength offer advantages for bridge construction and repair. Recently, for example, a $3 million, two-lane, 540-foot bridge was constructed in Canada using carbon-fiber-reinforced polymer and glass-fiber-reinforced polymer beams that weigh 80 percent less and are six times stronger than conventional steel beams. In addition, they should last 50 percent longer than steel or concrete and, by eliminating these materials, greatly reduce the need for preventive maintenance to avoid corrosion damage, according to one engineering assessment.[23]

Composites also are useful for seismic reinforcement. An advanced composite renewal method, which involves wrapping thin carbon-fiber composite jackets around bridge support pillars, may replace steel jacketing. This retrofitting technology uses advanced composites for bridge column wrapping and deck repair; these weigh only 300 lbs. but offering similar strength and more durability than 3,000 lbs. of concrete. This promises to be competitive with respect to cost, speed of repair (ten to fifty times faster than steel), ease of use, and performance under earthquake conditions.[24]

The FAA and the Boeing Company have joined in a Cooperative Research And Development Agreement (CRADA) to launch a $21 million research effort that will address the increased runway pavement impact of the next generation of large civil transport aircraft, such as the Boeing 777. As part of this agreement, a test machine is being developed that will help identify new procedures necessary for designing airport pavements to meet the requirements of these new aircraft. Supporting this research effort are the Army Corps of Engineers and DMJM/Cornell Joint Venture.

[23] Bodamer, David, "A Composite Sketch," Civil Engineering, January 1998, p. 57.
[24] Brecher, Dr. Aviva, "Materials Research and Technology Initiatives," U.S. Department of Transportation, Research and Special Programs Administration, November 1995, DOT-T-96-01, p. 16.

Additional and focused cooperative research with industry could lead to faster, more efficient construction and rapid infrastructure renewal. Opportunities in this area where industry already is leading the way include construction traffic control technology, computerized construction management and scheduling, trenchless excavation, and laser-guided construction vehicles.

FHWA Contract Research Program

The thrust of this research program is to promote the evolution of the highway community from state-of-the-practice to state-of-the-art. The long-term research projects authorized by Section 6001 of ISTEA focused on innovative, cutting-edge emerging technologies with promise for infrastructure renewal and preservation.[25] Work is underway on technologies such as robotics for highway inspection; high-performance materials for pavements; coatings, adhesives and structures; use of waste and recyclable materials for highway construction; and decision-analysis tools. This program also funds cooperative efforts with other agencies, including the National Institute of Standards and Technology (NIST), the National Science Foundation, the Army Corps of Engineers; and with industry (see discussion of partnerships in Chapter 3) to enable early application of new technologies. Both national and international technology transfer activities are included in this initiative.

For example, the FHWA is working with the NIST to improve the understanding of the relationship between acoustic emission (AE) signals and micro-cracking of structural steel. This effort included the development of a high-fidelity broad band AE sensor and a high-capacity digital wave form recorder. Computer imaging techniques are used to display and study the actual micro-fracture process and reconstruct the bridge steel fracture history. AE records then are correlated with micro-structural fracture data to determine characteristic signatures for distinct types of fractures.

Efficient and effective maintenance and repair of roadways and bridges requires timely and accurate data collection and evaluation. In the past, collecting such data has been expensive, time-consuming and labor-intensive. In addition, inconsistent inspection posed significant problems in developing reliable test results. Consequently, the FHWA has targeted the development of new non-destructive evaluation (NDE) technologies as a major highway research priority. These technologies can scan a structure, highway lane, or bridge; record data; and store or transmit the results for expert analysis. NDE technologies that are being developed or tested include the following:

- Eddy current crack detection;
- Forced diffusion thermography crack detection;
- Radar imaging of bridge decks;
- Wireless data acquisition for bridge load rating;
- Remote deflection measurements for bridge load rating; and
- Acoustic strain gauges for bridge load rating.

[25] Section 502 of TEA 21 also authorizes a similar "Advanced Research Program".

U.S. DOD/TRANSCOM Programs

Since the reduction of U.S. military forces stationed outside of the continental United States, the ability to move military power rapidly in support of National security objectives worldwide demands a modern, efficient, and seamless transportation system. This system will include both government and commercial maritime facilities and vessels. The U.S. Transportation Command (TRANSCOM), one of the nine unified DOD commands, is the single manager of all DOD transportation requirements in peace and war, including air, land, and sea. USTRANSCOM sponsors a number of R&T-oriented programs, including the Army's Strategic Mobility Program, Ports for National Defense, Deployment Technologies, Agile Ports, and National Port Readiness Network, that focus on using technologies to increase the speed and effectiveness of the deployment of U.S. forces. These programs are conducted with other agencies, including the Defense Advanced Research Projects Agency, MARAD, and the Center for Commercial Development of Transportation Technologies (CCDoTT). Appendix C describes some of the DOD R&T programs relevant for civilian infrastructure preservation programs.

Asset Management

Asset Management involves a systematic, interdisciplinary approach to maintaining, upgrading, and operating physical infrastructure assets. It goes beyond traditional engineering analysis to include management and economic considerations when deciding the best course of action with respect to transportation facilities. Making informed choices regarding maintenance and reconstruction requires the ability to monitor condition indicators and accurately predict infrastructure performance. Advanced sensors, computer information systems and other new technologies are important enabling tools for Asset Management. The use of Asset Management to focus attention on transportation infrastructure as an asset that requires monitoring and replenishing is relatively recent, although it has been practiced by capital-intensive businesses for some time.

Asset Management provides useful tools for establishing infrastructure maintenance requirements. For example, using Asset Management data and analysis, the U.S. Air Force was able to demonstrate to the Congress a need to establish an annual stipend for maintaining existing infrastructure based on asset depletion rates. Thus, as new facilities are added to and deleted from the inventory, or facilities within the inventory are rehabilitated, maintenance funding is adjusted accordingly. Effective use of Asset Management also could reduce the financial burden of physical infrastructure preservation for all modes. The management techniques and tools are helpful for privately owned infrastructure, such as railroad tracks and ports, and for publicly owned roads, bridges, and transit systems.

Asset Management is an emerging DOT program that will be undergoing major development in 1998, with significant deployment unlikely before 1999. FHWA will work with the American Association of State Highway and Transportation Officials (AASHTO) to develop Asset Management policy tools and assist with professional tool development. A key recommendation is that technology that has been used to improve the safety and efficiency of operations should be applied to increase the efficient management of infrastructure assets.

Implications for Transportation R&T

Clearly, DOT's R&T innovation efforts are alive and well. Just as clearly, DOT R&T programs are missing opportunities to explore the potential of new technologies that were developed to improve operations but also have applications for surface transport infrastructure maintenance, monitoring, and rapid renewal. The DOT R&T emphasis on sensing, locating, and telecommunications technology for ensuring safe and efficient operations reflects rapid advances in these same tools by the private sector. However, using the data and the power generated by these technologies primarily for modally specific operational improvements results in missing many of their possible benefits for physical infrastructure preservation and renewal as well as cross-modal synergy. Promising technologies and innovations with potential applications to cross-modal surface transportation infrastructure preservation include sensing, locating, computer and telecommunications technologies for monitoring; Asset Management databases and advanced models for maintenance; and durable advanced materials and computerized tools suitable for rapid renewal and construction techniques.

Extending the applications of these technologies to different transportation infrastructures will help to allocate resources more effectively and efficiently. The importance of rapid renewal – the repair and replacement of infrastructure with minimal operational disruption – suggests a need for a new emphasis on research and technology for monitoring that also can support resource allocation decisions. In fact, as shown in Box 2, a well-managed rapid renewal effort can enable a region to restore key services more quickly and cost-effectively. For example, monitoring data could be used for setting maintenance and reconstruction priorities, as well as for allocating resources during inclement weather conditions. In addition, these capabilities facilitate more cost-effective use of the human resources devoted to maintenance and monitoring, and enable more widespread use of improved infrastructure management techniques such as Asset Management.

Box 2

Rapid Renewal after Natural Disasters

Industry has shown that with the proper incentives, techniques for rapid renewal can be implemented and reconstruction of essential connections completed much faster than is customary. The rapid restoration of damaged California freeways after the devastating Northridge earthquake in 1995 illustrates that contractors can deliver extraordinary performance in rapid reconstruction and renewal, saving users millionsof dollars in avoided delays. The California Department of Transportation (Caltrans) estimated that the direct, transportation-related costs associated with travel disruption and delay on the four freeway segments in the Los Angeles basin damaged by the earthquake exceeded $1.6 million per day.

Using expedited contracting procedures invoked during the state of emergency, Caltrans was able to restore all of the damaged freeway links within 10 months, including repairing the severed Santa Monica Freeway in just 74 days.[26] The fast-track design, bid, and approval process allowed the rebuilding projects to begin within 12 days of the earthquake. The incentive program allowed early completion bonuses of up to $15 million for each segment. The contractor for the I-10 segment of the reconstruction completed work 66 days early, earning a bonus of $200,000 per day. Using this experience for subsequent projects, Caltrans avoided 16 days of traffic disruption by accelerating the construction of a 540-foot-long bridge in 34 days. The contractor was awarded $4.4 million for the new Highway 1 bridge at Carmel, and an additional $320,000 as an incentive payment for early completion.[27]

The products of the Travel Model Improvement Program, notably the TRANSIMS and bi-criteria assignment models, could contribute to an Asset Management system. These tools are intended to estimate travel demands at various service levels and provide estimates of accessibility and mobility. These types of tools would enable decision-makers to make tradeoffs between different facility closure and detour scenarios, quantify the operational impact on travelers, and estimate subsequent travel changes.

Properly applied, an Asset Management approach can enhance the performance and maximize the useful life of physical infrastructure by careful allocation of scarce budgetary resources to help meet growing traffic demands. Paving the way for widespread implementation of Asset Management will require improved modeling and data base tools and techniques, adapted and tailored to transportation applications. Asset inventory, condition assessment, performance trend indicators, alternative benefit/cost analysis

[26] Caltrans News Release #95-012, March 22,1995.

[27] Caltrans News Release #95-011, March 17, 1995; and Caltrans News Release #95-024, May 4, 1995.

techniques, and impact prediction tools are needed to keep pace with advances in sensors, communications, and information systems that are enabling "real-time" monitoring. Researchers already are using fiber optic sensors in decks and along beams to monitor deflections remotely and to calculate strain on bridges throughout the day via telephone and Internet data links. As the costs of these systems decrease, the financial burden associated with gathering and analyzing the necessary data for advanced management systems will be reduced.

Finally, funding for infrastructure preservation R&T programs is less than ten percent of all DOT R&T funding. Estimating the depreciated value of the surface transportation physical infrastructure and the savings associated with widespread implementation of technology innovations, however, is difficult. Some transportation infrastructure experts have attempted to do this. For example, the Transportation Research Board (TRB) has estimated that an improvement of only one percent in the durability and performance of pavement, asphalt materials, coatings, and structural elements for the Nation's highways and bridges would generate savings of $10 to $30 billion over 20 years.[28] In addition, the Civil Engineering Research Foundation (CERF) estimated that life-cycle cost savings gained from using advanced concrete and asphalt in highway pavements would offset higher front-end costs by more than a factor of six. At the current lane-mile replacement rate, the Nation's annual savings on materials alone could total approximately $500 million, as a result of increased service life as well as reduced maintenance and travel delay costs.[29] In other words, experts hold that advances in technology, once they are widely applied, can save taxpayers billions of dollars over time.

[28] Transportation Research Board
[29] Civil Engineering Research Foundation

Chapter 3

Technology Innovation and Dissemination Programs

Technological innovation, broadly defined, is critical to meeting the ever-increasing demands for transportation system capacity. Efforts must be coordinated across the transportation community to take full advantage of the potential of new technologies, processes, and operational approaches. Fortunately, the current era of steady technological advances and tool development shows great promise. Federal R&T is complemented by the continuing efforts of equipment manufacturers and many service providers to improve their products in response to market forces. Similarly, transportation carriers constantly seek to improve their technology, operations, and practices so they can provide better and more cost-effective services. State and local government agencies with transportation responsibilities also explore how best to carry out their missions within their resource constraints.

However, if the benefits of new technologies and innovations resulting from research are to be realized, effective means must be found to transfer the latest knowledge of these tools, concepts, and applications to practitioners in the field. A select group of DOT technology innovation and dissemination programs and activities were reviewed to consider various strategies for fostering innovation, and to identify lessons learned about what is needed for success. The Federal programs discussed in this chapter are those aimed directly at technology transfer or at creating new partnerships for that purpose. They have a near-term focus that could have a significant impact on monitoring, maintenance, and rapid renewal for surface transport infrastructure. For the most part, they focus on developing and implementing technologies that address specific problems, rather than on programs with broader, enabling technological goals. In addition, efforts were made to ensure coverage of all modes of transportation.

Beyond the programs considered in this chapter, there are many additional DOT R&D programs and initiatives, such as the Innovations Deserving Exploratory Analysis (IDEA) program. Such programs were not included because their primary goals are to extend the frontiers of knowledge or achieve research breakthroughs, rather than to advance the state-of-the-practice through the adoption of innovative methods and technologies by surface transportation agencies.

Market Context for Infrastructure Innovation

Before describing these programs, however, it is useful to acknowledge the substantial difficulties that infrastructure-related innovations and their proponents must overcome before they can move into widespread use. Principal among these barriers is the fragmented nature of both the construction industry (the infrastructure providers) and its market, the public and private owners of surface transportation infrastructure. Most of the surface transportation construction firms are small, local companies and contractors that are the backbone suppliers of labor and equipment for most local projects. The construction industry as a whole has a relatively small number of very large firms that focus on large, complex projects and conduct business both nationally and internationally.[30]

In a similar fashion, the market for innovations in surface transportation infrastructure technology is dispersed because the infrastructure ownership is varied (as detailed in Chapter 1). The owners of most highways, roads, and bridges usually are public sector entities, such as state, regional, or local governments. Nearly all of the railroad infrastructure owners are part of the private sector. Regional authorities or major cities own the largest airports.[31] Port terminals and other buildings usually are privately owned, although a private railroad or local government authority may own the connecting surface infrastructure. Taken together, the many infrastructure owners and the fragmented nature of the providers contribute to the slow pace of adopting surface transportation infrastructure innovations.

Other major barriers are part of the research and technology innovation development process itself. For example, the process of demonstrating and evaluating innovative approaches and materials for transportation infrastructure (as well as for vehicles and operations) is lengthy and expensive. Implementation may be greatly delayed, or even aborted, by user concerns relating to life-cycle cost, long-term performance, safety, security or other uncertainties normally associated with the innovation process. Overcoming these barriers is critical to reaping the benefits of innovation.

Typically, changes in the methods, tools, and materials used in infrastructure construction and maintenance come slowly. Factors inhibiting such change include: uncertainty as to the costs and benefits of implementation, funding constraints or laws that preclude trading reduced life-cycle costs for higher initial investments, a lack of familiarity with new technologies and processes, questions of compatibility with current systems and workforce skills, and institutional and regulatory barriers. These concerns discourage potential vendors and suppliers from developing and marketing innovative products, because they fear limited markets and low profits. In addition, the fragmented nature of the construction industry poses a serious obstacle to realizing the potential advantages of new construction materials, design tools, and concepts.

Consequently, credible trial use, evaluation, and demonstration of surface transportation infrastructure innovations usually is necessary to spur the timely deployment of even the most promising new technologies and techniques. This process must be comprehensive

---

[30] In 1996, 400 firms were reported to specialize in the construction of highways and streets, and another 80 in constructing bridges and tunnels. The total assets of these firms were slightly more than $16 billion. The top 15 firms in each group accounted for more than 50 percent of the total assets. Source: *Ward Business Directory of U.S. Private and Public Companies, 1996.*

[31] Smaller airports, which are not discussed at length in this document, often are privately owned.

and address the full range of issues, including a complete characterization of costs and benefits; workforce requirements; implementation guidance, procedures and training aids; necessary preconditions; and special considerations.

With Congressional encouragement, the Department of Transportation and other Federal agencies have responded by developing, supporting, or participating in numerous special programs to facilitate the advancement of significant technology innovations, disseminate results to the transportation community, and promote implementation by public and private sector users. Many R&D and technology demonstration efforts have been undertaken in partnership with state and local governments, industry trade associations and consortia, professional organizations, and universities. Each of the programs highlighted below focuses primarily on either operations or infrastructure; in general, each has as its principal purpose either cooperative research and development or technology transfer. However, in some cases, such as the Intelligent Transportation Systems (ITS) effort, a program may include research and development as well as technology transfer and implementation support.

Selected Programs

Priority Technologies Program (PTP)

The Priority Technology Program (PTP) is dedicated to supporting the demonstration, testing, and evaluation of promising market-ready technological innovations to accelerate their implementation. The program was created by the FHWA under ISTEA and was funded at approximately $2 million annually through the end of FY 1997. The PTP adopted a "lead State" concept, in which a State that was interested in benefiting from a particular innovation agreed to a cost-sharing arrangement for demonstrating its potential and for deploying and evaluating its performance in the field.

The Strategic Highway Research Program (SHRP)

The Strategic Highway Research Program (SHRP) was designed to improve the safety, durability, and performance of the Nation's aging highways. The five-year, $150 million research program initially was funded by Congress in 1987 from the Highway Trust Fund. The SHRP research emphasized developing innovative technology products in four program areas: asphalt, concrete and structures, pavement performance, and highway operations. State and local transportation officials, members of academia, and industry officials conducted the research. The SHRP was considered successful, producing a number of new technology products and services during its first phase.

Among these "products" were the Superpave® asphalt materials mixture design and analysis system, winter maintenance techniques combining roadway weather information systems with snow and ice control strategies, and other "products" with direct applicability to highway agency operations. Superpave enables the design, construction, and testing of flexible pavements that last longer and require less maintenance than conventional asphalt concrete pavements. Superpave pavements have the potential to last up to ten percent longer than conventional pavements. However, Superpave is not as forgiving as conventional asphalt paving materials. Using Superpave requires greater technical sophistication and tighter process control on the part of construction crews and inspectors to assure proper results. These factors may represent additional up-front costs to an infrastructure owner.

Although specific SHRP research funding ceased in 1993, the benefits of the program continue to be realized through a systematic implementation program funded by FHWA. The Research and Technology Executive Board (RTEB) and the SHRP Implementation Coordination Group (SICG) provide overall oversight and coordination of the FHWA SHRP implementation efforts, including the following:

- Publication of, broad consensus on, and participation in the SHRP Implementation Plan[32] for fielding products and for technical training and technology transfer support; and
- Preparation, training and fielding of technology module "showcase packages" for demonstration and delivery to the States via FHWA regional offices and through industry and State workshops.

Products have been developed, modularized, and packaged for Asphalt, Concrete and Structures, Highway Operations, and Long Term Pavement Performance under the guidance of Technical Working Groups (TWGs), which include FHWA, State DOTs, industry, associations, and users. The AASHTO Task Force on SHRP Implementation and the TRB SHRP Committee provide external support and advice. This implementation program is designed to involve the public and private highway community in the development, evaluation, promotion, and adoption of SHRP technology, and to involve private industry in the manufacturing of SHRP products. [33]

Many of the Road Weather Information Systems (RWIS) applications received initial support from the SHRP and their products continue to be disseminated, including information on snow and ice control practices and on storm monitoring and communications. Individual State and local transportation agencies are now devoting their own resources to continuing some of the efforts initiated under SHRP, an indicator of the success of the program's technology development implementation efforts.[34] A

[32] See the Internet Web site at http://www.tfhrc.gov/pubrds/winter94.

[33] Additional information on SHRP is available on the Internet at http://ota.fhwa.dot.gov/roadsvr.

[34] Similar applications of weather information systems to highway maintenance and operations can be found overseas, particularly in 'cold weather' countries such as Sweden and Finland. In fact, the Swedish National Road Administration (SNRA) has estimated that their system generates cost savings equal to three times the annual cost of the system. J. Schiavone, R. Puentes and C. Eng, "ITS and Meteorology: A Critical Partnership", 1997, *passim.*

comprehensive evaluation of SHRP benefits recently was conducted under the auspices of the FHWA. The "lessons learned" from SHRP are summarized in special issues of *TR News* detailing the benefits of applied transportation research from the perspectives of the States and of the Federal government.[35]

Long-Term Pavement Performance Program (LTPP)

The Long-Term Pavement Performance (LTPP) Program was initiated under the SHRP umbrella. The LTPP is a 20-year study of in-service pavement to assess the value of innovative designs, pavement structures, materials, and methods of maintenance and rehabilitation for a broad range of climatic, environmental, soil, maintenance, and loading stress conditions. The program's ultimate goal is to increase pavement service life by applying the results of these efforts. The LTPP is a partnership involving the FHWA, AASHTO, and TRB; and State and Canadian Provincial DOTs, with industry and academic participation. More than fifteen other Nations also are participating in the program by managing complementary studies. The LTPP is managed by the FHWA with oversight provided by the Research and Technology Executive Board (RTEB), and external advice and comment provided by the TRB's LTPP Committee. Under TEA 21, it is funded at an annual level of about $16 million. About 85 percent of the funds are allocated to data collection and technical operations support for LTPP and to limited SHRP follow-on field studies; the remainder (approximately 15 percent) is allocated to data analysis.

The LTPP is the largest pavement performance research project ever undertaken. The database developed through this program eventually will include twenty years of performance data based on periodic data collection and condition monitoring of approximately 2,800 in-service pavement test sections located throughout the United States and Canada. Data analyses focus on three time periods: near-term (three to five years), mid-term (five to ten years), and long-term (ten to twenty years). Different data products are dynamically integrated into AASHTO guides for material mixes, design and test specifications, and construction and maintenance methods modifications. Most importantly, performance models are developed and refined to generate predictions that are tailored to local environmental and use conditions.

Efforts are underway to develop testing protocols for Portland cement concrete bond strength, thermal coefficient of expansion, and creep compliance testing for asphalt mixtures. LTPP research efforts have included developing a non-destructive testing procedure to quantify layer thickness; a localized expert system for rating preventive maintenance treatments; guidelines for preventive maintenance treatments; and a technical assessment of the adequacy of existing procedures for the design of new and rehabilitated pavements.

[35] Issues 188 (January-February 1997); 189 (March-April, 1997); and 190 (May-June 1997), respectively.

National Cooperative Highway Research Program (NCHRP) and Transit Cooperative Research Program (TCRP)

Both the National Cooperative Highway Research Program (NCHRP), which is a cooperative program involving participants from the AASHTO, TRB, and FHWA; and the FTA-sponsored Transit Cooperative Research Program (TCRP) are managed by the TRB. These programs identify selected State research projects of national significance and showcase them to the transportation research community. Such applied research programs serve to generate a pool of promising technologies and also serve as incubators for potential innovations.

Local Transportation Assistance Program (LTAP)

The LTAP (formerly known as the Rural Technical Assistance Program) has been managed by the FHWA since 1981. Its purpose is to help local transportation agencies meet the growing demand for improved local roads and bridges by providing these agencies with access to highway technologies and training. The program, with annual funding of approximately $10 million, provides hands-on training courses and materials to local agencies. These are provided through the FHWA's National Highway Institute (NHI), as well as a Nation-wide network of fifty-seven technology transfer centers located at universities, State transportation agencies, and American Indian Tribal Governments.

The American Public Works Association (APWA) operates the Technology Transfer Clearinghouse, an LTAP resource center, under contract to the FHWA. Topic areas for assistance include roads and bridges, drainage, equipment, personnel management, materials, project schedules and survey methods, and safety-related activities.

ITS

Although the ITS program employs somewhat different types of incentives, its purpose is consistent with those of the SHRP and other technology support programs: to identify, promote, develop, and deploy helpful technologies. Since the enactment of ISTEA in 1991, Federal assistance has contributed to significant progress in developing devices and systems that improve traffic management, support the selection of optimum routes and modes by drivers and travelers, and enhance the productivity of the nation's commercial vehicle fleet on the highway network. Under the stewardship of the JPO, a national ITS system architecture has been drafted. Standards and protocols are being developed to enhance the interoperability of ITS systems and equipment across jurisdictions. Intermodal program emphases are being developed with the guidance of an intermodal steering committee and the support of the JPO. Deployment incentives in the form of special funding are made available to States and localities choosing to implement ITS applications consistent with national guidelines.

University Transportation Centers Program (UTCP), and University-Based Consortia and Cooperative Research Programs

Since 1987, the U.S. DOT has been investing in the University Transportation Centers Program (UTCP), a network of ten regional university-based research consortia. This program is co-funded by the FHWA and the FTA, with program management provided by the RSPA. The 1998 TEA 21 legislation authorizes $192 million for university transportation research over the next six fiscal years. Each UTC is a consortium of six to twelve universities with a research and education focus based on regional transportation needs. Matching funds are provided by States and local transportation authorities and by industry. At least five percent of UTC funds are dedicated to outreach and technology transfer activities.

Under ISTEA, three National Centers and five University Research Institutes (URI) were established. One example is the Infrastructure Technology Institute (ITI) at Northwestern University, which receives funding of $3 million annually; the Center focuses on infrastructure advanced materials research and applications.[36] It operates a national information clearinghouse for technical resources related to infrastructure renewal materials and technologies. Faculty, students, corporate, and State partners also perform research and demonstrations in key technical areas, and cooperate with the Center for Advanced Cement-based Materials (ACBM), also located at Northwestern. The National Science Foundation (NSF), NIST, FHWA, and companies in the concrete and ceramics industries fund the ABCM. Ongoing projects include non-destructive infrastructure test and evaluation (NDT/NDE), advanced coatings to prevent corrosion, and a high-strength weldable steel.

Airport Pavement Programs

In addition to the FAA's Airport Pavement Technology Program (discussed in Chapter 2), significant contributions to airport pavement research and technology come from the FAA's Center of Excellence for Airport Pavement Research. In 1995, the FAA designated the University of Illinois at Urbana-Champaign (UIUC) as a Center of Excellence (COE) in Airport Pavement Research. This COE, which also includes Northwestern University, was established to conduct basic research in the area of airport pavement technology. Currently, the COE is conducting 13 research activities, ranging from the development of "High Performance Concrete for Airport Pavements" to "Mechanistic-Based Airport Pavement Design Concepts/Procedures."

[36] See the ITI Internet home page at http://www.iti.acns.nwu.edu.

Technology Transfer and the Federal Laboratory Consortium

Technology transfer, as defined by one DOT administration, is "the process by which knowledge, facilities, or capabilities developed by Federal laboratories or agencies are transmitted to the private sector to expand the U.S. technology base and to maximize the return on investment in Federally funded R&D."[37] The Stevenson-Wydler Act of 1980 (PL 96-480) mandates that each of the more than 600 Federal laboratories establish an Office of Research and Technology Applications (ORTA) and set aside one-half of one percent of their annual research and development (R&D) budget for "technology transfer" purposes.

The Federal Technology Transfer Act of 1986 (PL 99-502) further amended this legislation to add incentives for Federal laboratories to work cooperatively with universities and the private sector for the transfer and commercialization of technologies, and formally chartered the Federal Laboratory Consortium (FLC) to assist in this process. The FLC was established in 1974 to act as a service organization for participating laboratories in transferring technologies to the private sector and State and local government. This legislation also enabled laboratories to enter into formal Cooperative Research and Development Agreements (CRDAs or CRADAs) with private companies, educational institutions, and other public agencies. Through these agreements, Federal laboratories can share facilities, equipment, services, and personnel resources (although not appropriated funds) with these non-Federal partners to develop an idea, prototype, or product for introduction into the marketplace. The laboratories are authorized to assign patent rights and license technologies to partners, and to retain royalties paid to them under such arrangements. This authority to enter into CRADAs was extended to government-owned, contractor-operated (GOCO) Federal laboratories by the National Competitiveness Technology Transfer Act of 1989.

Partnerships for Technology Implementation

Each DOT modal administration has formed partnerships of varying sorts with its constituents. Among the most relevant for infrastructure monitoring and renewal is the FHWA support of the Highway Innovative Technology Evaluation Center (HITEC) and ConMat programs centered at the Civil Engineering Research Foundation (CERF).

HITEC: Established by the FHWA in 1992 under a cooperative agreement with the CERF, the HITEC facilitates the evaluation, demonstration and deployment of innovative materials, products, services, systems and technologies for transportation infrastructure applications. To speed up the process of innovation implementation, the HITEC convenes an expert review and evaluation panel for each applicant. These panels are composed of interested public, private, and academic stakeholders, including State and local highway officials and highway users. In many cases, these users become 'change agents' themselves and increase the probability that successful applications will be deployed.

---

[37] *1993, Federal Aviation Administration Plan for Research, Engineering and Development,* Washington, DC: U.S. Dept. of Transportation, 1994, p. A-4.

A Technical Protocol guides the demonstration, testing, and evaluation process, and an Evaluation Report provides details on the product/process performance under operational field conditions, the practicality of construction or production, maintenance requirements, safety aspects, and environmental characteristics. HITEC Highlights are published quarterly to report on the status of ongoing evaluations.

The HITEC is a model partnership for successful and timely technology deployment, based on an initial customer survey that identified barriers to innovation in highway materials and construction technologies and tools. In its first year, more than 20 products were submitted to HITEC for evaluation and endorsement. Application fees cover part of the costs of field tests. To date, more than sixty evaluations of innovative infrastructure technologies are in process, many of which involve advanced materials. Each completed evaluation results in a brief Product Evaluation Bulletin, followed by a more complete Evaluation Report. Among the products that have been tested are advanced bridge materials, including composites, which are now being used in at least one bridge in twenty-one states. Other successful evaluations include the composite column wrap for seismic bridge reinforcement; a fiber reinforced polymer bridge retrofit system; a composite plastic marine piling, impervious to corrosion; and a recyclable plastic stop sign with improved reflectivity and night visibility. AASHTO has established a parallel testing effort specifically for its members. This activity, the National Transportation Product Evaluation Program (NTPEP), deals with new products for which accepted testing standards already exist.

ConMat: CERF's ConMat program focuses on using advanced, high-performance construction materials in new construction as well as in the repair, retrofit, and maintenance of existing facilities. Membership and potential collaboration is open to all members of the design and construction community, including designers, fabricators, equipment manufacturers, material suppliers, architects, contractors, and owners. ConMat's Smart Materials Working Group concentrates on accelerating the commercialization of "smart" materials and monitoring devices, including fiber-optic, strain gauges, piezoelectric and chemical sensors, and ultraflat antennae, micro-electromechanical devices, and microsensors.

CERF recently established additional Technology Evaluation Centers to evaluate public works innovations and environmental technologies. In addition, CERF plans to launch a new public-private partnership, the Partnership for the Advancement of Infrastructure and its Renewal (PAIR).

Cargo Handling Cooperative Program (CHCP)

Other types of Federal partnership aim to implement advanced technologies to streamline Federal maritime regulatory functions and safety and rescue operations for the coastal waterways. For one maritime-related, Federal/private partnership, the goal is to facilitate commercial vessel operations. The CHCP is a partnership designed to foster research and technology development by U.S.-flag carriers. An executive committee composed of representatives from the Maritime Administration, U.S. DOT, American President Lines, Crowley American Transport, and Matson Navigation Company administers the program. The program calls for improvements in cargo handling relating to the identification and prototyping of new technologies for container-chassis mating; as well as testing new technologies related to hand-held computers, electronic seals, tire maintenance and repair, overweight containers, and container stowage planning. MARAD and the private participants fund the CHCP. In each of the five years since the program's inception, $200,000 per year in Federal funds has been available to the CHCP from MARAD, and the three shipping companies provide additional resources. The ports of Oakland, CA and Jacksonville, FL are serving as test sites for these technologies.

Fostering Innovation

The Federal government plays a major role in fostering innovation through its specific and mandated responsibilities, and as part of its broader "stewardship" over the national transportation system. A constant stream of innovative technologies and approaches is being developed by the private sector; but regardless of where an innovation originates, its benefits cannot be realized without effective technology transfer efforts. Recognizing that the barriers to infrastructure-related innovation are substantial, the Federal commitment to fostering innovation includes a responsibility to address impediments to the deployment of potential improvements. DOT has a number of different organizations within its structure that are dedicated to various methods of technology transfer and moving new technologies into the field, both for operations, and to a lesser degree for infrastructure preservation. These DOT surface transportation technology transfer offices include:

- FHWA Office of Technology Applications (OTA);
- FHWA Turner-Fairbank Highway Research Center (TFHRC);
- FHWA National Highway Institute (NHI);
- FRA Office of Research and Development (RDV-30);
- NHTSA Office of Research and Development (NRD-01);
- FTA Office of Research Management (TRI-30);
- RSPA Office of Research Policy and Technology Transfer (DRT-10); and
- RSPA Volpe National Transportation System Center.

Through the programs carried out in these and other modal offices, the respective DOT agencies work with their constituents in a variety of partnership arrangements to facilitate and stimulate the deployment of innovations. Because the emphasis on technology transfer varies among the modes, most of the technology transfer efforts are mode-specific. In only a few instances are cross-modal or intermodal R&T synergies and cooperation actively sought and nurtured. Two examples of cost-effective cross-modal programs are the intermodal applications in the ITS area and the cooperative pavement research done by FAA and FHWA, which is clearly aimed at infrastructure preservation. Doubtless there are other instances, but it is important to recognize that there are many unutilized opportunities for cooperative research that could have sizable potential payoff for R&T. In some cases, such as sensing, locating and communications, technology applications already are used by all the modes and could have cross-modal benefits. Efforts might be undertaken to understand how the advantages of applying a particular technology to one mode may be generalized across other modes.

Programs for transferring technologies to address longer term, less conspicuous issues (such as structural fatigue) are more difficult to implement successfully. One way to bolster the use of technology innovations is to use partnerships involving both the public and private sectors, as the HITEC partnership demonstrates. Particularly in the area of rapid renewal, partnerships could leverage the interest of the private sector with the resources of the public sector to speed the adoption of new technology.

The most successful technology transfer programs have technologies that are ready for marketing; address problems that are costly, recurring, and highly visible to infrastructure owners; and have champions to lead the deployment among peer practitioners. Moreover, successful demonstrations of surface transportation infrastructure innovations that meet these criteria are critical to promoting their deployment. The Federal Technology Innovation Programs represent some of DOT's responses to these needs. These programs encompass innovations related to operational safety and efficiency, infrastructure condition monitoring and maintenance, and technology transfer.

Selected Federal Technology Innovation Programs are listed in Table 2, with an indication of the problem areas that they address. A review of the relative Federal funding levels for these programs reveals a great deal about the relative support for technology transfer programs related to infrastructure R&T. As shown in the FHWA R&T spending summary in Chapter 2, R&T programs related to infrastructure preservation receive less than half of that Agency's total spending on R&T. It is reasonable to raise again the question of whether this represents an appropriate Federal investment in programs critical to the future condition and performance of the surface transportation infrastructure.

Table 2.
Surface Transportation R&T Assessment
DOT Technology Innovation Programs

Program	Transportation Mode	Infrastructure Focus / Objective	Lead Agency(ies)
		OPERATION	
Intelligent Transportation Systems (ITS)	Highway / Transit	Safety Efficiency	FHWA/JPO, FTA,
ITS-IDEA (Innovations Deserving Exploratory Analysis)	Highway / Transit / Railroad	Safety Efficiency	TRB, FHWA/JPO, FRA, FTA, NHTSA
Cargo Handling Cooperative Program (CHCP)	Maritime	Efficiency	MARAD
Ship Operations Cooperative Program (SOCP)	Maritime	Efficiency	MARAD
Vessel Traffic Services (VTS)	Maritime	Efficiency	USCG
Positive Train Control (PTC)	Railroad	Safety	FRA
Highway-Rail Grade Crossing Research	Railroad / Highway	Safety	FRA
Transit - IDEA (Innovations Deserving Exploratory Analysis)	Transit	Efficiency	TRB, FTA
Transit Cooperative Research Program (TCRP)	Transit	Efficiency	TRB, FTA
Airport Surface Traction Research Program	Airport	Safety	FAA
		CONDITION	
Airport Pavement Technology Program	Airport	Monitoring & Maintenance	FAA
Pavement and Airport Runway Program	Airport	Monitoring & Maintenance	Army Corps of Engineers
LTPP – Long Term Pavement Performance Program	Highway	Monitoring	TRB, FHWA
National Cooperative Highway Research Program (NCHRP)	Highway	Monitoring, Maintenance & Rapid Renewal	TRB, FHWA
NCHRP - IDEA (Innovations Deserving Exploratory Analysis)	Highway	Monitoring, Maintenance & Rapid Renewal	TRB
FHWA Contract Research Program	Highway	Rapid Renewal	FHWA
		TECHNOLOGY TRANSFER	
Strategic Highway Research Program (SHRP) Implementation	Highway	Lead State, Training, and Incentives	FHWA
Local Transportation Assistance Program (LTAP)	Highway	Information and Training	FHWA
National Transportation Product Evaluation Program (NTPEP)	Highway	COTS Evaluation / Certification	AASHTO
HITEC – Highway Innovative Technology Evaluation Center	Highway	Evaluation / Certification	CERF, FHWA
National Highway Institute	Highway	Training	FHWA

Chapter 4

Progress Made under ISTEA and Lessons Learned

Under ISTEA, support was provided to a number of programs for which the goal was to deploy and implement innovations in technologies and materials. This Chapter discusses some of the lessons learned from these programs, identifies which of the Technology Innovation programs have been reasonably successful in achieving their goals, and reviews the reasons for this success.

Modal Programs

Highways: ISTEA included provisions directed at developing and introducing innovative methods and technologies for highway infrastructure monitoring, maintenance, and rapid renewal. Notably, this legislation provided more than $100 million for the explicit purpose of fostering the implementation of R&D products. However, at the outset, it must be acknowledged that measuring the impacts of Federally-funded highway research and implementation programs is difficult. In addition to the inherent difficulty of isolating program effects from external influences, few means exist to collect the necessary data. To assist in evaluating the effectiveness of Federally funded highway research, interviews were conducted with a small sample of highway agency representatives and research and program administrators. Their insights provide one measure of effectiveness.

One study has found that the rate of adoption of innovations by State highway agencies has improved recently.[38] However, the results of the interviews suggest that the overall rate of innovation in highway agencies has not changed enough to make a significant improvement in infrastructure preservation processes or costs in the near term. Moreover, most interviewees did not anticipate a significant acceleration in innovation, given the decentralized control over the nation's highways by numerous independent agencies and organizations. Most of the interviewees believe that because of such fragmentation, research and technology implementation provisions should be an integral part of any major Federal surface transportation research initiative. They also believe that facilitating innovation is an important national role that extends beyond the research and technology products associated with DOT programs.

[38] One survey of state highway agencies indicates that innovation was accelerated by 3.5 years on average over a ten-year period. *Facilitating the Implementation of Research Findings: A Summary Report*, National Cooperative Highway Research Program (NCHRP) Report 382, Transportation Research Board, National Academy Press, 1996.

Despite the difficulties associated with implementation, the pursuit of innovation is endorsed as essential by those interviewed. Funding pressures to "do more with less" are spurring a new focus on research that helps to identify better ways of "doing business." It is assumed that research results address relevant goals; have been proven in actual field conditions; and address critical institutional and organizational implementation factors.

Organizational and institutional barriers are widely recognized as significant impediments to realizing the benefits of a broad range of highway research results with the potential for high benefit/cost ratios. Barriers range from a simple lack of awareness regarding new developments, to concerns about readiness and proven effectiveness over time, to organizational policies and practices that hinder change. This suggests a need to evaluate innovations from the viewpoint of the intended beneficiaries — to focus on the outcome of field testing under real-world conditions, rather than the results of artificial academic experiments.

New methods, materials, and technologies that can extend the useful life of pavement and bridges and reduce life-cycle costs can play a key role in reducing the gap between apparent need and available resources. There are several examples of these innovations, such as "Superpave" asphalt pavements that increase pavement life by ten percent or possibly more (see Chapter 3). However, significant up-front investments in staff training, expanded testing facilities, or more costly materials may be required to reap longer-term savings. Such tradeoffs are difficult for agencies that are under pressure to produce tangible near-term improvements. This creates a bias toward making minimal improvements on a large number of roads, rather than concentrating funding on a small number of facilities to create more significant improvement over the long run.

Federal research programs have modified their goals over the past decade, shifting gradually from developing materials and technologies for building new roads and bridges to maintaining and rebuilding existing facilities. It is true that many innovations are relevant to reconstruction as well as new construction; it also is true that research is being conducted on condition monitoring and infrastructure modernization. New facilities account for less than one-half of one percent of the highway inventory, and the cost of maintaining traffic flow during reconstruction can on occasion equal or exceed the costs of the facility itself. Therefore, more resources could be directed at the challenges of monitoring, maintaining and rapidly renewing existing road and bridge facilities.

Transit: Attitudes within the transit industry are changing significantly. According to the Urban Mobility Corporation Innovation Brief on mass transit,

> "[c]oncepts and ideas that appeared radical a decade ago — such as competitive contracting and transit brokerage — no longer seem threatening. Technologies that looked forbidding and intimidating to the older generation of transit operators are taken for granted by the younger managers, educated and trained in the age of computers. There is a new willingness to look at

transit services from a market standpoint and to treat the transit user as a customer."[39]

Most representative of this change is the application of advanced traffic management and travel information systems to public transit operations in both urban and suburban areas. Innovative partnerships among public agencies and the private sector are resulting in major investments in intelligent transportation, ranging from research and development and operational tests to real-world deployment. Understandably, transit agencies are most interested in technologies that improve operations and save costs. From that perspective, ITS technologies are more attractive than infrastructure monitoring and renewal.

Rail: New technologies and track materials have allowed railroads to improve their track performance. Freight railroads and Amtrak have upgraded their tracks, replacing them with stronger rails and improving the track ties. Multi-year research results of the jointly funded FRA/railroad industry Heavy Axle Load testing program at the Facility for Accelerated Service Testing (FAST) at Pueblo, Colorado, have shown that modern rails made of cleaner premium steels have a longer fatigue life: up to five or ten times longer than rails made of conventional steels. In addition, given the recent trend towards track reduction, railroads will be able to concentrate their capital investments on improving the maintenance of their remaining tracks and signal systems.

Emerging maintenance methods and technologies have the potential to reduce maintenance costs and enhance safety for the railroad industry. The defect detection methods, for instance, could have predictive or even prescriptive capabilities. Maintenance worker productivity has improved as advanced maintenance technologies, including better track defect detection technologies, are implemented, and better scheduling techniques are used. In addition, recent increased use of lubricants has led to significant reductions in rail wear, while automated and mechanized maintenance allows for better control of surface geometry. These reduce overall wheel and rail forces and the resulting track degradation.

Ports: Advanced technologies have the potential to improve port infrastructure maintenance and rehabilitation, which would increase the capacity, safety, and cost-effectiveness of the U.S. port system. Significant opportunities exist for improving infrastructure capacity and throughput through the joint-use of military facilities and promotion of dual-use technologies. The ongoing defense conversion programs offer the potential for improving the capacity and throughput of the existing port infrastructure. Given cost issues and environmental restrictions on physical capacity expansion, more joint civilian use of military facilities and diffusion of dual-use technologies could be cost-effective approaches to increasing capacity. Notable among current efforts are the U.S. TRANSCOM initiatives to leverage commercial technologies, streamline landside lift

[39] "Public Transit — Searching for New Paradigms." *Innovation Briefs*. Urban Mobility Corporation, Vol. 8, No. 7, Sep/Oct 1997.

operations, and establish in-transit visibility. Many of the benefits from the DOD partnership efforts may accrue to the civil sector, which could take advantage of a global commercial intermodal transportation network, including vessels, logistics management services, infrastructure, terminals and equipment, communications and cargo tracking networks.

Despite this potential, the complexity of the operations and technologies involved in ocean shipping has made it increasingly difficult to pursue more effective Federal R&T and infrastructure maintenance policies. Public-private partnerships, joint ventures, and extensive training have emerged as the most effective approaches to managing these needs. MARAD's CHCP program is moving to a focus on training, and to encouraging broader participation by DOD and private sector beneficiaries.

Lessons Learned

Based on this assessment of the surface transportation infrastructure research and technology transfer programs, a number of important factors are key to the success of any innovation. The following appear to be critical to successful programs.

The results of innovative research activities must be of strategic significance to the intended users — strategic in the sense that the result relates to a critical agency function, and significant in the sense that it make a discernible difference in performance or cost from the viewpoint of the implementing organization. At a minimum, this implies a need for the endorsement of the Chief Executive Officers within implementing agencies; ideally, the agency leaders will provide a strong mandate for and commitment to implementing favorable findings.

Among the most important lessons learned is that *applied research should not be initiated without the commitment of prospective implementers. In addition, such research should not be considered complete until the results are implemented*.

User-defined performance criteria and measures are helpful in guiding research activities. *Early and ongoing involvement of intended users is essential to ensure meaningful results that will be practical and applicable in the appropriate institutional context*. Users control implementation by choosing whether to adopt an innovation based on their acceptance criteria. Consequently, it is important to establish such criteria in functional terms early in the research process and to affirm these criteria periodically.

The research process must include testing under controlled and "uncontrolled" field conditions. Controlled testing is necessary to isolate and analyze critical technical variables, whereas "uncontrolled" testing is necessary to reveal and assess institutional impediments to implementation. Another testing element relates to establishing performance-based specifications and test protocols for pre-qualifying or certifying a new product as suitable for acquisition and use by public agencies. For example, AASHTO's NTPEP and CERF's HITEC programs have established a standard nation-wide qualifying procedure to try to circumvent the need for each of the highway and public works agencies in various jurisdictions to qualify a new product for itself.

Pilot implementations and demonstrations are helpful to showcase "final" results and implementation procedures to key members of the user community and to secure their endorsement, which can pave the way for rapid adoption by others. Testimonial support by leading users is a powerful force for change. Constructive comparisons of best practices can promote adoption, because most agencies do not wish to be among the last to adopt a widely accepted innovation. The key is getting a "critical mass" of user acceptance so that adoption of the innovation will proceed on its own merits.

Support for making the transition to a new way of doing business is an important factor contributing to success in adopting an innovation.[40] The "lead state" concept, in which a state highway agency that implements an innovation serves as a peer counselor supporting other states as they make the transition, can be highly effective in overcoming hesitancy on the part of highway agencies at trying something that has yet to be proven in practice. Training, such as that offered by the National Highway Institute, is recognized as a key factor as well.[41] Such activities foster peer-to-peer implementation support.

The systematic evaluation, documentation and dissemination of implementation results often is neglected. However, *capturing and reporting the benefits of innovations as they are implemented is key to building momentum for more widespread deployment.* Efforts should be made to ensure that documentation of implementation results is developed and made available to interested parties.

Incentives can facilitate the introduction of new technologies and innovative techniques by helping agencies to deal with the costs of implementation. In many instances, deciding to "spend money now" to "save money over time" is a difficult proposition for agencies that are under pressure to deliver near-term tangible results. In addition, there are costs associated with adapting to the use of a new technology, such as deployment support and training; these large up front investments can be major impediments to innovation. For example, the use of Superpave requires laboratory procedures and facilities unlike those for conventional pavement. Any agency that wants to experiment with Superpave must find a way to cover the costs of acquiring the appropriate laboratory facilities, and of operating that laboratory in parallel with other facilities. Federal assistance in covering these costs is helpful in speeding the adoption of new technologies and techniques.

[40] NCHRP Report 382, *Facilitating the Implementation of Research Findings: A Summary Report*, Transportation Research Board, National Research Council, 1996.
[41] "Stewardship Report Documenting Benefits of Research and Technology Efforts," Federal Highway Administration, Report No. FHWA-SA-96-044, December 1995.

Chapter 5

Findings and Conclusions

Construction of major new surface transportation infrastructure capacity has slowed dramatically in the United States, while traffic volumes and freight tonnage continue to rise moderately and steadily for all surface transportation modes. The combination of increasing travel volume and fixed capacity is creating more congestion and inflicting more wear on the infrastructure. In addition, air and marine freight cargo traffic is growing, especially international shipments, and larger, faster ocean freighters are on the drawing boards. These industry changes are already generating more demand for landside access and better intermodal connections to the busy surface transportation system.

A surface transportation physical infrastructure system that is in good condition and that carries people and freight cost effectively is fundamental to meeting four of DOT's five Strategic Goals: safety, mobility, economic growth and national security. DOT's 1997 *Conditions and Performance Report* shows that the U.S. surface transport system is functioning at an acceptable, though not optimum, level. Thus, it is essential to ask what resources are necessary to assure that the surface transportation infrastructure remains in sufficiently good condition to ensure that these goals are met over the coming decades. DOT estimates that an annual investment of $46 billion would be required from all sources just to maintain current conditions and levels of congestion. An additional $34 billion would be required to correct deficiencies and provide a higher level of service.

The Nation's transportation infrastructure managers must find ways to do things better, cheaper, and faster – as well as safely. To the extent possible, the advantages of new technologies, tools, materials, and methods must be explored and their movement into the field accelerated. Under these circumstances, R&T programs to help this process appear to be more important than ever. However, research for this report found that approximately 90 percent of DOT R&T resources and most Departmental technology development and technology partnership efforts are focused on transportation system operations. Less than 10 percent of DOT's R&T resources are allocated to infrastructure preservation and renewal. R&T for transportation infrastructure has been carried out primarily by the FHWA, which estimates that about 30 percent of its FY 1998 R&T funding is used for this purpose. Without further analysis it is difficult to determine just what the appropriate amount for infrastructure renewal might be, but it is important for DOT to consider that question seriously.

Promising Technologies and Applications

In 1997 the TRB released its report, "Developing Long Lasting, Lower Maintenance Highway Pavement Research, Research Needs (FHWA)." This study was conducted to determine the technological feasibility of constructing pavement that will last up to 50 years without the need for major rehabilitation; to identify the research needs associated with long-lived, lower maintenance pavement; and to describe the issues associated with the use of more durable pavement.

Efforts such as this TRB report point to ways technologies can help to allocate resources and to make other infrastructure system challenges more manageable. However, the results of such activities can be even more widely useful if they take into account the needs and circumstances of other related parts of the transportation infrastructure, including other modes and even other applications of the same materials or process under review. Many technology categories show promise for use in the monitoring, maintenance, and rapid renewal of all types of surface transportation infrastructure, including intermodal facilities. These include the following:

- Many types of sensing, positioning, computer, and communications technologies;
- Advanced materials;
- Nondestructive testing and tools;
- Rapid construction methods; and
- Advanced modeling tools and cost models to assist in setting maintenance and management priorities.

Sensing, locating, computer, and communications technologies already play a key role in many current modal R&T programs, although most of these are focused on improving operational safety and efficiency. However, the same technologies, with some adaptations, could support infrastructure monitoring to forecast and predict problems, gauge incipient failures, and facilitate condition-based, "just-in-time" renewal.

Many surface transportation agencies already have established systems for managing segments of their physical infrastructure, particularly pavement and bridges; one example is the FHWA's bridge management system (BMS). These systems help target budgetary resources so as to realize the maximum benefit from infrastructure improvements. However, each system addresses a segment of the surface transportation infrastructure separately, and cannot by itself provide an overview of the condition and needs of all facilities that must be managed. A technique relatively new to surface transportation, Asset Management, will provide a systematic process of maintaining, upgrading, and operating physical assets in a cost-effective manner, and shows great promise for improving the monitoring, maintenance, and rapid renewal of surface transportation infrastructure. The process combines engineering principles with business practices and economics and facilitates a logical approach to infrastructure decision-making.[42]

In addition to new sensors for monitoring infrastructure condition, technologies that have Asset Management applications include Geographical Information Systems (GIS) and the Global Positioning System (GPS). These allow data to be spatially referenced, stored, and sorted to assess the overall conditions and operational performance along a specified route between two points, not just for individual facilities along the way. The potential of these various technologies is just beginning to be realized; it is important that R&T and technical assistance efforts be provided to ensure that their capabilities are widely used. In addition, R&T resources to support improved modeling tools and techniques for Asset Management could begin to address this difficult infrastructure issue, both for individual modes and for intermodal connections.

Federal R&T programs generally have not emphasized construction techniques for rapid renewal. Hence, the development of time saving techniques has been left to the few large private sector firms and projects that have the resources and incentives to devote to such efforts. For example, innovative engineering and construction methods enabled the forty-five year-old, two-lane George P. Coleman Bridge spanning the York River in Virginia to be dismantled and replaced by a new four-lane, 1,145 meter structure with only nine days of traffic disruption. Twenty-four days were allotted for bridge shutdown, with a penalty of $8,000 per hour for any delay in restoring traffic, and a $4,000 per hour incentive for early restoration. Virginia DOT was able to reduce the estimated $117 million cost of bridge replacement by $34 million through reuse of existing caissons to support the new superstructure. Even more important to bridge users, however, this minimized the time commuters were faced with a fifty mile detour that added up to two hours to the trip between Williamsburg and the Gloucester area.[43] This example demonstrates the time and money savings possible from the use of rapid renewal techniques. Recognizing the importance of faster construction, FHWA has made accelerated construction and maintenance an R&T program priority.

Given the considerable traffic congestion in major metropolitan areas, the fact that traffic patterns can change relatively rapidly, and the relatively fixed supply of infrastructure, more Federal attention to rapid renewal techniques, materials, and design and construction technologies appears to be warranted. New technology applications are being developed by the private sector at an extraordinary rate. Advanced materials and techniques for rapid construction also are likely to be developed by the private sector. However, without sufficient technology transfer efforts, the benefits of these technologies for public sector

---

[42] U.S. Department of Transportation, Federal Highway Administration and the American Association of State Highway and Transportation Officials, *Asset Management Advancing the State of the Art Into the 21st Century Through Public-Private Dialogue,* Publication No. FHWA-RTh97-046.

[43] "Barging in with the Best and the Brightest," *Consulting Engineer,* Aug/Sep 1997, American Consulting Engineers Council; "PB Notes," Parsons Brinkerhoff, 1996; and "George P. Coleman Bridge Reconstruction Project in Yorktown, VA," The Construction Corner, Virginia Tech.

infrastructure may not be realized. R&T on appropriate and cost-effective applications, management systems, and modeling tools for construction planning and scheduling could promote greater use by public officials of these rapid renewal technologies.

Technology Transfer Programs

Moving advanced technologies into the infrastructure market poses many challenges. An advanced technology requires leadership, political appeal, and funding advantages that outweigh the resistance often associated with long-established ways of doing business. In addition, there may be practical limitations, such as the size of pre-fabricated components being manufactured and transported, that cannot be overcome by technology transfer itself. Research into successful technology transfer programs indicates that the technologies must be market ready, address problems of significant impact to infrastructure owners, have sufficient funding, and have champions to lead the transfer efforts among peer practitioners.

The Strategic Highway Research Program's (SHRP) Snow and Ice Removal program is an example of successful technology transfer to State DOTs, particularly in Northern, mountain and 'snow belt' regions. This effort addressed a costly, highly visible problem that recurs annually and has environmental consequences -- these factors combine to make it a top political priority. Other programs that address relatively long-term issues, such as the development of cost-effective composite bridges, lack such high political visibility and are much more difficult to "sell" at the state and local level. For effective implementation, particularly in an emerging industry that has not developed an authoritative professional organization, institutional issues relating to establishing standard codes, specifications, and practices must be addressed.

Recognizing that R&T generates practical benefits only when the results are applied in practice, DOT modal agencies work in appropriate and different ways with their constituents to facilitate the commercialization and deployment of promising innovations. FHWA studies have estimated that technology applications and transfer for the highway community require at least the same amount of resources as were required by the initial technology research. Consequently, a significant portion of the FHWA's R&T budget is devoted to technology development and transfer, as well as to programs for implementing new technologies. Research for this report indicates that if DOT decides to accelerate infrastructure-related R&T innovation activities, parallel efforts will be needed to foster the implementation of the innovations. Promising ways to enhance the effectiveness of technology transfer include identifying champions who can work with lead states to ensure successful demonstrations, providing documentation of the effectiveness of new technologies, and fostering peer-to-peer information exchanges. To facilitate deployment, new ways of partnering between the public and private sectors and providing incentives for innovation adoption would be useful.

Focusing R&T for Infrastructure Renewal and Preservation

This review of DOT R&T has indicated a Department-wide dedication to the value of R&T consistent with the mission and purpose of each modal organization. However, for many institutional reasons, the potential cross-modal synergies of the resources the Department devotes to R&T programs have not yet been realized. A notable exception is the ITS Joint Program Office which, after several years of effort, has succeeded in providing a focus for ITS technologies for highway use and traffic operations, and for transit vehicles and operators. JPO is sponsoring the development of programs that include highway, transit, railroad, and maritime interests, as well as intermodal issues.

A similar, coordinated Department-wide R&T effort could focus on harnessing the benefits of these and other useful technologies, as well as advanced materials, and applying them to infrastructure condition monitoring, maintenance, and rapid renewal. FHWA's current infrastructure-related R&T programs provide a platform on which to build a broader Departmental effort. The Department could also focus efforts to seek cross-modal applications, explore and implement cross-modal synergies, and facilitate transfers of technology applications across modes. To meet the Department's goal of improving intermodal linkages, some joint efforts among highway, port, airport, transit and rail research groups for surface transport infrastructure technology development and applications seem to be warranted. In addition, the Department may choose to initiate cooperative interagency R&T programs to realize technology benefits from other Federal agencies.

To accomplish all this successfully, the DOT may want to consider establishing a center or focal point for infrastructure preservation that would concentrate on issues associated with physical infrastructure monitoring, maintenance, and rapid renewal. This center could track progress against benchmark goals, established by consensus among R&T experts. These goals might include such items as increasing estimated pavement life by 10 years across the states; reducing time required for maintenance, construction, and reconstruction by a reasonable percentage; and reducing or eliminating user time lost through reconstruction. Having identified the importance of benchmarks, it is only fair to reiterate that gains in infrastructure condition from new technologies become apparent only over time. The challenge of fitting physical infrastructure-related R&T programs into the framework of the Government Performance and Results Act is readily acknowledged.

Appendix A

Acronyms

AASHTO	American Association of State Highways and Transportation Officials
ACBM	Advanced Cement-based Materials
AE	Acoustic Emission
APWA	American Public Works Association
ATIP	Automated Track Inspections Programs
ATIS	Advanced Traveler Information Systems
ATMS	Advanced Traffic Management Systems
BART	Bay Area Rapid Transit system
BMS	Bridge Management System
Caltrans	California Department of Transportation
CCDoTT	Center for Commercial Development of Transportation Technologies
CERF	Civil Engineering Research Board
CHCP	Cargo Handling Cooperative Program
CMAQ	Congestion Mitigation Air Quality
CMCS	Chassis-Mounted Container System
COE	Center of Excellence
COTS	Commercial Off-The-Shelf
CRADA	Cooperative Research And Development Agreement
CRDA	Cooperative Research and Development Agreement
DOD	Department of Defense
DOT	Department of Transportation
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Facility for Accelerated Service Testing
FHWA	Federal Highway Administration
FLC	Federal Laboratory Consortium
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
FTSS	Federal Track Safety Standards
FY	Fiscal Year
GAO	General Accounting Office
GIS	Geographical Information Systems
GOCO	Government-Owned, Contractor-Operated
GOE	General Operating Expenses
GPS	Global Positioning System
GRMS	Gage Restraint Management System
HITEC	Highway Innovative Technology Evaluation Center
HPC	High-Performance Concrete

HPS	High-Performance Steel
ICC	Interstate Commerce Commission
IDEA	Innovations Deserving Exploratory Analysis
ISTEA	Intermodal Surface Transportation Efficiency Act
ITI	Intelligent Transportation Infrastructure
ITS	Intelligent Transportation Systems
JPO	Joint Program Office
LTAP	Local Transportation Assistance Program
LTPP	Long-Term Pavement Performance Program
MARAD	Maritime Administration
MTAMS	Marine Terminal Automated Management Systems
MTMC	Military Traffic Management Command, Department of Defense
NCHRP	National Cooperative Highway Research Program
NDE	Nondestructive Evaluation
NDT	Nondestructive Testing
NHI	National Highway Institute
NHTSA	National Highway Traffic Safety Administration
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NSTC	National Science and Technology Council
NTPEP	National Transportation Product Evaluation Program
ORTA	Office of Research and Technology Applications
OST	Office of the Secretary of Transportation
PAIR	Partnership for the Advancement of Infrastructure and its Renewal
PTC	Positive Train Control
PTP	Priority Technologies Program
R&D	Research and Development
R&T	Research and Technology
RE&D	Research, Engineering and Development
RPU	Remote Processing Unit
RSPA	Research and Special Programs Administration
RTEB	Research and Technology Evaluation Board
RWIS	Road Weather Information Systems
SHRP	Strategic Highway Research Program
SICG	SHRP Implementation Coordination Group
SNRA	Swedish National Road Administration
SOCP	Ship Operations Cooperative Program
STP	Surface Transportation Program
TCRP	Transit Cooperative Research Program
TEA 21	Transportation Equity Act for the 21st Century
TEU	Twenty-foot container Equivalent Unit
TRANSCOM	U.S. Transportation Command, Department of Defense
TRB	Transportation Research Board

TWG	Technical Working Group
UIUC	University of Illinois at Urbana-Champaign
URI	University Research Institute
USCG	United States Coast Guard
UTCP	University Transportation Centers Program
VTS	Vessel Traffic Services

Appendix B

Estimate of R&T Funding of Physical Infrastructure Maintenance, Monitoring, and Renewal FY 1998[1]

R&T Program	Total for Program	Amount for Infrastructure Maintenance, Monitoring, and Renewal	
Highway R&D[2]	$61,087,000	Pavements	$10,500,000
		Structures	$15,256,000
Technology Assessment & Deployment[3]	$13,311,000	Roadway Applications	$1,080,000
		Structures & Soils	$2,383,000
Technology Implementation Partnerships[4]	$11,000,000		$4,290,000
Long Term Pavement Performance	$15,000,000		$15,000,000
National Technology Deployment Initiative[4]	$56,000,000		$21,840,000
ITS R&D[5]	$31,500,000		$0
NHI[4]	$8,000,000		$3,120,000
Advanced Research[4]	$1,000,000		$390,000
National Advanced Driver Simulator	$13,250,000		$0
International[4]	$900,000		$351,000
GPS Oversight	$1,000,000		$0
R&T Technical Support	$10,000,000		$0
Totals	$222,048,000		$74,210,000

Source: Federal Highway Administration, Office of Associate Administrator for Research and Development, March 1998.

Notes:

1. Funding is taken from FY 1998 Appropriations Conference Report and the Administration's proposed NEXTEA legislation. Infrastructure maintenance, monitoring, and renewal is estimated to be 35 percent of total FHWA proposed FY 1998 R&T program. Turner Fairbank Highway Research Center Rehabilitation and MBE were not included since they are not R&T activities. UTC, URI, Eisenhower Fellowships, SPR, and LTAP were not included since much of the work in these programs is done with minimal, if any, direction from FHWA.

2. Data and analysis from other parts of Highway R&D may support infrastructure maintenance, monitoring and rehabilitation, but were not included in the table. Examples include the following: Policy's traffic monitoring ($3.360 M), and economic and conditions and performance ($2.484 M); Planning's travel demand modeling ($1.122 M) and congestion management and mobility ($0.531 M).

3. Subdivisions of Roadway Applications and Structures and Soils were taken from the FY 1998 Budget Justifications. Amounts were determined by assigning prorated shares of the enacted amount. For instance, the budget request was $1.2 million for Roadway Applications out of a requested $14.8 for TAD. So $1.08 million was assumed for Roadway Applications under the enacted total of $13.311 million for TAD.

4. The amount intended for infrastructure renewal for these items was determined by applying the average amount (39 percent) calculated for Highway R&T and Technology Assessment and Deployment.

5. The entire amount for ITS activities in FY 1998 is approximately $226 million. However, only $31.5 million was enacted for ITS R&D in the FY 1998 appropriations.