The Federal Role in Highway Research and Technology

Special Report 261

Transportation Research Board

THE NATIONAL ACADEMIES

The Federal Role in Highway Research and Technology

Research and Technology Coordinating Committee

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

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Preface

The Research and Technology Coordinating Committee (RTCC) was convened in 1991 by the Transportation Research Board (TRB) of the National Academies to provide a continuing, independent assessment of the Federal Highway Administration's (FHWA) research and technology (R&T) program. Funding for the committee is provided by FHWA.

A previous RTCC report describes research, development, and technology transfer in the highway industry (TRB 1994). Since preparing that report, the RTCC has examined many specific aspects of highway R&T, some at the request of FHWA and some under its own initiative and with FHWA's support. Much has happened to the structure and funding of highway R&T since 1994, especially as a result of passage of the Transportation Equity Act for the 21st Century (TEA-21) in June 1998. TEA-21 led to increased awareness among the highway industry that highway R&T is a shared responsibility and that federal highway R&T cannot address all highway transportation issues or serve all potential industry customers. This awareness has brought focus to the need for improved coordination among the various highway R&T activities, an idea this committee has supported in the past.

TEA-21 also called for TRB to establish a study committee to determine the "goals, purposes, research agenda and projects, administrative structure, and fiscal needs for a new strategic highway research program." That committee proposed a Future Strategic Highway Research Program (F-SHRP) modeled after the first SHRP. This program would be focused, time constrained, management driven, and designed to complement other existing highway research programs.

The passage of TEA-21 influenced the formation of the National Highway R&T Partnership Forum in late 1998 by FHWA, the American Association of State Highway and Transportation Officials, and TRB. The purpose of the forum was "to engage the entire highway transportation community in the identification of highway R&T needs and to address the benefits to be realized by forming partnerships to fulfill those needs." Participation in the partnership effort was completely voluntary but ultimately involved hundreds of individuals and more than 160 organizations. The RTCC assigned a committee member to monitor each of the forum's working groups. A summary of R&T needs prepared by the forum is included in Appendix B.

As these activities were getting under way, the committee decided to examine whether the focus and activities of the federal highway R&T program are appropriate in light of the needs of the nation's highway system and the roles and activities of other highway R&T programs. The RTCC worked closely with the F-SHRP committee while carrying out this analysis; indeed, the F-SHRP committee had four members in common with the RTCC. By agreement of the National Academies, the two committees shared draft materials. This report presents the findings resulting from the RTCC's examination of federal highway R&T and a proposal for a change in direction aimed at strengthening the overall R&T enterprise. The report was prepared as a companion to the F-SHRP committee's report [*Strategic Highway Research: Saving Lives, Reducing Congestion, Improving Quality of Life* (TRB 2001)] and is directed toward key federal highway R&T decision makers (Congress and FHWA), as well as the stakeholders in federal highway R&T.

The term "federal highway R&T program" is used in this report to refer to the combined responsibilities and actions of Congress, the administration, and FHWA in funding federal highway research, determining research needs, setting research program priorities, and executing the research program. Although the recommendations in this report are aimed primarily at FHWA's R&T program, they are discussed in the context of other programs within the highway R&T enterprise—the state R&T programs, the National Cooperative Highway Research Program, and private-sector research. These other programs focus on highway infrastructure issues and are supported by highway industry stakeholders. The committee recognizes that there are other research programs directly related to the highway system, especially those of the Federal Motor Carrier Safety Administration and the National Highway Traffic Safety Administration. In addition, research undertaken by the Environmental Protection Agency, the National Science Foundation, and the Department of Defense involves topics of interest to highway agencies and researchers.

The recommendations in this report are aimed at the current focus of FHWA's R&T program. This focus is similar to that of the other highway R&T programs. Nevertheless, the committee believes there are significant opportunities for fundamental, long-term research that would be beneficial to the national R&T enterprise and that FHWA, as the mission agency responsible for the nation's highway program, is well positioned to both promote and undertake. Although this report presents recommendations that involve some changes in FHWA's program, it also recognizes FHWA's past R&T accomplishments and suggests the continuation of many of the agency's activities in support of the nation's highway R&T programs.

The committee would like to recognize the FHWA staff members who provided valuable information and background material for this study. Dennis Judycki, Marci Kenney, Tom Krylowski, and Jason McConachy of FHWA's Office of Research, Technology and Development were particularly helpful in preparing material for the committee and participating in several discussions about specific research management issues. The committee also benefited from presentations by representatives of the working groups of the National Highway R&T Partnership Forum, including Thomas E. Bryer, Pennsylvania Department of Transportation; Dennis J. Christiansen, Texas Transportation Institute; Elizabeth Deakin, University of California, Berkeley; Leanna Depue, Central Missouri State University; Francis B. Francois; Ian MacGillvary, University of Iowa; Alan E. Pisarski; Phillip J. Tarnoff, University of Maryland; and Mary Lynn Tischer, Arizona Department of Transportation.

The study was conducted under the overall supervision of Stephen R. Godwin, TRB's Director of Studies and Information Services. Walter J. Diewald served as project director and prepared this report under the direction of the committee. The committee wishes to thank Suzanne Schneider, Assistant Executive Director of TRB, who managed the report review process. The report was edited by Rona Briere with the assistance of Alisa Decatur and prepared for publication under the supervision of Nancy A. Ackerman, Director of Reports and Editorial Services.

This report has been reviewed by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report: Michael S. Bronzini, George Mason University; Randall Erickson, North Oaks, Minnesota; Damian Kulash, Eno Transportation Foundation; Morris Tanenbaum [National Academy of Engineering (NAE)], Short Hills, New Jersey; and Gary D. Taylor, Michigan Department of Transportation. Although the individuals listed above

have provided constructive comments and suggestions, it must be emphasized that responsibility for the final content of this report rests solely with the authoring committee and the institution.

The review of this report was overseen by H. Norman Abramson (NAE), San Antonio, Texas, and Lester A. Hoel (NAE), University of Virginia, Charlottesville. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

References

Abbreviation

TRB Transportation Research Board

TRB. 1994. *Special Report 244: Highway Research: Current Programs and Future Directions.* National Research Council, Washington, D.C.

TRB. 2001. *Special Report 260: Strategic Highway Research: Saving Lives, Reducing Congestion, Improving Quality of Life.* National Research Council, Washington, D.C.

Contents

Acronyms

AASHTO	American Association of State Highway and Transportation Officials (formerly AASHO)
ACI	American Concrete Institute
AISC	American Institute of Steel Construction
ARTBA	American Road and Transportation Builders Association
ASBI	American Sequential Bridge Institute
ASCE	American Society of Civil Engineers
ATA	American Trucking Associations; Air Transport Association
BPR	Bureau of Public Roads (successor of ORI)
BTS	Bureau of Transportation Statistics
CAAA	Clean Air Act Amendments
CBUs	core business units (FHWA)
CERF	Civil Engineering Research Foundation (ASCE)
COST	Cooperation on Science and Technology (program)
COTA	Congressional Office of Technology Assessment
CVISN	Commercial Vehicle Information Systems and Networks
CVO	commercial vehicle operations
DOT	U.S. Department of Transportation
ECMT	European Conference of Ministers of Transportation
EPA	Environmental Protection Agency
EUREKA	European Research Coordination Agency
FAA	Federal Aviation Administration
FARS	fatality analysis reporting system (NHTSA)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FRP	fiber-reinforced polymer
FTA	Federal Transit Administration

F-SHRP	Future Strategic Highway Research Program
GAO	General Accounting Office
GIS	geographic information system
GPRA	Government Performance and Results Act (1993)
HITEC	Highway Innovative Technology Evaluation Center (CERF)
HMA	hot-mix asphalt
HP&R	Highway Planning and Research (now SP&R)
IDEA	Innovations Deserving Exploratory Analysis (TRB program)
IIHS	Insurance Institute for Highway Safety
IRF	International Road Federation
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
ITS	intelligent transportation systems (successor to IVHS)
ITS/JPO	Intelligent Transportation Systems Joint Program Office
IVHS	intelligent vehicle–highway systems
IVI	Intelligent Vehicle Initiative
LTAP	Local Technical Assistance Program
LTPP	Long-Term Pavement Performance (program)
MPO	metropolitan planning organization
NAE	National Academy of Engineering
NAPA	National Asphalt Paving Association
NAS	National Academy of Sciences
NASS	National Automotive Sampling System (NHTSA)
NCAT	National Center for Asphalt Technology
NCHRP	National Cooperative Highway Research Program (TRB)
NCP	National Coordinated Program (of Highway Research, Development, and Technology)
NHI	National Highway Institute (FHWA)
NHS	National Highway System (consists of nearly 159,000 miles of roads, includes only 4 percent of the 3.9 million miles of public roads, but carries more than 40 percent of the nation's highway traffic, people, and goods)
NHTSA	National Highway Traffic Safety Administration
NIST	National Institute of Standards and Technology
NRC	National Research Council
NSC	National Safety Council
NSTC	National Science and Technology Council

NSF	National Science Foundation
NTSB	National Transportation Safety Board
OECD	Organization for Economic Cooperation and Development
OMB	Office of Management and Budget
ORI	Office of Road Inquiry (predecessor to FHWA and part of U.S. Department of Agriculture)
OST	Office of the Secretary of Transportation
OSTP	Office of Science and Technology Policy (White House)
PBCAT	pedestrian and bicycle safety crash analysis tool
PCA	Portland Cement Association
PCI	Precast/Prestressed Concrete Institute
PIARC	Permanent International Association of Road Congresses
RAC	Research Advisory Committee (AASHTO)
R&D	research and development
R&T	research and technology
RSPA	Research and Special Programs Administration (DOT)
RTCC	Research and Technology Coordinating Committee
RTD	Research and Technological Development (program)
RTR	Road Transport Research (OECD program)
RWIS	roadway weather information systems
SBUs	service business units (FHWA)
SCOH	Standing Committee on Highways (AASHTO)
SCOR	Standing Committee on Research (AASHTO)
SHRP	Strategic Highway Research Program
SP&R	State Planning and Research (States can spend up to 2 percent of their federal-aid highway construction funds on planning and research; up to 25 percent of these funds can be spent on research; this is referred to as the SP&R Program. A portion of these funds is used to support NCHRP.)
STAA	Surface Transportation Assistance Act of 1982
STPP	Surface Transportation Policy Project
TEA-21	Transportation Equity Act for the 21st Century (1998)
TCRP	Transit Cooperative Research Program (TRB)
TFHRC	Turner-Fairbank Highway Research Center (FHWA)
TOPS	TCRP Oversight and Project Selection Committee
TRB	Transportation Research Board (NRC)
TRIS	Transportation Research Information Services (TRB)
TRL	Transportation Research Laboratory (United Kingdom)

TTI	Texas Transportation Institute (Texas A&M University System)
UTC	University Transportation Center
VMT	vehicle-miles traveled
VNTSC	Volpe National Transportation Systems Center (DOT)

Executive Summary

The American public wants safer roads that can help reduce fatalities and injuries from highway crashes; new and reconstructed highways that are more compatible with established communities and the natural environment; highway rehabilitation and repair projects that are performed quickly to reduce traffic disruption and provide smooth, long-lasting pavements; and systems that manage traffic to reduce congestion and provide highway users with precise, reliable information about traffic conditions, incidents, and alternative routings. Achievement of many of these goals is possible and perhaps even essential to sustain the nation's economic growth, improve its quality of life, and preserve the environment for future generations, but it will require continuing innovation delivered through a strong national highway research and technology (R&T) effort.

Organizing and supporting such an effort has always been challenging. The highway industry—the joint public–private enterprise responsible for the highway system—is highly decentralized. More than 35,000 government units manage the highway system, and tens of thousands of private contractors, material suppliers, and other organizations provide supporting services. Highway R&T reflects the way the industry is organized by also being decentralized—an approach that keeps much of the research close to those who implement its results.

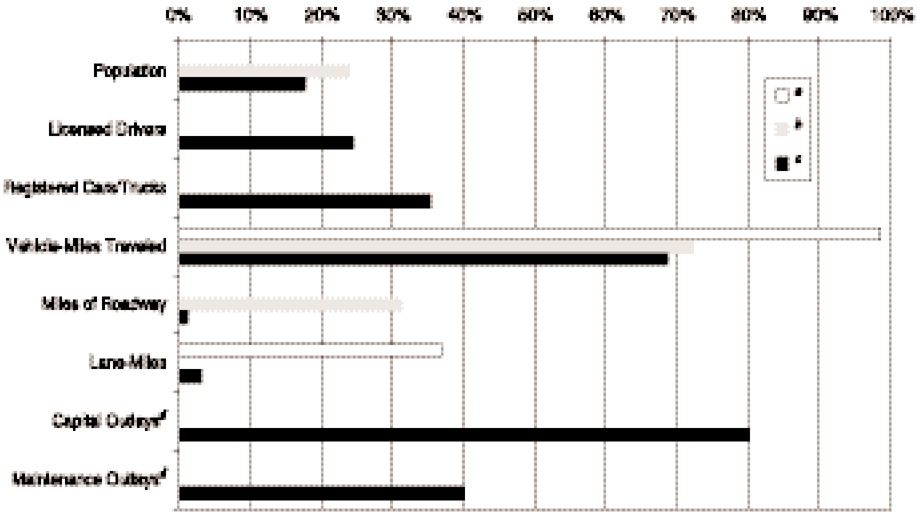
This report examines the federal role in the nation's overall highway R&T effort. Its emphasis is on determining whether the focus and activities of the federal program are appropriate in light of the needs of the highway system and its stakeholders as well as the roles and activities of other national highway R&T programs.

Challenges Facing the U.S. Highway System

The U.S. highway system is large and complex. It is the nation's biggest public infrastructure system, comprising more than 3.9 million mi of roadways, more than 583,000 bridges and other related structures, and a wide range of traffic control and safety systems and equipment. Spending for highways for all units of government in 1999 was more than $117 billion, representing more than two-thirds of all U.S. spending on infrastructure. Annual user expenditures for passenger and freight transportation and equipment total more than $900 billion.

These expenditures support an enormous amount of travel. In addition, drivers, vehicles, and miles traveled are all increasing at a faster pace than population growth (see Figure ES-1). Moreover, the growing congestion experienced by most highway users is readily understood if one compares the much larger increase in annual vehicle-miles traveled (demand) with the increase in lane-miles (capacity) during the 17-year period in the figure. People use roadways for most passenger trips. Highways account for 2.7 trillion vehicle-miles traveled per year and in 1995 were used for nearly 90 percent of daily passenger trips and 92 percent of passenger-miles traveled. Truck traffic is a major contributor, as evidenced by the doubling of the number of large trucks (Class 8) from 1982 to 1997. Revenues of all intercity commercial carriers increased considerably between 1986 and 1996; for example, revenues for United Parcel Service shipments more than doubled during the period.

Highway research has yielded many advances and innovations that have contributed to improvements in all aspects of highway system development. These include the Superpave® pavement design system, which reduces costs and extends pavement life relative to traditional designs; an automated data-collection system for commercial truckers, based on intelligent transportation system technologies, that reduces the cost of regulatory compliance for both truckers and state highway officials; use of composite materials to strengthen concrete bridge structures and reduce seismic-induced damage; and improved roadside safety devices that minimize the loss of life and property when vehicles run off the road.



[a]Freeway characteristics for 68 metropolitan areas (TTI 2001).
[b]Area or highway system characteristics for 68 metropolitan areas (TTI 2001).
[c]U.S. data (FHWA 2000a).
[d]The outlays shown represent nominal dollar amounts (not adjusted for inflation).

Figure ES-1 **Changes in key variables related to highway transportation, 1982–1999.**

Despite these advances, however, today's aging highway system faces daunting challenges. These challenges arise from the demand–capacity imbalance noted above, as well as from highway user preferences; from legislation, including the 1991 and 1998 federal-aid highway program reauthorization bills; and from the need to sustain a well-functioning highway system as an integral part of the nation's overall transportation system. These challenges include increasing traffic congestion, complex repair and rehabilitation needs, concerns about highway safety, environmental and energy issues, the need for improved planning and decision-making tools, and the need to assess the role of highways in the nation's transportation system.

Highway Research and Technology Programs

Change, improvement, and innovation based on highway research have long been important to the highway system. Developing and implementing highway innovations through research is primarily a public-sector activity, although it is often undertaken in conjunction with private-sector members of the highway industry. This situation results from the largely public-sector ownership and management of the highway system. However, highway R&T is not a single, centrally managed program. It consists of many individual programs, including a federal highway R&T program,[1] the various state R&T programs, the National Cooperative Highway Research Program (NCHRP), and many private-sector activities.[2] Universities also make an important contribution to highway research. Individual highway R&T programs have their own roles and specific responsibilities based on program ownership and purpose. Nonetheless, the programs are not isolated from each other and benefit from considerable professional interaction and information exchange.

The Federal Highway Administration (FHWA) R&T program responds to the agency's mission and responsibilities for carrying out the federal-aid highway program authorized by Congress. The program addresses a wide range of topics and includes many related activities in support of other highway R&T programs. The majority of the program is aimed at incremental improvements leading to lower construction and maintenance costs, better system performance, added highway capacity, reduced highway fatalities and injuries, reduced adverse environmental impacts, and a variety of user benefits (such as improved travel times and fewer hazards). A small portion of the program funding, about $900,000, supports research focused on breakthrough technologies capable of effecting improvements in highway performance and cost reductions. Such speculative, high-risk research has potentially high payoffs but is unlikely to be addressed in other highway R&T programs because of the risk or cost involved.

Each state highway agency has a research program that addresses technical questions or problems of immediate concern to the agency on the basis of local needs and conditions. Results from the individual state programs are shared with and are often of considerable interest to other states. NCHRP's applied research addresses issues common to most states and appropriate for a single, focused investigation. Private-sector research encompasses individual programs conducted or sponsored by companies that design and construct highways and supply highway-related products, national associations of industry components, and engineering associations active in construction and highway transportation. The research tends to focus on near-term issues and to be aimed at improving business operations or creating a business advantage. Finally, university researchers conduct research under contract to the FHWA, state, NCHRP, and private-sector highway R&T pro-

[1] The term "federal highway R&T program" is used in this report to refer to the combined responsibilities and actions of Congress, the administration, and the Federal Highway Administration in funding federal highway research, determining research needs, setting research program priorities, and executing the research program.

[2] These programs are described in Chapter 3.

grams and provide education and training opportunities for future transportation professionals. The roles described above are logical for the individual programs, beneficial to the national highway R&T effort, and unlikely to change because of their successful track records and strong constituency support.

Assessment of Federal Highway R&T Program

In examining the role of federal highway R&T, the Research and Technology Coordinating Committee recognized four contextual features of the highway industry and highway innovation that are important for understanding the federal role in highway R&T in terms of what it is and what it could be:

- *Many stakeholders*—Federal highway R&T has many external and internal stakeholders. External stakeholders include highway users, the highway industry, and people and communities served and affected by highways. Some of these entities are critical to the implementation of innovations, while others have a clear stake in the direction and management of highway research programs. The program's internal stakeholders include FHWA's core business units and service business units, as well as the other modal administrations and federal agencies outside the U.S. Department of Transportation, especially if they have research programs with common interests and research opportunities. In recent years Congress has played an increasing role as an internal stakeholder by directly appropriating funds for research activities.
- *One program among many*—With more than 50 programs that sponsor highway research in the United States, highway R&T is highly decentralized. Although this approach keeps the research close to important stakeholders and those who implement the results, it can result in unnecessary duplication, results that are not transferable, significant research gaps, and inadequate follow-up on promising results. Federal highway R&T cannot operate autonomously in this environment.
- *Barriers to innovation*—Highway innovation is difficult because the highway industry is so decentralized, its procurement practices at times provide little incentive to innovate, and there is considerable aversion to risk in the public sector. Achieving widespread implementation of innovations often requires a great deal of proactive technology transfer.
- *Important federal role*—For many decades the federal government, primarily through FHWA, has provided substantial funding for highway R&T, supported program staff and technology transfer activities in every state, organized international technology scans, and gathered and disseminated information about research activities and promising results. Its continued support of the State Planning

and Research (SP&R) Program has exerted an important influence on the state R&T programs.

Successful research programs incorporate two types of features: (*a*) those that are characteristic of effective research programs regardless of the topic area or field involved and (*b*) those that are tailored to the specific context in which the program operates. Drawing on both types, the committee identified eight characteristics as key to the success and effectiveness of the federal highway R&T program:

- Clear mission with well-defined goals that complement other R&T programs,
- Significant opportunities for technological progress and innovation,
- Early and sustained external stakeholder involvement,
- Provisions for open competition and merit review to safeguard the federal R&T investment,
- Mechanisms for information management and dissemination,
- Rigorous program evaluation,
- Adequate resources, and
- Appropriate leadership of national highway R&T activities.

Recommendations

The federal role in highway R&T is vital to highway innovation. Only the federal government has the resources to undertake and sustain high-risk—but potentially high-payoff—research, and only the federal government has the incentives to invest in long-term, fundamental research. In the committee's judgment and given the characteristics of federal agency research articulated by the National Science and Technology Council of the Office of Science and Technology Policy, FHWA's R&T program is missing an opportunity to address this critical federal responsibility. The following are the committee's recommendations for improving and strengthening this and other aspects of the federal highway R&T program.

FHWA's R&T program should focus on fundamental, long-term research aimed at achieving breakthroughs in the understanding of transportation-related phenomena. In the judgment of the committee, at least one-quarter of FHWA's R&T research expenditure should be invested in such research.[3]

[3] This recommendation for more fundamental, long-term research is consistent with a previous committee recommendation (TRB 1994). The amount recommended here, one-quarter of FHWA's R&T budget, is approximately $52 million in terms of its Fiscal Year 2001 budget and less than 8 percent of its annual expenditures for highway R&T in all programs.

Fundamental, long-term research goes beyond solving problems incrementally. It involves and draws on basic research results to provide a better understanding of problems and develop innovative solutions. For example, fundamental research aimed at improving understanding of the properties of pavement materials at the molecular level could lead to better asphalt and concrete pavements by improving the predictability of the life-cycle performance of different pavement designs. Similarly, fundamental research on individual travel behavior, lifestyle choices, and household activity patterns could lead to the development of better predictive models of regional travel demand to replace current descriptive models calibrated with aggregate data. Such research has the potential for high payoffs, even though it tends to be risky and typically requires longer to complete. Current expenditures for fundamental, long-term research at FHWA are less than 0.5 percent of the agency's R&T budget. The consensus of the committee is that this funding level is too low for such an important activity that is appropriate to a federal agency, especially since the state and private-sector highway R&T programs are unlikely to undertake this type of research.

FHWA's R&T program should undertake research aimed at (*a*) significant highway research gaps not addressed in other highway R&T programs and (*b*) emerging issues with national implications.

State, private-sector, and university highway R&T programs encompass successful problem-solving efforts, but they do not invest in certain kinds of research for several reasons, including scope, scale, and time frame. For example, although the private sector has undertaken research on how to produce improved retro-reflective pavement markings, it has had little interest in pursuing research to develop a mobile retroreflectometer that would enable public agencies to determine whether existing markings meet safety standards. Such research has been undertaken by the public sector. Similarly, research on emerging issues is appropriate for federal agencies. For example, the federal government could examine how traffic diversion due to increased congestion on urban freeways can affect the performance of alternative routes not built to Interstate design standards.

The committee recommends that FHWA adopt the goal of allocating approximately one-half of its R&T resources to topics addressing significant gaps in other highway R&T programs and emerging issues with national implications.[4]

[4] The combination of this recommended research with the fundamental, long-term research recommended earlier is needed to change the current focus of FHWA's R&T program on short-term, problem-solving research.

This share would leave one-quarter of FHWA's R&T resources for other activities related to the agency's federal mission responsibilities, including research related to policy and regulations, technology transfer and field applications, education and training, and technical support.

FHWA's R&T program should be more responsive to and influenced by the major stakeholders in highway innovation.

These stakeholders include the federal, state, and local government agencies that construct, maintain, and administer the nation's public highways; the private companies that supply materials, equipment, and services used by these agencies; and a wide array of highway users, communities, and public interest groups. FHWA's recent solicitation of highway research needs through the National Highway R&T Partnership Forum activity is a noteworthy first step toward obtaining broad stakeholder input. Although the forum has produced useful information on research needs, more substantive stakeholder involvement in the decision making, priority setting, and resource allocation for FHWA's research program is essential to ensure that the program addresses the problems faced by those building, maintaining, using, and affected by the nation's highways. A significant challenge for the agency is informing Congress about stakeholder perceptions of highway research needs and priorities.

Although a systematic approach to stakeholder involvement begins with problem identification, such involvement must carry through to implementation.

To maintain an appropriate program focus on fundamental, long-term research, decisions about what research to pursue should balance stakeholder problem identification with expert external technical review regarding which research areas and specific research directions hold promise for significant breakthroughs. Such decisions should also reflect a strategic vision for the national transportation system. FHWA's R&T program should be based on open competition, merit review, and systematic evaluation of outcomes.

Competition for funds and merit review of proposals are the best ways of ensuring the maximum return on investment of research funding and addressing strategic national transportation system goals. Designation of specific projects or research institutions without open competition occurs at the expense of missing creative proposals prepared by the most qualified individuals and organizations throughout the nation and does not reflect the consensus of national highway stakeholders on research needs.

Merit review and evaluation should include panels of external stakeholders and technical experts. To ensure nationwide representation on such panels, Congress should provide FHWA with funds and the authorization to meet this need.

Travel expenses for external stakeholders and technical experts involved in merit review and evaluation panels can be considerable. It is important that Congress recognize these costs and provide administrative funds for their reimbursement.

FHWA's highway R&T program should promote innovation by surveying research and practice worldwide, with the goal of identifying promising technologies, processes, and methods for use in the United States. The information from such surveys should be disseminated to the full range of highway stakeholders.

FHWA's research managers are well positioned to assume this role because of their extensive interactions with state highway agencies, private industry, other federal agencies, universities, and key highway research organizations throughout the world. They can leverage these interactions to undertake and promote the identification of promising innovations and disseminate this knowledge to all highway stakeholders. The agency's research on pedestrian safety measures used in Europe, for example, suggested several methods of crosswalk marking, signal operation, and traffic calming for application in the United States.

Two key elements of the federal highway R&T program are the University Transportation Centers (UTC) Program and the SP&R program. The UTC program is one of few opportunities for highway and transportation researchers to pursue investigator-initiated research. Although the amount of funding made available to individuals is quite modest, such funds are vital for attracting and supporting some of the nation's best young minds to highway and transportation research and thereby play an important role in graduate education.

University transportation research funded under the UTC program should be subject to the same guidelines as FHWA's R&T program—open competition, merit review, stakeholder involvement, and continuing assessment of outcomes—to ensure maximum return on the funds invested.

The SP&R program, which originated more than 60 years ago, has become an important component of the national highway R&T effort. Congress should continue to authorize this program.

The research portion of the SP&R program is the centerpiece of state highway agency R&T programs. The federal SP&R research funds, which amounted to $185 million in 2001, are matched by state funds on at least a 20:80 (state-to-federal) basis; although this contribution to research is significant, some states spend additional state funds on highway research. The SP&R program not only facilitates individual state highway R&T programs but also fosters research collaboration and partnering among the states in pooled-fund projects.

The committee endorses the findings and recommendations of the congressionally requested study to determine the need for and focus of a future strategic highway research program (known as F-SHRP).

The report of that study [titled *Strategic Highway Research: Saving Lives, Reducing Congestion, Improving Quality of Life* (TRB 2001)], which is being released concurrently with this report, calls for a large-scale, fixed-duration strategic research initiative aimed at the most important problems currently facing public highway agencies. F-SHRP is designed to yield research products for immediate use. It will provide a natural complement to a federal highway R&T program focused on long-term, fundamental research. F-SHRP is aimed at making substantial progress toward four critical research goals:

- Developing a consistent, systematic approach to performing highway renewal that is rapid, causes minimum disruption, and produces long-lived facilities;
- Preventing or reducing the severity of highway crashes through more accurate knowledge of crash factors and of the cost-effectiveness of selected countermeasures in addressing these factors;
- Providing highway users with reliable travel times by preventing and reducing the impact of nonrecurring incidents; and
- Developing approaches and tools for systematically integrating environmental, economic, and community requirements into the analysis, planning, and design of new highway capacity.

It is important that the proposed funding for the F-SHRP research—derived from federal-aid highway program allocations to the states that would otherwise be spent on construction, maintenance, and other authorized activities—not be viewed as a substitute for funding for other state and federal highway R&T programs.

The above recommendations call for a strong federal highway R&T program designed to maximize the investment of public funds in a research effort that is vital to the nation's economy and the quality of life of all its citizens. The recommendations directed at FHWA call for strong leadership, clear vision, stakeholder involvement, and accountability in all facets of the program. If these reforms are implemented, the committee would support a significant increase in the agency's R&T budget.

An FHWA R&T budget of twice the current level, while significant, would nonetheless amount to only about 1 percent of annual total public highway expenditures. Even this increase would leave the funding low compared with research expenditures in other important sectors of the economy or other federal mission agencies.

Finally, the committee recognizes that reforming the federal highway R&T program in accordance with the above recommendations will require the cooperation and contributions of Congress, FHWA, and highway R&T stakeholders. Congress provides the funding and funding flexibility; FHWA manages the program and conducts research; and highway R&T stakeholders contribute in many ways, including implementing innovations.

Therefore, if Congress agrees with the committee's recommendations for an improved federal highway R&T program, it should provide FHWA with the funding and funding flexibility needed to undertake the recommended changes. Without such changes in its R&T funding and funding flexibility, FHWA will be unable to reform its R&T program as the committee has recommended. If FHWA's highway R&T program cannot be reformed, highway R&T stakeholders should explore with Congress other mechanisms for carrying out federal highway research.

Highway transportation is too important, the stresses too severe, and innovation too critical to do anything less.

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Abbreviations

FHWA	Federal Highway Administration
TRB	Transportation Research Board
TTI	Texas Transportation Institute

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CHAPTER 1

Introduction

The U.S. transportation system is a critical component of the nation's economy. Highways are a key element of the system, used for 90 percent of all passenger trips and movement of more than half of the nation's freight tonnage. Highway travel enables interactions between locations and people for work, school, shopping, recreation, health care, worship, and other activities. Moreover, it is increasingly apparent that a high-quality transportation system—including good highway transportation—is essential to a growing economy. Indeed, studies of federal involvement in various infrastructure elements have documented the contribution of capital investment in highways to industry output and productivity (see Nadiri and Mamuneas 1996; Lewis 1991). As the nation's economy—and its population—continues to grow, so, too, does the need to improve the durability, efficiency, productivity, and safety of highway and intermodal transportation systems and reduce their environmental impacts.

To ensure that the highway system continues to contribute to the goals of the nation's transportation system for safe and efficient travel, innovative solutions and new technologies are needed, and highway research must deliver them. Research can help identify ways to reduce highway crashes, injuries, and fatalities; decrease delays due to congestion, construction, and maintenance; provide smoother, longer-lasting pavement; and mitigate the environmental consequences of increasing highway use. It can also provide improved management processes, planning methods, contracting methods, and operating practices to promote economic efficiencies. Examples of successful highway research, such as those presented in Boxes 1-1 through 1-7, illustrate both the breadth and value of highway research. They also confirm that the research often takes time and many trials to yield useful results. This report examines the role of the federal highway research and technology (R&T) program, with the aim of determining whether its focus and activities are appropriate in light of the needs of the National Highway System and the roles and activities of other components of the national highway R&T enterprise.[1]

Context

Highway research is an important national investment. It addresses such broad concerns as planning, highway safety, traffic operations, pavements, structures, materials, maintenance, and the environment. Within these categories lie a wide range of issues and many interrelated topics. The benefits of highway research can be significant. For example, highway agencies can reap significant cost savings from the use of new pavement designs that cost less or last longer and from innovative instrumentation devices that provide early warning of distress or deterioration, leading to timely replacement or maintenance. Payoffs to highway users come from value-added devices such as surveillance systems for monitoring of and rapid response to traffic crashes, congestion, or other disruptions, which help reduce congestion and increase the efficiency of the existing highway system. Further payoffs come from the reduced risk of catastrophic losses that results from the use of innovative geotextiles for soil stabilization in road construction and from new strengthening techniques in which carbon

[1] The term "research and technology" (R&T) is defined here as including basic research, applied research, development, demonstration, technology transfer, and education activities. The term "federal highway R&T program" is used throughout this report to refer to the combined responsibilities and actions of Congress, the administration, and the Federal Highway Administration in funding federal highway research, determining research needs, setting research program priorities, and executing the research program.

BOX 1-1

Saving Time and Money with Information Systems

Information collection and transfer related to commercial vehicle operations (CVO) and regulatory compliance is estimated to cost carriers and government agencies more than $6 billion annually (Rubel 1998). In an effort to improve operational efficiencies and reduce costs, the Federal Highway Administration (FHWA) and others began exploring ways to automate many of these collection and transfer activities. An initial research product developed by FHWA could keep track of much of the safety, credentials, tax, insurance, and hazardous materials information needed to meet the requirements of a host of federal and state regulations and permit processes.

In 1996, researchers recognized that intelligent transportation systems (ITS) products, such as on-board transponders, offered the potential of transmitting information to roadside scanners. However, without a common architecture and standards, systems and databases could not communicate with each other. FHWA therefore began work on a system that would link ITS and automation elements into a single architecture that could eventually be shared by all CVO interests in North America. This system, Commercial Vehicle Information Systems and Networks (CVISN), was aimed at removing travel and information boundaries for interstate carriers. CVISN would collect and exchange motor carrier safety information, automate interstate carrier registration and fuel tax payments, and screen commercial vehicles at fixed or mobile roadside sites. Moreover, the information would be accessible almost instantly to all authorized parties. FHWA fostered partnerships among state governments, motor carriers, shippers, insurance companies, and others to ensure that major stakeholders would be involved in the development and implementation of the system and that key issues would be addressed. Research was undertaken to standardize the network of information and communication systems. The states of Maryland and Virginia agreed to participate in a prototype program in 1996, and by 2001, all 50 states were participating to some degree in CVISN.

Once a pilot program was under way in eight states, FHWA began focusing on implementation issues and working with the states to facilitate

continued

BOX 1-1 *continued* Saving Time and Money with Information Systems

widespread deployment. The estimated benefits are significant (see the CVISN Deployment Tracking Database at www.itsdeployment.edu.ornl.gov/cvisn/). They include a dramatic reduction (from 90 days to 60 min) in the time it takes for a truck safety inspection report to be made available to state motor carrier safety enforcement authorities. In a study of 40,000 commercial motor vehicle inspections, safety inspectors using the advanced safety information systems were able to remove an additional 4,000 (an increase from 8,000 to 12,000) unsafe drivers and vehicles from the nation's highways (DOT 1998). Better information means government agencies can focus limited resources on operators whose records indicate a history of safety problems, and low-risk carriers, vehicles, and drivers face fewer and simpler roadside inspections.

Significant cost savings can be achieved with CVISN. In a case study involving eight states, it was estimated that deployment of the electronic credentials portion of CVISN would have a benefit-cost ratio as high as 6:1. The greater reliability of truck data from CVISN can also help deter tax evasion and save individual states $500,000 to $1.8 million per year (DOT 1996). Cost-benefits can also accrue to the motor carriers. The American Trucking Associations Foundation has estimated that electronic screening could reduce time spent at weigh stations, resulting in lower labor costs for companies that pay their drivers by the hour. The savings-to-cost ratio ranges from 2:1 to 7:1, depending on the company size (ATA 1996).

fiber sheets are used to wrap bridge piers to mitigate earthquake effects. Safety research also benefits the entire nation because it addresses a major public health issue—the deaths, injuries, and economic and social losses due to highway crashes.

The highway industry is a highly segmented, decentralized, and multifaceted collection of components of varying size, responsibility, and impact. It includes federal, state, and local government agencies responsible for constructing, operating, and maintaining U.S. highways, as well as scores of private companies of various sizes and specialties that carry out much highway design and most highway construction work and supply materials, equipment, and services used by the public agencies. Although the federal role in highway transportation does

BOX 1-2

Seismic Strengthening for Highway Structures Through Use of Composite Materials

Earthquake engineering and seismic design of bridges are comparatively young disciplines. However, extensive bridge damage and traffic disruptions due to earthquakes in California in 1971 and 1989 stimulated considerable research aimed at both improved seismic design of highway structures and better retrofit techniques for existing bridges. Between 1971 and 1986, research sponsored by FHWA and the California Department of Transportation (Caltrans) and performed at the University of California at San Diego (UCSD) led to significant changes in seismic design practice for constructing new bridges and for constructing existing bridge columns with steel jackets. Many bridges have been strengthened using these new materials.

After the 1989 Loma Prieta earthquake, researchers at UCSD, with support from FHWA, Caltrans, and the Advanced Research Projects Agency, investigated potential applications of composite materials for both new construction and repair of older bridges. Advanced composites have been found to improve the strength of bridge columns and supporting elements. Tests on epoxy-impregnated fiberglass and carbon fiber materials have shown that they strengthen existing structures. Although advanced composite materials are expensive, their long life expectancy and resistance to corrosion make them competitive if the life-cycle cost of a bridge in a highly corrosive environment is considered.

not involve ownership of any part of the public road system outside of federal property, the federal government has a significant interest in providing for and maintaining a strong national highway system as part of the nation's overall transportation system. Furthermore, because providing highway infrastructure is essentially a public-sector domain, issues related to improving the system through innovation and new technology are addressed primarily by the public sector, though often in conjunction with private-sector members of the highway industry.

BOX 1-3

The Superpave® Design System

States estimate that collectively they spend more than $10 billion annually on asphalt—more specifically, hot-mix asphalt (HMA)—pavements. Even modest improvements in HMA performance mean significant savings. Longer-lasting pavements also require fewer rehabilitation projects, reducing the incidence of work zone congestion and delays and the attendant hazards.

Superior performing asphalt pavements (Superpave), an HMA design system developed to provide a smooth ride over an extended life at a reasonable cost, offers such performance improvements. The Superpave system addresses predominantly two forms of pavement distress: rutting (permanent deformation), which is caused by inadequate shear strength in the asphalt mix, and low-temperature cracking, which results when the tensile stress of the pavement exceeds that of the asphalt cement. Developed under the Strategic Highway Research Program (SHRP), a 5-year research program that focused on a few key areas of highway technology, the Superpave system unifies HMA pavement design, mix design, and construction and, when fully mature, will include a sophisticated model for predicting pavement performance among competing mix designs.

When the SHRP research ended in 1993, some aspects of Superpave, such as software that would facilitate the design of pavement mixes and predict their performance, were incomplete. The SHRP sponsors—FHWA, the American Association of State Highway and Transportation Officials, and the Transportation Research Board—decided to continue the innovation effort and carry out an implementation program. A task force of energetic champions from state highway agencies developed a program of technical assistance and support to encourage rapid and widespread implementation of Superpave. By 2000, more than half of the HMA projects awarded by state departments of transportation were using the Superpave design, and this percentage is expected to continue to increase.

Assessing the potential value of Superpave and the research that led to its development is difficult until the pavements prove themselves through

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BOX 1-3 *continued* The Superpave Design System

their design lives. According to one study, switching to Superpave binders could yield annual savings to the nation of $1.8–$2.9 billion. New York state engineers have estimated that if Superpave extends pavement life by 1 year, it will save that state $1 billion over 30 years. Although work is under way to document more fully the benefits of the Superpave system, that effort could take years. Meanwhile, pavement engineers point to the growing acceptance of the Superpave design, especially for high-level roadways (e.g., Interstates, major arterials) as a key indicator of a successful research product.

Highway R&T likewise is a multifaceted and decentralized collection of components, not a single, centrally controlled or located program.[2] Its components include the federal highway R&T program, state highway agency R&T programs, the National Cooperative Highway Research Program, and private-sector research funded by companies and associations. In addition, university research supports these programs. Each program has its own role and specific responsibilities based on its ownership and purpose. Nonetheless, the programs are not isolated from each other, but involve considerable professional interaction and exchange of information.

Study Purpose and Approach

Passage of the Transportation Equity Act for the 21st Century in June 1998 led to increased awareness within the highway industry that highway R&T is a shared responsibility. Moreover, although federal highway R&T deals with many important national issues, it cannot address all highway transportation issues or serve all potential industry customers. Awareness of such limitations has brought increased attention to the need for a clear understanding of the roles and responsibilities of the various highway R&T programs and improved

(*text continues on page 23*)

[2] These observations are based on comments made to the committee by Thomas Deen, former executive director of the Transportation Research Board, who also stated that in the United States, "we believe that one size does not fit all and, therefore, that a decentralized highway R&T program is more responsive to individual needs than a centralized program."

BOX 1-4

Roadside Safety Research: A Continuing Success Story

The history of research on roadside safety hardware closely follows the evolution and increasing use of the nation's highway system. Improvements in roadside safety hardware are based on many individual research successes. In the 1960s, a significant number of fatalities were occurring at exit ramp gore areas. Research sponsored by FHWA and the Texas Department of Transportation (TxDOT) and performed at the Texas Transportation Institute produced design concepts and prototype designs for crash impact attenuators. Private industry saw an opportunity and eventually developed the family of impact attenuators seen on today's highways. As a result, fatalities on crash cushions and impact attenuators are relatively rare events.

In the early 1970s, the (then) New York State Department of Highways developed a family of weak post guardrails and median barriers, sometimes called light post guiderails (because they flex). Although these traffic barriers were not intended to handle heavier vehicles, they significantly reduced the severity of impacts by automobiles in such states as New York, Pennsylvania, Connecticut, Virginia, South Dakota, and North Dakota. Today, there is renewed interest among many states in using three-cable roadside barriers and median barriers because they cost less than other alternatives.

During the 1960s and 1970s, General Motors (GM) conducted many median barrier and roadside safety studies. One such study led to the development of a concrete crash barrier designed to guide a striking vehicle back onto the roadway. In 1973, FHWA sponsored a pooled-fund study on such concrete crash barriers to determine their potential for wider application. Crash tests showed that the original GM shape caused small cars to roll over. Another barrier design, the Jersey barrier designed by the New Jersey Department of Highways, was shown to be superior to the GM barrier and is still widely used. A later study resulted in the development of another alternative, the F-shape, which performs even better than the Jersey barrier in tests. During the last 15 years, more and more states have been switching from the Jersey barrier to the safer F-shape barrier. A recent in-service study of the Jersey

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BOX 1-4 *continued* Roadside Safety Research: A Continuing Success Story

barrier indicated that of 62 collisions occurring during a 7-month period, only 14 were serious enough to be reported to police. Remarkably, none of the 62 collisions involved an occupant injury (Fitzpatrick et al. 1999).

During the mid-1970s, FHWA and TxDOT conducted a series of tests on luminaire supports with slipbase, coupling, or frangible bases. The objective of these support designs is to reduce damage to vehicles and injuries to vehicle occupants should they be struck during a run-off-the-road crash. Research and tests led to several breakaway luminaire support designs that are widely used today as an alternative to fixed-post designs.

In 1978 FHWA conducted crash tests on bridge rails designed in accordance with loading and geometric design criteria in the 1965 American Association of State Highway and Transportation Officials (AASHTO) Bridge Specifications. All of the aluminum bridge rails tested failed as a result of wheel snagging and barrier penetration problems. These findings led state highway agencies to discontinue installing aluminum beam-and-post bridge rails. In addition, FHWA and AASHTO began requiring that bridge rail designs be crash tested prior to installation. A series of pooled-fund studies has been undertaken to crash test a large variety of bridge rail designs. Today, vehicle penetration of a bridge rail is a rare event.

In the early 1980s, blunt-end and turned-down guardrail terminals and guardrail-to-bridge rail transitions were contributing significantly to the number of people killed in guardrail collisions. FHWA devised a promising alternative design, and several private firms subsequently developed a series of energy-absorbing terminals based on that design. In-field evaluations of these devices led to the conclusion that design improvements would lead to a higher likelihood of proper installation and improved safety. In a limited sample, approximately 5 percent of all impacts resulted in serious and fatal injuries with the new design, as compared with 20 to 35 percent with the earlier design (Buth et al. 2000).

In 1993 FHWA adopted the proposed standards developed in a National Cooperative Highway Research Program project, which provided design standards to accommodate the light truck class of vehicles as mandated by Congress. Tests of the existing guardrail designs showed that when mounted on strong steel posts, they did not meet the new standards. Research led to alternative designs with significantly improved performance for vehicles such as vans, sport utility vehicles, and pickup trucks.

BOX 1-5

New Tool for Analyzing Bicycle and Pedestrian Crashes and Identifying Countermeasures

As the nation strives for greater compatibility between highways and the communities they serve, efforts are under way to accommodate pedestrian and bicycle travel in planning and operations. In 1998, 5,220 pedestrians and 761 bicyclists were killed, accounting for 14 percent of all traffic fatalities. An additional 69,000 pedestrians and 53,000 bicyclists were reported to be injured as a result of collisions with motor vehicles. As part of its pedestrian–bicycle safety effort in response to these collisions and their consequences, FHWA has developed a tool to assist highway planners and engineers in analyzing the causes of pedestrian and bicycle crashes and identifying potential countermeasures. The agency, in cooperation with the National Highway Traffic Safety Administration (NHTSA) and the North Carolina Highway Safety Research Center, has developed a pedestrian and bicycle safety crash analysis tool (PBCAT).

PBCAT enables the user to develop a database that focuses on crash types and describes the precrash actions of the parties involved. The software can then generate analyses of crash types by location and provide a basis for developing alternative countermeasures to help prevent bicycle and pedestrian accidents. PBCAT draws on an extensive crash database prepared by NHTSA in the 1990s to form the basis for identification of countermeasures.

Research on PBCAT and related tools continues. Future plans for wider application of PBCAT involve the development of an expert system to assist planners and engineers in selecting appropriate countermeasures on the basis of local traffic conditions and roadway geometry. FHWA is developing an expert system for identifying alternative countermeasures, based on the PBCAT database. The agency is also planning to conduct several improvement projects to assess countermeasures using intelligent transportation system technologies.

More than 400 local and state agencies have ordered the first generation of this software since its release in December 1999. Use of the software

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BOX 1-5 *continued* New Tool for Analyzing Bicycle and Pedestrian Crashes and Identifying Countermeasures

by the city of Orlando, Florida, illustrates its potential. In response to national media attention about the city's high rate of pedestrian injuries and fatalities, Orlando used PBCAT to help identify crash types and potential countermeasures. Analysis of the data resulted in a detailed list of recommended pedestrian crash countermeasures and led to a safety improvement plan that has been adopted by the city to reduce pedestrian-related crashes. The analysis also helped the city select the most appropriate locations for countermeasures based on the severity of the problem being addressed and the funding available for various types of improvements. More information about this example is available at www.metroplanorlando.com/.

coordination among these efforts.[3] Such understanding will help highway users and others obtain greater benefit from the public investment in highway R&T.

In this context, the present report was prepared by the Research and Technology Coordinating Committee, a special committee convened by the Transportation Research Board of the National Research Council and funded by the Federal Highway Administration (FHWA) that provides continuing guidance to FHWA on highway R&T opportunities and priorities. The purpose of the report is to examine whether the focus and activities of the federal highway R&T program are appropriate in light of the needs of the highway system and its stakeholders, as well as the roles and activities of other highway R&T programs.

Organization of the Report

Chapter 2 presents information about the key public and private components of the highway industry, describes the barriers to innovation in highway

(*text continues on page 29*)

[3] The committee defines coordination of research programs as the combination of formal and informal steps taken to organize and manage the research activities within different research programs to achieve common goals, based on input from the users and beneficiaries of the research products and with a minimum of overlap or duplication.

BOX 1-6

Roadway Weather Information Systems

Fewer crashes, reduced costs, better service, fewer environmental impacts, and lower insurance rates are all potential benefits of the improved roadway weather information systems (RWIS) produced by research. With highways playing such a critical role in people's everyday lives and snow and ice being a problem in 40 states, reliable predictions of when water on highways will turn to ice and when snow will stick to the road rather than melt are important. Sensors that monitor the temperature of roadway surfaces and subsurfaces, combined with forecasting and communication systems, have resulted in considerable accumulated savings in labor, equipment, and materials for transportation agencies in North America and Europe. Information from RWIS enables informed decisions about staffing, timing, strategies, and the amount of equipment and materials needed. In research conducted as part of SHRP, it was estimated that such systems would have a 5:1 benefit-to-cost ratio. The benefits of RWIS were also shown by a weather index that related costs of snow and ice control to weather severity and frequency of snow and ice events.

After SHRP ended, research on the RWIS technology continued, particularly investigations into the proactive use of chemicals to prevent snow and ice from bonding to pavement. Data collected on anti-icing methods during the mid-1990s in a cooperative research effort involving 15 state departments of transportation supported the hypothesis that pavement temperature is a key element when implementing anti-icing measures, and that precipitation character and traffic volume are also important (Ketcham et al. 1996).

The report of a recent study conducted for the National Cooperative Highway Research Program documents the benefits of the RWIS technology and describes current practice (Boselly 2001). It was found that careful application of RWIS and anti-icing techniques could result in roadways being cleared sooner, at lower cost, and with less damage to pavement, equipment, and the environment. A more dramatic example of

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BOX 1-6 *continued* Roadway Weather Information Systems

the benefits of RWIS and anti-icing technologies was their successful application in a critical period during the U.S. military involvement in the conflict in Kosovo. U.S. researchers and highway engineers provided direct advice to an American lieutenant charged with keeping 68 miles of road in Kosovo clear of snow and ice. By implementing RWIS and anti-icing technologies, the U.S. military was able to keep a vital supply link open for its troops despite a 2.5-ft snowstorm in the mountains of Albania (FHWA 2000).

BOX 1-7

Examples of Successful State Highway Research

The following is a sampling of successful state highway research efforts. Although the benefits of some of these projects are small, most have application across states.

Automated Hydrologic Analyses

Bridge and highway engineers must consider the frequency, magnitude, and timing of floods and the floods' effects on highway infrastructure. Standard hydrologic modeling tools are not designed for engineering analyses and consider conditions at a single design point. They also require much time and effort; a change in the location of the proposed highway structure or an error in the data could negate weeks of work. A new geographic information systems (GIS)–based computer model developed at the University of Maryland for the Maryland State Highway Administration (MSHA) reduces the time required for such analyses and improves the integrity of the output. MSHA estimated that after using the model, GISHYDRO2000, on 83 projects, it had saved approximately $994,600 in staff costs. Such savings will continue for future projects.

continued

BOX 1-7 *continued* Examples of Successful State Highway Research

Recycling of Used Tires to Reduce Costs

A series of research projects undertaken by the Maine Department of Transportation (MDOT) and the New England Transportation Consortium—a pooled-fund effort involving five New England states—has shown that tire shreds have acceptable engineering and environmental characteristics for use as lightweight fill for highway embankments and retaining-wall backfill. Seeking to make use of some of the more than 800 million discarded tires currently available nationally, MDOT has used tire shreds in several projects, with considerable cost savings. Its Portland JetPort Interchange project used about 1.2 million tires and saved an estimated $600,000. These savings included material costs and savings obtained relative to alternative disposal of the tires by the Maine Department of Environmental Protection.

Fiber-Reinforced Polymer Composites for Strengthening of Bridges in Oregon

Several historic reinforced concrete bridges in Oregon were found to be deficient for carrying current traffic loads. Engineers sought a solution that would strengthen the bridges without affecting their appearance. The Oregon Department of Transportation, in collaboration with Oregon State University and a private firm, examined the potential for using fiber-reinforced polymer (FRP) composites for structural reinforcement. Tests on the Horsetail Falls Bridge in the Columbia River Gorge, built in 1914, validated the use of FRP composite for bridge strengthening. The method used saved the state $37,000 over a conventional repair cost of $67,000 and did not significantly alter the appearance of the bridge. The state plans to use this method on at least four bridges per year for the next several years.

Biological Control of Purple Loosestrife

Purple loosestrife is a noxious weed species that has become a common problem throughout North America. For any highway construction proj-

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BOX 1-7 *continued* Examples of Successful State Highway Research

ect that affects wetlands significantly, mitigation options that deal with landscape alterations must be identified. At many construction project sites, loosestrife quickly becomes established despite preventive measures. Because loosestrife grows vigorously and rapidly and adapts easily to many types of wetland habitats, it tends to overtake native vegetation, creating monotypic stands. The New Hampshire DOT, in conjunction with the state's department of agriculture, undertook a study of biological control agents, focusing in particular on types of beetles that could be used to manage the purple loosestrife. The study, on a 9-acre wetland site at which loosestrife had become dominant, took place over a 2-year period. The beetles reduced the loosestrife population and enabled other indigenous plant species to return to the site. The beetles were subsequently introduced to 12 other sites. All 13 sites continue to be monitored. Use of the biological control at the initial site saved about $20,000 in labor costs alone.

Modified Aggregate Test to Expedite Superpave

The adoption of Superpave by the Kansas Department of Transportation (KDOT) was hindered because of the need for a microscopic examination of fine aggregates available at only one location in the state. KDOT engineers needed a field test method that could differentiate samples of crushed material with slight contamination from blends of crushed and uncrushed material. In addition, they needed practical limits for good performance. Research led to a field test method, accepted by ASTM, that required less than 30 min to complete. This method takes an estimated 3 h of employee time less per test as compared with the ASTM test method. The state expects to save about 1,900 employee hours per year with this method.

New Precast Bent Cap System

Faced with the replacement of 113 bridge spans on an elevated section of Interstate highway in downtown Houston, the Texas Department of Transportation (TxDOT) decided to use the existing concrete columns,

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BOX 1-7 *continued* Examples of Successful State Highway Research

but needed a quicker method of replacing the bent caps (the horizontal connections between columns) than the traditional cast-in-place approach. User delay costs were estimated to be more than $100,000 a day, and TxDOT engineers needed an alternative approach to expedite construction. TxDOT therefore contracted with the Center for Transportation Research at the University of Texas to develop and test a precast design method that would enable contractors to connect new precast bent caps to the existing bridge columns with any of several alternative connection systems. The center developed and verified in laboratory tests the adequacy of a design that enabled the construction to be completed in only 99 days, as compared with the 548 days required for conventional construction. With research costs of $289,200, the research effort was deemed highly cost-effective.

New Ramp-Metering Algorithm to Improve Systemwide Travel Times

Ramp metering has the potential to improve freeway operations by restricting and evenly spacing the traffic entering a freeway. Ramp metering a freeway system requires an algorithm that can be used to calculate and implement the meter control system at tens of locations under a wide variety of traffic demand conditions and in the face of random traffic incidents and crashes. The Washington State Department of Transportation (WSDOT) contracted with the University of Washington Department of Electrical Engineering to develop an algorithm that would balance the conflicting objectives of ramp metering and take account of the variations in local traffic conditions. The algorithm was tested on two Interstate corridors, and the results were so promising that WSDOT decided to implement it on all ramps in the Seattle area. Although absolute benefits were difficult to determine, tests showed that on one Interstate segment, the algorithm decreased mainline congestion noticeably and increased flow. On another segment, the ramp queues decreased significantly, but mainline congestion increased only marginally.

transportation, reviews the drivers of the need for such innovation, and identifies major highway system issues that can be addressed by R&T. Chapter 3 provides an overview of key highway R&T programs, their current funding levels, and their research focus. Included is a comparison of highway R&T funding with R&T funding in other federal agencies and selected sectors of the economy. Chapter 4 presents the key characteristics of an effective federal highway R&T program and an assessment of the FHWA program in light of these characteristics. On the basis of this assessment, Chapter 5 offers recommendations for improving and strengthening the federal highway R&T program.

References

Abbreviations

ATA	American Trucking Associations
DOT	U.S. Department of Transportation
FHWA	Federal Highway Administration
NCHRP	National Cooperative Highway Research Program
TRB	Transportation Research Board

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CHAPTER 2

The U.S. Highway System and the Innovation Challenge

CHAPTER HIGHLIGHTS

- The highway system is the nation's largest infrastructure system.
- The system demands significant investment by both the public and private sectors.
- Continuing challenges necessitate research and innovation.
- Highway innovation continues to face a number of barriers.

This chapter presents the major issues driving the need for innovation and new technologies for the nation's highway system. The first section briefly describes the highway system and the nature and extent of highway travel. The second delineates the industry components—public and private—that own, construct, operate, and maintain highways. The third section reviews major impediments to more widespread highway industry innovation. This is followed by a discussion of several major highway system issues that can be addressed by research aimed at providing innovation and new technologies to meet the nation's safety, mobility, and economic goals.

HIGHWAYS AND HIGHWAY TRAVEL

The U.S. highway system is the nation's largest public infrastructure system. It consists of more than 3.9 million miles of roadways, more than 583,000 bridges and other related structures, and a wide range of traffic control and safety systems and equipment (FHWA 2000a). The overall system has an asset value of more than $1,300 billion, representing better than 87 percent of the nation's total transportation infrastructure assets. Spending for highways by all units of government in 1998 was above $100 billion, more than two-thirds of all U.S. spending on transportation infrastructure (Buechner 1999).

User expenditures for passenger and freight highway transportation are considerable. Private-sector spending for highway transportation in the United States was $688 billion in 1997, 82.5 percent of all expenditures for passenger transportation. In 1996, Americans spent more than $225 billion on new automobiles and trucks.[1] More than $402 billion was spent in 1997 for truck freight transportation in the United States, about 79 percent of the nation's freight transportation expenditures.

Small-package delivery revenues from for-hire trucking rose 96 percent to $15.7 billion in the decade prior to 1997. Business outlays for highway transportation–related equipment (trucks, trailers, buses, and automobiles) rose to $125.6 billion in 1997, representing 20 percent of all business expenditures for nonresidential durable equipment of all types. Truck traffic could increase even more quickly if Internet-based or e-commerce continues to expand.[2]

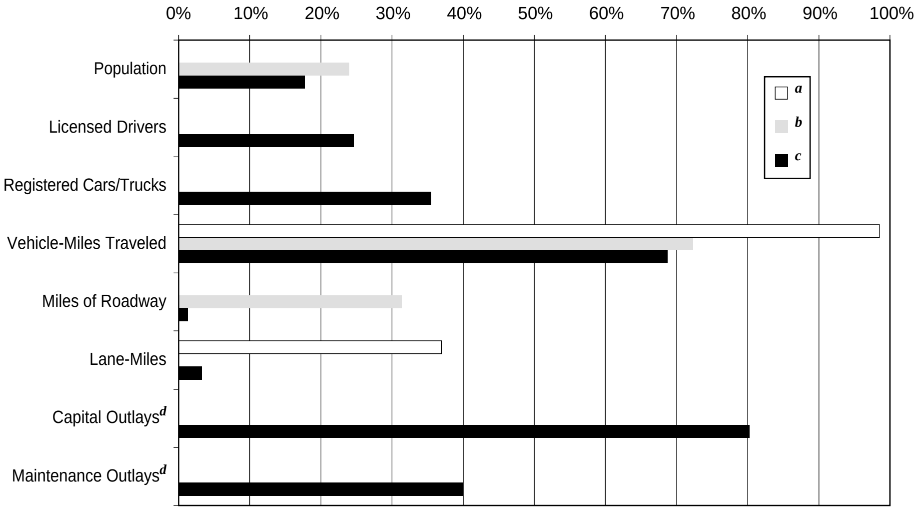
Such expenditures support an enormous amount of travel, and drivers, vehicles, and miles of travel are increasing at a faster pace than population growth (see Figure 2-1). Moreover, the growing congestion experienced by most highway users is readily understood if one compares the much greater increase in annual vehicle-miles traveled (demand) with the increase in lane-miles (capacity) during the period shown in the figure (1982–1999). People use roadways for most passenger trips. Highways account for 2.7 trillion vehicle-miles traveled per year and in 1995 were used for nearly 90 percent of daily passenger trips and 92 percent of passenger-miles traveled. Truck traffic is a major contributor, as evidenced by the doubling of the number of large trucks (Class 8) from 1982 to 1997. Revenues of all intercity commercial carriers increased considerably between 1986 and 1996; for example, revenues for United Parcel Service shipments more than doubled during the period.

Public and Private Roles in Highway System Management

The highway system is owned, operated, and maintained by a highly decentralized group of mostly public agencies. More than 35,000 public agencies in the

[1] Committee estimates based on compilations from several sources.

[2] The U.S. Department of Commerce recently estimated online sales in 2000 at $25.9 billion (*Washington Post,* February 22, 2001). Other estimates of business-to-consumer commerce for 2000 range from $7 billion to $200 billion; estimates for business-to-business commerce range from $52 billion to $406 billion for the same period (Nagarajan et al. 2001).



[a]Freeway characteristics for 68 metropolitan areas (TTI 2001).
[b]Area or highway system characteristics for 68 metropolitan areas (TTI 2001).
[c]U.S. data (FHWA 2000a).
[d]The outlays shown represent nominal dollar amounts (not adjusted for inflation).

Figure 2-1 **Changes in key variables related to highway transportation, 1982–1999.**

United States have highway transportation responsibilities (see Table 2-1). These agencies rely on the private sector—traditionally for materials and construction, and increasingly for design, construction management, and maintenance. The private sector of the highway industry, consisting of tens of thousands of private firms providing materials and services, is decentralized and geographically diverse.[3] The roles and responsibilities of the public and private components of the highway industry are described in the following subsections.

Highway Agencies

The federal–state–local intergovernmental highway partnership was established early in the 20th century and has served the system and the nation well. The roles of the different levels of government have evolved over time. The modern era of highway development began with the creation of a new class of highways and a new highway funding mechanism in the Federal-Aid Highway Act of

[3] Ongoing consolidation in some sectors of the industry is changing this characterization.

Table 2-1 **Highway Mileage and Expenditures Classified by Administrative Responsibility**

Administration	Number of Agencies	Highway Miles (% of total) for Which Responsible	1999 Revenues (% of total) Used for Highways by Collecting Agency ($ millions)	1999 Expenditures for Highways (% of total) by Expending Agency ($ millions)
Federal agency	5	118,391 (3)	26,016 (22)	1,424 (1)
State agency	52	773,903 (20)	62,097 (53)	71,414 (61)
County agency	2,815[a]	1,766,394 (45)	NA	NA
Town and township	14,051[a]	1,206,917 (31)[b]	NA	NA
Municipality	18,100[a]	—	29,765 (25)	44,595 (38)
Other jurisdictions[c]	—	66,399 (2)	NA	NA
Total	35,023	3,932,004	117,878[d]	117,433[d]

NOTE: NA = not available.

[a] Estimates based on census data.

[b] Municipal mileage is combined with town and township mileage.

[c] "Other jurisdictions" include state park, state toll, and other state agencies; other local agencies; and roadways not identified by ownership.

[d] Differences due to funds placed in reserve.

SOURCES: U.S. Department of Commerce (1999); FHWA (2000b).

1956. That act also significantly affected the governmental roles in highway transportation, and subsequent legislation has continued to refine these roles (see Appendix A for more detail). The 1956 act created the 41,000-mi network now known as the Eisenhower System of Interstate and Defense Highways. It also created the Highway Trust Fund, which is based on receipts from federal user taxes on motor fuels, tires and tubes, new buses, and trucks and trailers, as well as a use tax on heavy trucks. A key provision of the act was that the federal government—through the trust fund—provided 90 percent of the highway construction costs for the new Interstate highway system.[4]

[4] The federal government plays a significant role in financing the highway system. However, it owns and directly administers just 5 percent of the system, mostly roads on public lands (e.g., military bases, parks, and national forests).

The Federal Highway Administration (FHWA), then the Bureau of Public Roads, became and continues to be the federal agency responsible for the federal-aid highway program and for the development of regulations, policies, and guidelines for achieving national highway goals through the agency's programs. In 1999 FHWA dispersed more than $26 billion for highways, primarily from the Highway Trust Fund. The agency's mission is to "provide the best highway system in the world by continually improving the quality of the system and its intermodal connections" and "in cooperation with all [its] partners to enhance the country's economic vitality, quality of life, and the environment."[5] To this end, the agency's strategic goals address safety, mobility, productivity, the human and natural environment, and national security.

Each of the 50 states, plus Washington, D.C., and the Commonwealth of Puerto Rico, has an independent highway agency. These agencies are responsible for the segments of the federal Interstate highway and primary highway systems within their borders, as well as their own networks of state highways. The states own more than 20 percent of the nation's highways. An average state owns about 24 percent of the highways within its borders, with state ownership ranging from 8.5 percent in North Dakota to 91.5 percent in West Virginia. In 1997 the states provided about $54 billion for highway-related purposes from vehicle and driver licensing fees and fuel taxes. States often provide direct assistance to local governments by performing construction and maintenance on some locally owned roads and by distributing state revenues to local governments as grants for highway purposes.

At the local level, the nation's more than 2,800 counties own and manage about 1.7 million miles, or 44 percent, of all highways, an average of about 600 miles each. More than 35,000 municipalities, towns, and townships own and manage nearly 25 percent of the nation's highways. Local highway and public works agencies are largely responsible for traffic operations and street maintenance in their jurisdictions. In addition, to receive federal transportation funds, all urbanized areas with populations of 50,000 or more are required to have in place a metropolitan planning organization responsible for transportation planning. More than $44 billion was spent for highways by all local government units in 1997.

Private Sector

The organization of highway agencies in states, counties, and municipalities has from the beginning made highway building a local enterprise, spawning a large

[5] See www.fhwa.dot.gov/mission.html.

number of highway contractors and construction companies that serve local markets and some that extend outside state boundaries. Limiting the market reach of much of the highway industry are the large quantities of low-cost, locally available materials used in highway building that can be costly if transported long distances. Moreover, some states still have statutes that make it difficult to spend state funds outside the state. Such statutes benefit local highway builders and material suppliers and bolster the traditional decentralized nature of the highway industry.

Much of the construction, maintenance, and rehabilitation of the highway system is performed or supported by a highly diversified industry consisting of thousands of engineering firms, commodity suppliers, construction companies, contractors, and equipment manufacturers and suppliers. These companies vary in size. In the past, most were small and worked in a single state, but consolidation is changing this situation in many specialty areas.[6]

Barriers to Highway System Innovation

Innovation in the highway sector usually involves improving performance, cost-effectiveness, quality, or safety or reducing environmental consequences. However, certain characteristics of the public sector, and the highway industry in particular, act as barriers to change and innovation (TRB 1999):

- *Diverse, decentralized, and multifaceted highway industry*—There are more than 35,000 highway agencies with an assortment of political, regulatory, and administrative characteristics, as well as differences in size, budget, and staff capabilities. The private-sector portion of the industry includes thousands of engineering firms, suppliers, contractors, and equipment manufacturers. With so many agencies and companies involved, innovation can proceed slowly at times.
- *Constraints of public-sector procurement practices*—Procurement in the public sector is driven largely by a low-bid process based on specifications and procedures established to satisfy the need for open competition, accountability, and the safety, health, and well-being of the population.[7] Nevertheless, such a process can discourage contractors who have developed new products or methods because specifications determine how facilities are built, the types of materials used, the designs followed, and the construction processes used. Reforms and new practices,

[6] Highway administrators on the committee noted that this change is reflected in fewer bidders on most highway construction contracts than in years past.

[7] State legislatures and local governing bodies establish many procurement requirements.

including design–build, construction warranties, and partnering arrangements, are being used more widely, but changing existing procedures is a slow process.

- *Low tolerance for risk in the public sector*—Innovation involves risk, but public-sector decision makers work in an environment that does not reward risk taking. Moreover, many public facilities are large, with high fixed costs and long economic lives. As a result, construction innovation must be assessed not only within the context of the original installation (i.e., a facility's initial cost and design) but also over a very long time period (i.e., whether the facility will continue to perform as expected and what it will cost to operate and maintain it). Even when seeking innovative solutions to system problems, public officials are often deterred by the risks associated with unintended and unexpected consequences.
- *Difficulty of characterizing and predicting system and component performance*—Difficulties in characterizing the complex interactions among the fundamental properties of many highway system components hinders the understanding and implementation of potential innovations. The committee has identified examples in past reports. For example, pavement innovation is constrained by the uncertainties inherent in predicting future traffic demand and truck axle loadings (TRB 1997a), and travel forecasting is limited because of the inability to model traveler decision making accurately (TRB 1997b).
- *Conflicting public- and private-sector incentives*—Market forces that stimulate much commercial innovation operate differently in the public sector. Although innovation can help achieve performance improvements or cost savings, it usually involves certain higher initial costs and uncertain future benefits, a difficult combination in light of the atmosphere of intense public scrutiny and accountability faced by public decision makers.
- *Highway projects being organized in a manner that does not promote innovation*—Several factors associated with the way highway construction and maintenance activities are organized and undertaken constrain innovation. Highways and bridges are usually built by a temporary alliance of contractors and subcontractors under a system of contracts and subcontracts. Contractors focus on task completion. Although they may contemplate new ways to accomplish specific tasks, they are less likely to consider innovations that redefine the project itself. The contracting team disbands after project completion, leaving the owner agency responsible for the operation and maintenance of the completed facility; thus the owner agency wants a facility it knows and understands. In addition, construction of public facilities involves considerable variation in local materials and conditions and a generally harsh operating environment, further discouraging divergence from standard design guidelines and prescribed methods. These factors limit the use of new ideas and methods (TRB 1996). Finally, highways usually pass

through multiple jurisdictions, some of which may have less-skilled or less-experienced highway officials, adding to the reliance on traditional design and construction standards.

- *Organizational limits to change*—The way public agencies are organized affects the speed of adoption of innovations. State and local highway agencies focus on managing highway construction and maintenance contracts with the private sector. They have limited staff expertise and few resources to assemble "full information about what has been learned about a problem" (TRB 1998, p. 6). Relevant public-works research programs aimed at providing new technologies have been described as generally underfunded, scattered, and directed at diverse but narrowly specific program objectives (COTA 1991). Several initiatives have been launched to assist in overcoming such obstacles.[8]

What Drives the Need for Highway System Innovation

Today's aging highway system faces daunting challenges, including a growing need for rehabilitation and rebuilding of many highway segments that must continue to meet high travel demand in a context of increasing congestion, emerging safety problems, and widespread environmental concerns. Table 2-2 characterizes the highway transportation environment highway agencies face as they address these problems. Although many of these challenges represent highway user preferences,[9] others stem from changes brought about by legislation in 1991 and 1998 that reauthorized federal highway program expenditures (see Box 2-1 for more detail). Still other challenges derive from the need to sustain a well-functioning highway system as an integral part of the nation's transportation system. The following subsections describe many of these challenges.[10]

Increasing Traffic Congestion

As shown earlier in Figure 2-1, a study of 68 urban areas conducted by the Texas Transportation Institute (TTI) revealed that from 1982 to 1999, vehicle-miles

[8] The Highway Innovative Technology Evaluation Center, housed in the Civil Engineering Research Foundation, develops nationally recognized and impartial evaluation plans for unique products for which no standard evaluation methods exist. The National Transportation Product Evaluation Program, located within the American Association of State Highway and Transportation Officials, evaluates standard products for which test methods or protocols have already been developed.

[9] Highway users want smooth pavements, and they are least satisfied with the delays they encounter because of construction (FHWA 2001).

[10] Many of these challenges are reflected in the highway research agenda prepared by the working groups of the National Highway R&T Partnership Forum (see Appendix B).

Table 2-2 **Changing Context of Highway Transportation Programs**

Historical Highway Program		Evolving Highway Program
Building roads	**Emphasis**	Protecting and enhancing highway investment, adding capacity as needed
Making connections and adding capacity	**Purpose**	Improving connections while supporting and balancing economic, social, and environmental goals
Capacity expansion through new construction	**Activity focus**	Infrastructure renewal, targeted construction, and transportation system management
Standards-based construction, low-bid procurement	**Business model**	Performance-based construction, reconstruction, and rehabilitation; increased privatization
Highway construction agency	**Corporate identity**	Transportation system service agency
Greenfields construction	**Predominant operating environment**	Renewing existing facilities while addressing increasing traffic demand

traveled increased more rapidly than either lane-miles of freeways and major arterials or population growth (TTI 2001). Vehicle-miles traveled increased by 98 percent, freeway and arterial lane-miles by 37 percent, and population by 24 percent. During the same period, the amount of travel under "extreme congested" conditions increased from 6 to 18 percent of all travel.[11] The study also showed that drivers in more than half the cities studied needed from 20 to 50 percent more time to complete their journey in rush-hour than in off-peak, uncongested conditions.

The effects of traffic congestion and delay include increased travel time and fuel consumption, lost productivity of people and trucks, and additional environmental impacts. Congestion also impedes just-in-time delivery—a key to successful competition in global markets. An isolated vehicle breakdown or crash that increases travel time for other highway users can mean that components do not arrive in time to be installed on schedule or that businesses need more inventory to accommodate unreliable delivery schedules. The total annual cost

[11] Extreme congested conditions on freeways are defined by an average speed of 32 mph, while free-flow conditions are defined by an average speed of 60 mph (TTI 2001).

BOX 2-1

Recent Key Highway Program Changes

About every 6 years, Congress debates and passes legislation that establishes the program categories and funding for surface transportation. This legislation was known as the "highway bills" until the 1991 bill was titled the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), reflecting many changes already under way and others still needed in the nation's transportation system. ISTEA changed the way highway agencies and highway users plan and manage the surface transportation system and broadened the scope of the highway R&T program. Among the changes ISTEA brought about in the highway program were the following:

- Half of all federal funding for highways, transit, or other surface transportation uses was made flexible (available for a variety of uses) for the first time.
- Requirements were added for a more open transportation planning process at the state and metropolitan levels.
- Significant funding was reserved for maintenance and rehabilitation of existing highway, bridge, and transit systems.
- Funding was set aside to support alternatives to the highway system and reduce its negative impacts on communities.

In 1998 the Transportation Equity Act for the 21st Century (TEA-21) reauthorized much of ISTEA and authorized new programs aimed at reducing automobile dependence and highway impacts. The Congestion Mitigation and Air Quality program, which had provided funding for transportation projects designed to reduce congestion and improve air quality, was continued, and its funding was increased. The Transportation Enhancements Program, aimed at encouraging diverse modes of travel, fostering local economic development, and bringing direct benefits to communities through transportation projects, was also continued. In addition, TEA-21 created a completely new Transit Enhancements Program for enhancement-like activities related directly to transit. The act also provided funding for initiatives related to job access, parking buyouts, new rail

continued

BOX 2-1 *continued* Recent Key Highway Program Changes

starts, bicycle and pedestrian facilities, coordination of transportation and land use, and innovative finance methods.

As a result of ISTEA and TEA-21, total spending on transit, pedestrian and bicycle facilities, and highway maintenance has risen more rapidly than spending on new highway construction. Federal program spending on bicycle–pedestrian projects increased from about $5 million in 1990 to more than $210 million in 1999 (STPP 2000). Nevertheless, overall federal highway expenditures as a share of total federal surface transportation expenditures have increased since 1985.

of congestion in the 68 urban areas included in the above study was estimated at $78 billion in 1999; this equates to about $620 per person per year in these areas (TTI 2001).

In fact, metropolitan areas are realizing that infrastructure expansion is not possible along many highway corridors because of space limitations, as well as high costs and community and environmental concerns. This means that in many cases, the need to add transportation capacity without inducing more highway travel must be addressed through operational improvements and promotion of other modes.

Complex Repair and Rehabilitation Needs

Data indicate that the condition of highways and bridges is improving and could continue to do so if current spending is sustained (FHWA 2000a).[12] Increasingly, however, repair and rehabilitation are needed on urban Interstate highways and other urban freeways and expressways that pass through heavily traveled corridors in built-up areas, as well as on key sections of rural Interstates with high traffic volumes and inadequate alternative routes. Such projects are likely to be complex and costly for highway agencies, local communities, highway users, and others because of traffic and business disruptions and the limitations placed by existing rights-of-way and nearby community and economic development on potential

[12] Data are available for all roads except rural minor collectors, rural local roads, and urban streets. Roads and streets are classified according to FHWA's highway functional classification system.

design options, construction alternatives, and environmental improvements. Unless innovative and creative solutions can be found for such projects, their costs will continue to rise, and fewer resources will be available for the growing number of other, less noticeable but increasingly important repair and rehabilitation projects. Moreover, innovative methods developed for major corridor rehabilitation and reconstruction projects can offer less intrusive and disruptive ways of conducting projects aimed at implementing safer highway designs and mitigating environmental and community impacts.

Concerns About Highway Safety

In 2000 there were an estimated 11 million vehicle crashes, more than 3 million injuries, and more than 42,000 deaths associated with highway transportation. If past trends continue, 33 million people will be injured or killed in traffic crashes by 2010. Motor vehicle–related injuries are the leading cause of death among children and young adults (1 to 24 years of age) in the United States. Up to half of serious head injuries and 60 percent of spinal cord injuries are the result of motor vehicle crashes. Thus, despite a 12 percent reduction in highway crash–related injuries and an 8 percent reduction in highway fatalities between 1988 and 1998, crash-related injuries and deaths remain a major public health concern. Indeed, in 1999 traffic crashes and the associated injuries and deaths exacted a social and economic toll estimated at more than $180 billion (NSC 2000).

Although the highway safety record has improved over the years, persistent problems, such as driving while under the influence of alcohol and drugs and run-off-the-road crashes, remain. New problems, such as the disproportionate number of rollovers among sport utility vehicles and pickup trucks that leave the road and the increasing number of crashes involving drivers who exhibit aggressive driving behavior, continue to emerge. Providing emergency medical assistance to persons involved in motor vehicle crashes, especially in remote areas with limited medical facilities, is also arising as a major challenge.

Environmental and Energy Issues

Highway agencies face a wide range of environmental and energy issues stemming from the nation's dependence on the highway system. Environmental impacts—including ecological, aesthetic, historical, cultural, economic, social, and health issues—must be examined for highway construction projects.[13]

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[13] As required by the National Environmental Policy Act (see www.ceq.eh.doe.gov/nepa/regs/ceq/toc_ceq.htm).

Although such analyses generally apply to transportation project plans, there is a growing need to examine these impacts for the highway system at the corridor, metropolitan area, and regional levels. The need for data, analysis techniques, and decision models that can be used for these analyses also continues to grow. At the same time, highway agencies are increasingly faced with the need to mitigate these impacts for the existing system.

Energy consumption and pollutant emissions due to U.S. transportation, most of which are accounted for by motor vehicles, are also key concerns.[14] Urban air pollution, a highly visible side effect of motor vehicle use, remains one of the nation's most vexing environmental problems. Highway vehicles are the largest single source of transportation-related emissions for nearly every type of air pollutant, contributing slightly more than half of nationwide emissions of three of the Environmental Protection Agency's six criteria pollutants for measuring air quality—carbon monoxide, nitrogen dioxide, and ozone (BTS 1999, p. 119, Table 5-9).[15] Continuing long-term growth in motor vehicle transportation may increase the risk of global climate change and of losses in biological diversity and ecosystem functioning (TRB 1997c). Even as transportation decision makers seek short-term measures to reduce and mitigate such impacts, they are increasingly recognizing the need for new ways of addressing the fundamental issue of providing transportation in a more energy-efficient and environmentally friendly manner.

Need for Improved Planning and Decision-Making Tools

As job opportunities of all types are increasingly generated in suburban locations far from city centers and remote rural concentrations of poverty, transportation facility and service decisions are becoming more complex. There is a growing realization that in addition to the need for better survey tools, modeling techniques, and analytical decision tools for planning and decision making, more information is needed about some fundamental issues that underlie these tools and methods. These issues include individual travel behavior and how travel decisions are made, how transportation and land use interact to affect travel demand, and how transportation system changes affect individual travel behavior.

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[14] Petroleum supplies about 97 percent of transportation energy, and motor vehicles consume the largest single portion of this fuel. Petroleum availability is not considered a critical problem today but could become one if worldwide demand continues to grow at an increasing rate, along with the nation's dependence on foreign sources (Greene 1996; BTS 1997).

[15] The other three criteria pollutants are lead, sulfur dioxide, and particulates.

Need to Assess Role of Highways in the Transportation System

As noted earlier, there is a continuing need to examine more fully a broad range of topics related to assessing the role and consequences of highways in the nation's transportation system. These topics include how alternative land use and transportation scenarios can accommodate future growth in population and people and goods movement, how pricing and other behavior modification schemes can be used to encourage the use of nonhighway modes, how and the extent to which highway system changes induce travel, and how intermodalism can be utilized more effectively (TRB 1994). In light of the wide range of opinions on such issues, the kind of highway transportation system the nation wants in 20 or 30 years should be examined through research that addresses potential alternatives and consequences and considers the many diverse views involved.

Summary

The nation's highways represent its largest public infrastructure system. More than $117 billion is spent annually by more than 35,000 public agencies for constructing, operating, and maintaining the system. Annual user expenditures for passenger and freight travel are greater than $900 billion. However, even as passenger and freight movement continues to increase, challenges to the system's effectiveness abound. These challenges include badly needed road repairs; injuries, fatalities, and damage due to highway crashes; delays due to crashes, congestion, and road repairs; risks related to unsafe drivers and road conditions; and the many impacts of the highway system on individuals, communities, businesses, and the environment.

Highway agencies must address these challenges under heavy and escalating traffic conditions in communities that want a minimum of disruption to current activities, and must do so while under close scrutiny by environmental and neighborhood groups. In addition, highway agencies must continue to operate the balance of the system safely, reliably, and efficiently at minimum cost and with maximum benefit to taxpayers, the environment, and the traveling public. The complexity of these challenges underscores the need for new ways of looking at problems and for innovative solutions, offering significant research opportunities in all facets of the highway sector. Research supplies needed innovations and new technologies and provides essential training for future researchers and transportation professionals. Past research has yielded significant improvements in all areas (see the boxes in Chapter 1, for example), and research continues to be crucial for addressing both chronic and emerging problems. Moreover, the range of possible improvements is so broad, the research needs so diverse, and the nature of the system so complex that identifying specific research priorities is itself a complex task.

At the same time, innovation often faces barriers that can hamper and even prevent the needed application of new materials, methods, and procedures. Overcoming such barriers requires considerable effort from both the private and public sectors. Some barriers, such as low-bid procurement and detailed design specifications, were put in place to ensure financial and technical accountability or to prevent the use of inferior materials or products. The original goals of such policies and procedures must be borne in mind when changes are made to allow the use of new technologies. In some cases a new product or technology necessitates a trade-off between conflicting goals or requires the public sector to assume a higher level of risk.

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Abbreviations

BTS	Bureau of Transportation Statistics
COTA	Congressional Office of Technology Assessment
FHWA	Federal Highway Administration
NSC	National Safety Council
STPP	Surface Transportation Policy Project
TRB	Transportation Research Board
TTI	Texas Transportation Institute

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CHAPTER 3

Highway and Highway-Related Research and Technology Programs

Chapter Highlights

- Highway research and technology (R&T) comprises many independent programs, each with its own scope and management.
- The federal highway R&T program involves Congress and FHWA in funding, priority setting, and decision making.
- State highway research programs generally focus on issues of state interest; private-sector research focuses on issues affecting business operations or output.
- Absent federal highway R&T, some topics of national importance will not be addressed.
- The federal highway R&T program encompasses a range of activities aimed at supporting state, private, and university highway research.
- Congress has chosen to designate more research projects and research performers, eroding the ability of the program to address highway industry priorities.
- Highway R&T expenditures are low compared with those of other major industries.

Change, improvement, and innovation based on highway research have long been important to the highway system. Even before the federal-aid highway system was initiated in 1916, Congress provided funds for the Office of Road Inquiry, the precursor of the Federal Highway Administration (FHWA) research program, to assist the states by gathering information about highway laws, road-building materials, and the rail rates for such materials. Since then, FHWA, the states, many private companies, and national associations of industry components and engineering professions active in construction and highway transportation have supported considerable highway research and technology (R&T).[1]

This chapter first describes the principal U.S. highway R&T programs and characterizes them according to their underlying goals and rationale. Information is presented on their scope, management, priority setting, funding, and research performers. Highway-related R&T activities at several other federal agencies and in other countries are then described. The final section provides an overview of highway R&T program funding and a comparison of this funding with that of other industries and other federal agencies.

Principal Highway R&T Programs and Related Activities

The four principal highway R&T programs are FHWA's R&T program, state highway R&T, the National Cooperative Highway Research Program (NCHRP), and private-sector research.[2] State highway research and NCHRP are supported largely by federal funds. Coordination among these programs is mainly informal and based on professional relationships and collaboration among decision makers, researchers, program managers, and state highway personnel. Highway research also involves an increasing number of research partnerships, as described in Box 3-1. The following subsections describe the above four programs, as well as special highway research initiatives and the role of universities in highway R&T.

Federal Highway Administration Program

FHWA has the mission and responsibility to carry out the federal-aid highway program authorized by Congress.[3] The agency is also responsible for "highway

[1] Most local highway agencies do not have the funds or staff expertise to support R&T programs. However, these agencies often provide data and data collection support for others.

[2] State and private-sector highway R&T are actually collections of research programs; each state program and each association or corporate R&T program is independently organized and managed.

[3] The federal government, through Congress and the Executive Branch—principally the Department of Transportation and the Office of Management and Budget—gives considerable direction and

BOX 3-1

Highway R&T Partnerships

Research partnerships can provide an efficient way of combining staff and financial resources to address research topics of joint interest that require more resources than any of the individual partners can provide. Such partnerships involve formal agreements among agencies, companies, institutions, and other groups to address a topic of joint interest in a coordinated work effort that includes shared financial and staffing responsibilities. The results of research partnerships are shared openly by all partners.

The success of some recent research partnerships (e.g., some activities within SHRP, the Intelligent Vehicle Initiative), coupled with current research needs, suggests that more research partnerships could be beneficial to the highway industry. It is important that such partnerships be linked to strategic agency goals; include arrangements that commit funds, facilities, and personnel; and establish a specific project timetable with milestones.

safety programs, research and development related to highway design, construction, and maintenance, traffic control devices, identification and surveillance of accident locations, and highway-related aspects of pedestrian design."[4] Expenditures for FHWA's R&T program, the nation's largest individual highway R&T program, amounted to about $208 million in Fiscal Year 2001.[5] Table 3-1 shows the breakdown of federal highway R&T expenditures from 1998 through 2001. Reflecting the agency's role in administering the federal-aid highway program, FHWA's R&T addresses a wide range of topics and includes many related activities in support of other highway R&T programs (Table 3-2 provides examples).

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focus to the highway industry through funding, regulations, and program decisions. Congress allocates funds for the federal-aid highway program and FHWA's R&T program, and thus sets priorities. Its decisions support a vision for the nation's transportation system. Congress influences private-sector highway R&T through legislation on such issues as tax treatment for corporate research, the extent to which manufacturers are liable for product failures, and antitrust law.

[4] Subtitle 1 of Title 49, U.S.C., Section 104.

[5] Included in this total is funding for surface transportation research, technology deployment, training and education, intelligent transportation systems research and development (R&D), and the University Transportation Centers program.

Table 3-1 **FHWA R&T Expenditures by Category, 1999–2001 ($ thousands)**

Program	1999[a]	2000[b]	2001[c]
Surface Transportation Research	85,651	84,487	86,142
Technology Deployment	30,905	34,840	39,555
Training and Education	13,245	13,936	15,822
Intelligent Transportation Systems R&T	35,976	40,901	42,478
University Transportation Centers	22,649	23,755	23,953
Total	188,426	199,919	207,950

[a] After applying an obligation limit of 88.3 percent.
[b] After applying an obligation limit of 87.1 percent.
[c] After applying an obligation limit of 87.9 percent.
SOURCE: Based on FHWA budget information.

The program's payoffs are relatively certain and tangible—incremental improvements leading to lower construction and maintenance costs, better system performance, added highway capacity, reduced highway fatalities and injuries, reduced adverse environmental impacts, and a variety of user benefits (e.g., improved travel times, fewer hazards).

A small portion of FHWA's R&T program funding, about $900,000, supports research aimed at breakthrough technologies capable of effecting dramatic improvements in highway performance and cost reductions. Such research includes seeking wholly new ways to control vehicles on highways through electronics, build bridges using newly engineered materials, or even develop pavements based on new design procedures. Such speculative, high-risk research has potentially high payoffs and is unlikely to be addressed in other highway R&T programs because of the risks and costs involved.

The directors of FHWA's core business units (CBUs) define strategic research priorities, develop program and project plans within their individual business areas, and prepare budget proposals for carrying out research needed to deliver technology to the nation's highway agencies.[6] The agency's service business units (SBUs), resource centers, and division offices also participate in this

[6] The five FHWA CBUs address infrastructure, operations, planning and environment, safety, and federal-land highways.

Table 3-2 Examples of FHWA Activities That Support Other Highway R&T Programs

Program	Activity
National highway R&T	• Coordinate federal highway R&T with the U.S. Department of Transportation's national transportation system goals. • Evaluate the public costs and benefits of new highway technologies. • Identify and help remove barriers to the deployment of new highway technologies. • Monitor and coordinate highway system–related activities across federal agency R&T programs. • Monitor federal regulatory issues that affect the highway system and its users. • Monitor international R&T programs for new technologies. • Identify technology transfer best practices, and adopt and support them. • Educate audiences about the federal R&T program, its accomplishments, and its benefits.
Private-sector highway R&T	• Characterize national highway technology needs. • Examine technology options that otherwise would not be considered by commercial interests. • Partner with industry to help guide the initial stages of technology development.
Public-sector highway R&T	• Monitor and coordinate across highway R&T programs (making use of existing FHWA contacts with state, private-sector, and university research programs). • Evaluate user technology needs to identify information and technology gaps. • Facilitate state pooled-fund studies.

process by identifying research needs. The Research, Development, and Technology SBU has primary responsibility for conducting and managing research at FHWA. It is located at the agency's Turner-Fairbank Highway Research Center, which houses more than 300 staff, as well as research laboratories and equipment. Other offices within FHWA conduct research as well; for example, the Policy SBU undertakes research on highway policy issues.

FHWA also supports, at an annual cost of about $500,000, the Highway Safety Information System database, which includes crash, roadway inventory, and traffic-flow data from eight states. This database is used by researchers in FHWA, other federal agencies, NCHRP, universities, and private research organizations to study safety issues in such areas as roadway design, maintenance, and safety treatments.

The Intelligent Transportation Systems Joint Program Office (ITS/JPO) has a departmentwide role in ITS research and is managed by the departmentwide ITS Program Office. The head of FHWA's Operations CBU also serves as the ITS/JPO director. The ITS/JPO fosters and supports the application of advanced information technologies to improve surface transportation mobility, capacity, safety, and environmental compatibility. The primary focus of ITS research activities is the Intelligent Vehicle Initiative, aimed at development and commercialization of safety-enhancing ITS systems.

FHWA contracts for research with private firms, university researchers, and research institutes, and also performs research in house. Traditionally, the majority of the agency's research contractors have been selected through open, merit-based competition. FHWA technical staff manage the research program. In recent years, however, Congress has chosen to designate more research projects and research performers, modifying the extent of open competition in the federal program. Such designations can involve qualified research performers. However, they can also reflect successful lobbying by special interests without attention to the research needs of the national highway system, and ignore highway industry consensus on research needs and priorities, as well as stakeholder involvement in program decision making. Congressional designations under the Transportation Equity Act for the 21st Century (TEA-21) for 1999, 2000, and 2001 amounted to 44 percent, 42 percent, and 51 percent of FHWA's R&T spending, respectively. The trend is clearly upward, especially in light of the extent of such designations under the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), which amounted to about 16 percent annually.[7] Table 3-3 provides summary information on the FHWA R&T program.

State Programs

Each state highway agency has a research program that addresses technical questions associated with the planning, design, construction, rehabilitation, and maintenance of highways, as well as highway-related environmental issues in the state. State highway research projects often reflect local conditions related to highway use, weather and environmental conditions, materials availability, and

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[7] Committee estimate based on FHWA data. See Appendix E for details.

Table 3-3 **Information on Aspects of Federal Highway Administration's R&T Program**

Aspect	Summary
Program management	Managed by FHWA staff.
Agenda setting	Core business unit directors are responsible for defining research priorities and developing program and project plans. In so doing, they use input from relevant service business units, resource centers, and division offices, as well as some external input. Congress is taking an increasingly active role by designating research topics in annual appropriations bills without being guided by established national highway research goals or highway industry consensus on research needs.
Researchers	These include ones from private firms, research institutes, and universities as well as individuals. Some FHWA research is performed by agency staff. With the exception of congressionally designated projects, FHWA research is selected by agency staff. All FHWA research is managed and evaluated by agency technical staff.
Typical scope	This generally encompasses applied research, development, and testing designed to address a problem of widespread (national) interest. It also includes some fundamental and long-term research.
Researcher selection mechanism (level of competition)	Traditionally, researchers have been selected by FHWA staff in an open, merit-based competition. As noted, however, Congress has recently chosen to designate more research projects and researchers in annual appropriations bills.
Expert–peer review	FHWA does not use outside experts to review projects.

other factors. Projects are usually of short duration and involve seeking practical solutions for quick application to current problems. Nevertheless, certain states have developed considerable expertise in one or several research areas. Some state research yields results that are adopted by other states. State research has also led to changes in nationally applicable specifications.

A 1999 American Association of State Highway and Transportation Officials (AASHTO) survey of member states provides the best available estimate of state highway research funding. The survey results indicate that the states spent approximately $322 million on R&T that year (Harder 2000).[8] The primary source of this funding is the research portion of the State Planning and Research (SP&R) program, part of the federal-aid highway program. SP&R research funds amounted to approximately $144 million in 1999. The states themselves are the second-largest source of state R&T funds, providing a total of $146 million.[9] The balance of about $32 million is from other federal funds made available for state highway research. Using this information and an annual inflation rate of 1.025, the committee estimates that state spending for highway R&T in Fiscal Year 2001 was $338 million.

The states also participate in pooled-fund research that leverages limited financial, professional, and academic resources to deal more effectively with highway problems shared by several states or a region.[10] Such projects address topics of joint interest for which local conditions are sufficiently similar to support a single effort. Pooled-fund projects are often managed by FHWA. In 1999, states pooled approximately $15 million for projects in addition to funding for NCHRP (described below).

State research priorities are determined by each state, usually on the basis of suggestions from within the state highway agency and from local highway and transportation agencies. Research performers are generally selected from among private firms, universities, and research institutes in open, merit-based competition. States report using one or a combination of mechanisms to review and evaluate their R&T programs; 37 use peer exchanges, 27 use in-house officials, and 23 use input from user (customer) groups (Harder 2000). Table 3-4 summarizes key information on state highway R&T programs.

National Cooperative Highway Research Program

NCHRP is a voluntary, national pooled-fund highway research program funded by the states since 1962. Established under an agreement among AASHTO, FHWA, and the Transportation Research Board (TRB), the program was created to address common state needs related to Interstate highway

[8] The total for all 52 member departments of transportation is an estimate based on data from 47 respondents.

[9] This amount includes the required state match for SP&R funds [on a 20 (state):80 (federal) basis], plus all other state funds allocated for highway research.

[10] Although many pooled-fund projects have been successful, participation is constrained by regulations in some states that limit spending of state funds outside the state and require formal management agreements.

Table 3-4 **Information on Aspects of State Highway R&T Programs**

Aspect	Summary
Program management	Each state program is managed by state staff.
Agenda setting	Projects are nominated from within each state and selected by the state highway agency. Some states organize technical panels made up of potential users within the state to prepare research problem statements and monitor progress. Annual SP&R work plans are reviewed by FHWA. There is considerable flexibility to change work plan items and funding allocations within a state program.
Researchers	Researchers come mainly from universities, consulting firms, and research institutes. Some states have experienced researchers who conduct a portion of the research.
Typical scope	The scope of the program generally encompasses applied research, product development, testing, and technical assistance. The research products are intended for use by the state highway agencies.
Researcher selection mechanism (level of competition)	Researchers are usually chosen in an open, merit-based competition by state research staff.
Expert–peer review of research	Some states form technical review panels for program and project evaluation.

system design and construction issues. NCHRP funding stems from an agreement among the states to contribute 5.5 percent of the research portion of their SP&R funds to the program; in Fiscal Year 2001, this amounted to $30.6 million. As a result, NCHRP funding varies in response to fluctuations in federal-aid highway program funding.

Since 1962 NCHRP's research focus has broadened considerably to encompass the full range of issues related to highway transportation. Typically, NCHRP projects are problem oriented and designed to produce results that have immediate application—for example, by providing incremental improvements or recommending changes to specifications and guidelines prepared by AASHTO committees. AASHTO's Standing Committee on Research (SCOR), assisted by its Research Advisory Committee, selects the topics for NCHRP projects subject to approval by the AASHTO Board of Directors.

Projects are chosen from nominations by the state transportation agencies, AASHTO committees, and FHWA staff, which receive suggestions from TRB technical committees, university researchers, and other members of the highway industry. TRB convenes expert panels that oversee the selection and work of researchers for each topic. These panels, consisting of experts from the state highway agencies, FHWA, universities, and other highway industry organizations, prepare project work statements, help select contractors in open competition based on merit, and monitor the progress of the work. Table 3-5 summarizes information on the program. Box 3-2 provides more information about AASHTO's role in highway R&T.

NCHRP includes support for the Innovations Deserving Exploratory Analysis (NCHRP-IDEA) Program.[11] The program encourages the investigation of innovative but untested concepts offering the potential for technological breakthroughs in highway transportation. The investigations are small, researcher-initiated projects designed to demonstrate the feasibility of the innovative concepts. AASHTO support for the program indicates increasing interest among state highway agencies in more innovative concepts for highway use. Funding for the Fiscal Year 2001 NCHRP-IDEA program was $1 million.

Private-Sector Research

There is no single, or even dominant, private-sector highway research program. Private-sector research is the sum of individual programs conducted or sponsored by companies that design and construct highways and supply highway-related products, national associations of industry components, and engineering associations active in construction and highway transportation. The initiation of several new association programs, such as that of the Innovative Pavement Research Foundation, since the committee's previous report on highway research (TRB 1994) reflects growing private-sector support for short-term, highly focused research that meets the specific needs of members. Association research programs range from those with their own research staff and laboratories to those relying entirely on contract research. Associations such as the American Trucking Associations, the National Asphalt Paving Association, the Portland Cement Institute, and the American Institute of Steel Construction conduct research in

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[11] The NCHRP-IDEA program is one of several independent but similar programs. The others are the Transit-IDEA program, funded through the Transportation Cooperative Research Program; the High Speed Rail-IDEA program, funded by the Federal Railroad Administration (FRA); and the Safety-IDEA program, sponsored by the Federal Motor Carrier Safety Administration and FRA.

Table 3-5 **Information on Aspects of National Cooperative Highway Research Program R&T**

Aspect	Summary
Program management	Program is managed by TRB staff.
Agenda setting	Agenda is set largely by state highway agencies in the project submission process and by the AASHTO Standing Committee on Research (SCOR) in the project selection process. Projects are selected by SCOR from a list of problem statements submitted by state agencies, AASHTO committees, and FHWA staff. Projects are approved by the AASHTO Board of Directors.
Researchers	Researchers come mainly from private firms, universities, and research institutes.
Typical scope	Projects are problem oriented, designed to produce results that have immediate application, and generally focused on state highway agency needs. The Innovations Deserving Exploratory Analysis (IDEA) Program provides grants to researchers for the development of innovative solutions to highway problems.
Researcher selection mechanism (level of competition)	Researchers are selected in open competition by a panel of subject matter experts, research peers, and highway agency representatives. Selection is based on merit.
Expert–peer review	Project panels of subject matter experts, research peers, and state highway agency representatives review project plans and interim and final project results.

their fields. Private-sector and association research tends to be driven by profitability and addresses issues affecting business operations or output.[12] The committee estimates that annual highway R&T expenditures by associations are between $25 and $50 million.[13]

Except for a handful of companies, information on corporate research activities and expenditures is scarce because of the large number of firms involved and the proprietary nature of their research programs. Many companies simply do

[12] The three predominant aims of private-sector R&D have been described as "increased earnings/profit objectives, a desire to keep the company on the leading edge, and growth objectives" (CERF 1993, p. 20).

[13] This estimate is based on the data in Table 3-8 and discussions with association officials.

BOX 3-2

AASHTO's Role in Highway R&T

AASHTO, the national association representing state highway and transportation officials, plays an important role—both formally and informally—in highway research, serving as a coordinator; organizer; and forum for encouraging, reviewing, and prioritizing research activities. AASHTO develops voluntary standards and guidelines used widely in the design, construction, maintenance, and operation of highway and transportation facilities. Much highway research results in improvements to these standards and guidelines.

AASHTO's SCOR, which has a regionally balanced membership from state highway agencies, develops an annual program of NCHRP projects for AASHTO approval. In addition, SCOR assists other AASHTO committees in identifying research needs; advocates funding for highway research; and helps coordinate state involvement in national research activities, including the National Highway R&T Partnership Forum working groups. Serving as an advisor to SCOR is AASHTO's Research Advisory Committee, composed of managers of the state highway agency R&D programs. This committee provides an opportunity for direct information exchange among R&D managers and serves as an informal mechanism for coordinating state research.

AASHTO manages a joint development program aimed at producing and supporting software products that meet the unique needs of state transportation departments. It also directs the AASHTO Materials Reference Library, which is managed by the National Institute of Standards and Technology. The library's primary responsibility is to promote adherence to standards in the testing of construction materials by public- or private-sector laboratories serving the construction field, including the central laboratories operated by state departments of transportation.

Table 3-6 **Information on Aspects of Private-Sector Highway R&T Programs**

Aspect	Summary
Program management	Program is managed by corporate or association staff.
Agenda setting	Agenda is focused largely on problem-solving or trouble-shooting activities, is driven by profitability, and addresses issues affecting business operations or output. Agenda is set by need or desire to dominate a particular market segment.
Researchers	In-house staff perform some of the research. Some research is performed under contract by research institutes, universities, and possibly member organizations.
Typical scope	The scope of the program often encompasses problem-solving and troubleshooting activities. It can also include hardware and software development and generally involves quick-response activity.
Researcher selection mechanism (level of competition)	Selection is an organizational decision, usually based on qualifications and merit.
Expert–peer review	There is a variation among the individual organizations, but research projects are usually monitored closely by potential users of the research products.

not track actual research expenditures (CERF 1993). Private companies undertake research on such subjects as roadside safety equipment, traffic control devices, and flexible culvert and pipes. Limited data indicate that annual research spending by private companies for research on highway-related topics is between $50 and $100 million. Table 3-6 summarizes information about association and private-sector research activities. Table 3-7 provides information on highway-related research expenditures by some associations, grouped by highway construction category.[14]

Special Highway Research Initiatives

Special highway research initiatives have some or all of the following characteristics: they involve considerable resources, are focused largely on a few key issues

[14] Data were provided by the associations and institutes and aggregated by the committee.

Table 3-7 **Estimates of Highway-Related Research Expenditures by Selected Industry Associations for Major Highway Construction Categories**

Category[a]	Selected Associations[b]	Estimated Funding[c]
Concrete and concrete structures	Portland Cement Association American Concrete Pavement Association Reinforced Concrete Research Council American Concrete Institute Precast/Prestressed Concrete Institute American Concrete Pipe Institute National Ready-Mixed Concrete Association Concrete Reinforcing Steel Institute American Precast Concrete Pipe Association National Precast Concrete Association Innovative Pavement Research Foundation (funding from FHWA's R&T program is a congressional designation)	~$4 million
Asphalt, asphalt paving, and asphalt modifiers	Asphalt Institute National Asphalt Pavement Association National Center for Asphalt Technology Asphalt Rubber Producers Group Asphalt Recycling and Reclaiming Association Rubber Pavements Association	~$3.5 million
Aggregates	National Sand, Stone, and Gravel Association International Center for Aggregates Research	~$1 million
Steel and steel structures[d]	American Iron and Steel Institute American Institute of Steel Construction American Welding Society	~$1.5 million
Construction equipment[e]	Construction Industry Manufacturers Association	Less than $10,000

NOTE: This is a partial list of associations involved in highway R&T for which data were readily available.

[a] Additional categories, such as composite materials, sealants, and contractors, could be included; AASHTO also funds some research, as noted in the text.

[b] This is a list of the primary associations funding highway-related R&T; many professional societies, such as the American Society of Civil Engineers, the American Society of Municipal Engineers, and the Institute of Transportation Engineers, are actively involved in technology transfer and professional training activities; some are involved with the development of standards and specifications.

[c] Estimates are based on discussions with association representatives. Estimates shown are for highway-related research only.

[d] Does not include individual steel companies.

[e] Does not include individual equipment manufacturers.

or problems in need of a concentrated effort to ensure meaningful results, are undertaken for a specific time period, and have the support of key stakeholders. The following are examples of past initiatives.

The American Association of State Highway Officials (AASHO) Road Test, a $27 million cooperative research project, was carried out in the 1950s under an agreement among the National Research Council, AASHO, and the Bureau of Public Roads.[15] The states, the federal government, and the private sector funded the program; it was managed by the Highway Research Board, the predecessor to the Transportation Research Board (TRB). The program included research on both bituminous and portland cement concrete pavements, and on a group of single-span steel bridges of composite and noncomposite designs. Planning for the Road Test Program began in 1950; research tests began in October 1958 and were completed in late 1960. The Road Test results showed how load conditions (axle weights and repetitions) affect pavements of different types and thickness, and how the strength of concrete and overloads affect pavement life. These results led to the development of improved, empirically based pavement designs that were widely adopted around the world. A key result was the development of a measure of pavement smoothness and rideability—the serviceability rating—which is used to compare different pavements.

A second example is the Strategic Highway Research Program (SHRP). SHRP, recommended by a study committee of the National Research Council and authorized by Congress in 1987, was a highly focused, $150 million, 5-year effort designed to improve the performance of highway materials and highway maintenance practices (TRB 1984). It was a program of applied research aimed at materials, paving technology, and maintenance topics deemed to have been neglected in previous research.[16] Funded from the Highway Trust Fund, SHRP yielded several major accomplishments that have been implemented successfully by highway agencies throughout the United States. (Several research success stories presented in the boxes in Chapter 1 feature SHRP research results.)

A major future strategic initiative has been proposed. TEA-21 calls for a study to determine the need for and focus of a future strategic highway research program (F-SHRP).[17] The F-SHRP study committee has recommended a research

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[15] AASHO was the predecessor organization to AASHTO; the Bureau of Public Roads was the predecessor organization to FHWA.

[16] The program concentrated on six research topic areas in which additional, focused research promised significant benefits: asphalt, long-term pavement performance, maintenance cost-effectiveness, protection of concrete bridge components, cement and concrete in highway pavements and structures, and chemical control of snow and ice on highways.

[17] TEA-21, Public Law 105-178, Section 5112, "Study of a Future Strategic Highway Research Program."

program aimed at four critical research goals: developing a consistent, systematic approach to performing highway renewal that is rapid, causes minimum disruption, and produces long-lived facilities; preventing or reducing the severity of highway crashes through more accurate knowledge of crash factors and of the cost-effectiveness of selected countermeasures in addressing these factors; providing highway users with reliable travel times by preventing and reducing the impact of nonrecurring incidents; and developing approaches and tools for systematically integrating environmental, economic, and community requirements into the analysis, planning, and design of new highway capacity (TRB 2001).

Role of Universities

Universities play important roles in highway research. Many perform contract research for the FHWA, state, and NCHRP programs. Some have formed centers for research, education, and training in specialty areas related to highway transportation.[18] Such centers are an important adjunct to graduate programs that train future highway researchers and practitioners. Some universities engage in cooperative research programs supported in part by the participating universities. University faculty and researchers serve on advisory panels for research programs and individual projects. They also publish research findings in refereed journals and present them at professional meetings, thereby making the findings accessible to a broad audience, stimulating scholarly interchange on the research topics, and encouraging peer review of both methods and findings. Many universities are active in technology transfer, some through the Local Technical Assistance Program (LTAP), the largest coordinated national transportation technology transfer activity.[19] Universities also host technical conferences, often in cooperation with other public and private organizations, and publish proceedings for widespread distribution.

The University Transportation Centers (UTCs) program was initiated under the Surface Transportation and Uniform Relocation Assistance Act of 1987, which authorized the establishment and operation of transportation centers in each of the 10 federal regions. The program was reauthorized by ISTEA and again by TEA-21, which established education as one of the primary objectives

[18] Some universities provide support to professors and graduate students in the form of faculty release time, tuition waivers, reduced overhead, laboratory space and equipment, and the like. Although data on such support were unavailable, several committee members familiar with state budgeting for university research estimate that it can amount to between 25 and 50 percent of individual research project costs.

[19] Each state has an LTAP center; many centers are operated through university continuing education offices or transportation research centers.

of a UTC, institutionalized the use of strategic planning in university grant management, and reinforced the program's focus on multimodal transportation.

TEA-21 authorizes up to $158.8 million for grants to establish and operate as many as 33 UTCs throughout the United States in Fiscal Years 1998 to 2003.[20] Ten of these centers, designated as Regional Centers, were selected competitively in 1999. The other 23 UTCs are located at universities specified in TEA-21. (See Appendix C for more details on the UTC program.) Congressional designations for the UTC program in Fiscal Year 2001 amount to 93 percent of the potential grants. During Fiscal Year 2002, 17 existing centers will enter a competition for funding for the final 2 years of authorization. All UTCs are required to match the federal funding they receive dollar for dollar.

Other Highway-Related R&T Activities

Federal Agencies

Several federal agencies support research important to the highway industry. The goal of the Federal Motor Carrier Safety Administration (FMCSA; formerly FHWA's Office of Motor Carriers) is safe operation of trucks and buses through regulation and enforcement, education-outreach, and promotion of safety technologies. The agency's four primary areas of research are compliance and enforcement, driver alertness and fatigue, regulatory evaluation and reform, and commercial driver training. Car–truck proximity safety is a key topic for future FMCSA work. FMCSA's research budget in Fiscal Year 2000 was $6.4 million.

The National Highway Traffic Safety Administration (NHTSA) is responsible for reducing deaths, injuries, and economic losses resulting from motor vehicle crashes. The agency's R&T program focuses on vehicle-related safety; its budget for Fiscal Year 2001 totaled $64.6 million. About $11.2 million of this amount was for crash avoidance research (ways to help drivers avoid crashes), $14.2 million for biomechanics research (better understanding of occupant injuries), and $9.3 million for crashworthiness research (development and design of specific countermeasures to prevent driver, passenger, and pedestrian injuries). The agency's research budget also included $21.7 million for the National Center for Statistical Analysis, which supports two important national vehicle crash databases—the Fatality Analysis Reporting System and the National Automotive

[20] Designated university-based programs and recipients of federal highway research funds must match the federal funds, usually on a one-to-one basis, with federal, state, or other funds.

Sampling System—to improve the bases for crash countermeasures. NHTSA's driver behavior research budget was $7.3 million. In addition, the agency spent about $1 million on its vehicle research and test center in Fiscal Year 2001.[21]

The U.S. Department of Transportation's (DOT's) Research and Special Programs Administration (RSPA) periodically sponsors special studies on highway transportation, particularly on truck transportation of hazardous materials in support of its Office of Hazardous Materials Safety. RSPA's Fiscal Year 2001 research budget was about $7 million. The agency administers DOT's Volpe National Transportation Systems Center, which conducts projects involving research, analysis, and technology applications on behalf of FHWA and other DOT agencies. RSPA also oversees the UTC program.

Other DOT agencies, including the Federal Aviation Administration, the Federal Transit Administration, and the Office of the Secretary, fund some research related to highways. The Office of the Secretary conducts policy-related research on major issues affecting the nation's transportation system, often addressing the policy implications of emerging issues.[22] The Office of Intermodalism has the lead role in sponsoring and coordinating departmental research on the links between highway transportation and other modes. The Bureau of Transportation Statistics (BTS), with an annual budget of about $31 million, gathers critical data for studies in support of strategic planning and national transportation policy, frequently addressing issues and topics affecting highways. BTS also manages Transportation Research Information Services (TRIS) Online, a collaborative effort of TRB, the National Academies, and BTS to provide a public-domain, web-based version of the TRIS bibliographic database, which currently contains more than 500,000 records of published transportation research. In addition, BTS maintains the National Transportation Library, an online library that provides access to more than 2,000 full-text documents drawn from more than 30 state departments of transportation and university websites.

The Department of Defense, the U.S. Army Corps of Engineers, the National Institute of Standards and Technology, and the National Science Foundation fund research in technical areas that relate to highways, particularly the areas of materials and construction. The Environmental Protection Agency funds some research in topics of interest to the highway community. Box 3-3

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[21] NHTSA also administers approximately $207 million in formula grants annually to the states for the operation of highway safety programs.

[22] Recent topics include the effects of telecommuting on travel demand; the long-term potential of high-speed, magnetically levitated trains for intercity passenger travel; and remote-sensing data collection for system operations.

BOX 3-3

Interagency and Federal–State Highway Research Partnership

Under a recent interagency agreement between FHWA and the Cold Regions Research and Engineering Laboratory (CRREL) of the U.S. Army Corps of Engineers, CRREL will conduct three research studies. The first will involve examining the possibility of extending the season for concrete construction and repair. The second will focus on developing improved pavement subgrade failure criteria through full-scale accelerated testing. The third will be an examination of asphalt pavement damage related to tire pressure. The agreement involves pooling state funds to partially cover the research costs. FHWA is also participating in the funding and overall management of the research.

presents an example of a recent interagency highway research partnership involving the U.S. Army Corps of Engineers, FHWA, and several state highway agencies.[23] Finally, several national laboratories managed by the Department of Energy have recently been involved in transportation-related projects sponsored by FHWA and DOT.

Other Countries

Because developed countries face a number of similar highway transportation issues and problems, many support highway research. Each country has its own approach to managing its highway system and organizing and managing its highway R&T activities. Sources for highway research funding in other countries include the central government ministries responsible for transportation, public works, science, and environmental issues; regional governments; and the private

[23] Future interagency research on energy, environment, and planning topics related to surface transportation is the goal of the Surface Transportation Environmental Cooperative Research Program Advisory Board, a committee of the National Research Council established by TEA-21. The board is developing a national agenda to be used by federal agencies and Congress to establish future collaborative research partnerships.

sector, often in partnership with the public sector. Most Western European countries and Japan have separate research institutes for highway infrastructure and highway safety, and some of these are affiliated with technical universities.[24] In addition to supporting specific highway R&T projects, many national governments provide support for university research, technical research centers, and related activities that benefit highway transportation. In past years, FHWA and the state highway agencies have supported international scanning tours aimed at identifying and evaluating innovative technologies and methods and encouraging international research cooperation. Reports from these tours summarize key findings and provide recommendations for action in the United States.

Because few countries are as open with government budget information as the United States, data on highway research expenditures from other countries are scarce. Table 3-8 presents estimates of expenditures on research in the areas of highway infrastructure and highway safety for 18 countries, based on data from unpublished sources and responses to direct inquiries. Although these data are not strictly comparable because of variations in data sources and availability, they indicate relative funding levels. Many European countries also support cooperative highway R&T with other countries. The largest and best known of these programs are those organized through the Organization for Economic Cooperation and Development and the European Commission. Other, smaller cooperative efforts involve small groups of countries. For example, the Nordic countries have conducted considerable cooperative research on cold-climate road construction and maintenance issues. FHWA and TRB currently participate in several of these international cooperative research activities. More information on international highway R&T programs is provided in Appendix D.

In the late 1980s a few countries, most notably Australia and the United Kingdom, privatized their highway programs and research laboratories. One consequence was that the Transport and Road Research Laboratory, which was the focal point for highway research in the United Kingdom and a key participant in international highway research activities, was privatized as the Transport Research Laboratory (TRL) and began competing for public and private research funds. TRL now performs research under contract to clients in both sectors. An outcome of TRL's privatization is that the laboratory's highly regarded research report series is no longer distributed free to libraries throughout the world, although some individual reports can be purchased.

[24] Two voluntary forums have been created to improve cooperation and coordination among laboratories and institutes that carry out highway and highway safety research in Europe. The Forum of European Highway Research Laboratories and the Forum of European Highway Safety Research Institutes aim to encourage greater collaboration among member organizations, most of which are government funded, and to share research results with national governments, the European Commission, the highway industry, and highway users.

Table 3-8 **Estimated Minimum Expenditures on Highway and Highway Safety Research (millions of U.S. dollars)**

	Source of Funds			
Country	Government	Industry	Other	Total
Australia	10.0[a]	5.0[a]	—[e]	15.0
Austria	6.0[b]	1.8[b]	5.0[c]	12.8
Belgium	10.0	0.7[b]	—[e]	10.7
Canada	25.0	—[e]	—[e]	25.0
Denmark	2.7[b]	0.9[a]	—[e]	3.6
Finland	6.86	—[e]	—[e]	6.86
France	92.0	—[e]	—[e]	92.0
Germany	31.8	—[e]	—[e]	31.8
Greece	2.2[b]	0.1[b]	—[e]	2.3
Iceland	1.5	—[e]	—[e]	1.5
Ireland	4.1[d]	0.1[b]	—[e]	4.2
Netherlands	17.1	—[e]	—[e]	17.1
New Zealand	1.4[a]	—[e]	—[e]	1.4
Norway	7.44	0.6	—[e]	8.06
Portugal	0.7[b]	0.2[b]	—[e]	0.9
Sweden	43.7	—[e]	—[e]	43.7
Switzerland	6.0	—[e]	—[e]	6.0
United Kingdom	80.3[b]	8.0[b]	11.1[b]	99.4

[a] Highway safety research only.
[b] Information from an unpublished survey conducted by the Transport Research Laboratory in 1996.
[c] Expenditures by the Austrian Road Safety Board, a private association that focuses on highway safety issues.
[d] Calculated as 0.3 percent of annual national road construction budget.
[e] Data not found.
SOURCE: Unpublished data and committee survey.

Overview of Highway R&T Program Funding

FHWA and the states are the primary public sources of highway R&T funding (see Table 3-9). FHWA R&T funding for Fiscal Year 2001 was about $208 million. State spending for highway R&T in Fiscal Year 2001 is estimated at $338 million. NCHRP funding for that year, $30.6 million, is included in the

Table 3-9 **Major Highway R&T Program Funding and Funding Sources for Fiscal Year 2001 ($ millions)**

	Government			
Program Funding	**Federal**	**State**	**Private Sector**	**Total**
FHWA R&T[a]	208	NA	NA	208
State highway R&T	185	153	NA	338
Private-sector research	NA	NA	75–150[b]	75–150
University Transportation Centers	23.95	—[c]	NA	—[d]
NCHRP	30.6	—[e]	NA	—
All programs				621–696

NOTE: NA = not applicable.

[a] Includes funding for FHWA's Surface Transportation Research and Technology Deployment Programs and ITS R&D program.

[b] Committee estimate.

[c] The state match for University Transportation Centers is included in the $153 million in state government funding for state highway R&T.

[d] Amount is not included in the total because these funds originated in FHWA's R&T program.

[e] NCHRP is a state pooled-fund program because it stems from an agreement by the states to spend a portion of their SP&R funds on the program. SP&R funding is federally provided and so is included here.

state spending total. As noted earlier, information on private-sector highway R&T funding is scarce, and the amounts involved can only be estimated. On the basis of information collected by the committee, such funding is estimated at $75 million to $150 million per year. As a result, total highway R&T spending in Fiscal Year 2001 is estimated at between $621 million and $696 million.

Highway Industry Research Expenditures Compared with Those of Other Industries

Table 3-10 provides information on net sales and R&D expenditures[25] for the top 50 corporations in several major industrial sectors for 1997.[26] In terms of a

[25] Although this report addresses federal R&T activities and expenditures, the discussion in this section is based on data and information available for industrial R&D activities.

[26] More recent data are not available.

Table 3-10 **R&D Expenditures of Major Industrial Sectors as Percentage of Net Sales (Top 50 Corporations in R&D Spending in 1997)**

Sector	Net Sales ($ billions)	R&D Spending[a] ($ billions)	R&D as Percentage of Net Sales (percent)
Basic industries and materials	727	8.4	1
Motor vehicles and other surface transportation equipment	455	18.4	4
Aircraft and guided missiles	130	4.7	4
Medical substances and devices	168	19.8	12
Chemicals	210	6.8	3
Services	67	0.4	1
Information and electronics	567	45.8	7
Machinery	248	7.0	3
Highway system	117[b]	0.621 to 0.696	0.53 to 0.59

[a] The authors warn that "comparisons between industries should be made cautiously because the research and development (R&D) sales ratios may be as circumstantial as they are strategic. For example, in the pharmaceutical industry, R&D is performed not only for the sake of discovering new products, but also for the sake of product testing to meet regulatory requirements once a new product has been developed."

[b] Highway system expenditures.

SOURCE: For all but highway sector, Standard & Poor's Compustat, Englewood, Colo.

fraction of total industry revenues, the highway industry underspends these sectors considerably. As might be expected, research spending is extensive in high-technology industries, such as the medical substances and devices sector (12 percent of net sales) and the information and electronics sector (7 percent of net sales), which rely on the development of innovative products on a frequent basis. The motor vehicle and other surface transportation equipment sector, which is dependent on the highway system, spends 4 percent of its revenues on research activities. Two sectors, the basic industries and materials sector and the services sector, spend about 1 percent of revenues on research; although this figure is low compared with the other sectors, it is higher than highway industry R&T spending.

A limitation of such cross-industry comparisons is that an industry is often the end user of products developed or improved through research in other industries, such as steel, chemicals, and electronics. Hence, the improved equipment, materials, and procedures emerging from research in these industries could be significant contributors to highway system improvements. However, such contributions are very difficult to measure.

FHWA R&T Expenditures Compared with Those of Other Federal Agencies

Table 3-11 presents information on total and R&T Fiscal Year 2001 budgets for several federal agencies. The Department of Defense had the largest federal research agency R&T budget—more than $42 billion. The R&T budget for the National Institutes of Health for Fiscal Year 2001 was $20.1 billion. By contrast, the total DOT R&T budget was $0.747 billion, while that of FHWA was $0.208 billion.

Table 3-11 **Selected Federal Agency Total and R&T Budgets for Fiscal Year 2001**

Department or Agency	Total Annual Budget ($ millions)	Annual R&T Budget ($ millions)	R&T Budget as Percentage of Total Budget (percent)
Department of Defense	283,915	42,258	14.9
Department of Agriculture	69,599	1,961	2.8
Department of Health and Human Services (National Institutes of Health)	430,466	20,859	4.8
National Aeronautics and Space Administration	13,777	9,925	72
Department of Energy	16,739	7,744	46.3
National Science Foundation[a]	3,967	3,279	82.7
Environmental Protection Agency	7,495	609	8.1
Department of Commerce	5,549	1,201	21.8
Department of Transportation	50,611	747	1.5

[a] Unlike other agencies listed, the National Science Foundation is a research agency, not a mission agency.

SOURCE: For total budgets, Office of Management and Budget (www1.whitehouse.gov/omb/budget/index.html); for R&T budgets, American Association for the Advancement of Science R&D Funding Update, May 1, 2001 (www.aaas.org/spp/dspp/rd/prev02pt.htm).

Federal agency R&T budgets reflect decisions made by Congress, often in response to federal agency priorities as expressed in the President's annual budget proposal. Although in the past congressional action was largely reactive to such proposals, this situation began to change in the 1990s (COTA 1991). Data presented earlier in Table 3-1 reveal that although federal highway R&T spending has grown in recent years, the increasing number of congressional designations for highway R&T activities has resulted in less funding for the research needs of the national highway system and consensus research priorities developed by the highway system's stakeholders.

Summary

The nation's highway research activities are highly decentralized and involve many participants. This situation reflects the nation's approach to problem solving: locating it close to where solutions are being sought and providing quick responses when an immediate solution is needed.

The federal government plays several important roles in the national highway R&T program. Congress sets the tone when it reauthorizes the federal-aid highway program. It establishes the direction and budget for the highway program, sets the FHWA R&T program budget, and influences research priorities by supporting some programs and not others. Recently it has chosen to designate more research projects and research performers. Congress also determines the size of the state highway R&T and NCHRP programs by continuing to authorize SP&R funds from the federal-aid highway program. These funds establish the base for state highway R&T funding. They are also used—based on a voluntary agreement among the states—to fund the NCHRP program.

Congress and FHWA influence highway R&T by establishing and supporting a vision for the nation's highway system. Historically, FHWA has played a key role in highway research. Several factors, including greater congressional designation of research projects and research performers and increased state R&T activity in response to growth in SP&R funding, have reduced this role. Nevertheless, the agency continues to be responsible for addressing highway issues of national interest and managing the nation's largest single highway R&T program. FHWA operates the Turner-Fairbank Highway Research Center, which houses laboratories, test facilities, and research staff that support its R&T program. In addition, the agency supports the other highway R&T programs in many ways, including funding research and participating in collaborative and partnership efforts, organizing and managing pooled-fund studies, acting as a catalyst for public–private research initiatives, and providing technical and financial assistance important to the implementation of innovations.

The mission and scope of state and private-sector R&T programs are well defined. Although state highway R&T programs generally focus on issues of state interest, their research results can be applicable to national problems. Private-sector highway R&T focuses on issues affecting business operations or output. There is no incentive for the state programs to address issues that are national in scope. Furthermore, although private-sector research may address issues related to the national highway industry market, it is not likely to deal with national highway system issues. Thus, absent federal highway R&T, some highway-related goals and issues are unlikely to be addressed.[27] FHWA is in a position to address these issues and establish partnerships with the other research programs for this purpose. The agency's role in administering the federal-aid highway program and its contacts with all the states, many research universities, and most highway researchers position it strongly to be a leader in highway research, as well as in support activities for technology transfer and implementation.

On the basis of research investment as a percentage of total highway expenditures as compared with other important sectors of the economy, highway R&T spending is low. This situation reflects overall federal transportation R&T spending, which is low as compared with other federal agency spending. Congressional decisions to designate more research projects and research performers have reduced the flexibility of FHWA's R&T program even as the demand for innovation has grown. These decisions have also reduced federal R&T funding for national highway system R&T needs and consensus highway industry research priorities.

References

Abbreviations

CERF	Civil Engineering Research Foundation
COTA	Congressional Office of Technology Assessment
TRB	Transportation Research Board

CERF. 1993. *A Nationwide Survey of Civil-Engineering Related R&D,* CERF Report 93-5006. Washington, D.C., December.

[27] Such issues include many ITS topics, such as the architecture for the Commercial Vehicle Information System and Network, high-performance steel for highway structures, development of meaningful measures of air quality and air quality trends, and improved nondestructive test methods for evaluation of concrete and asphalt pavements.

COTA. 1991. *Rebuilding the Foundations: Public Works Technologies, Management, and Financing.* U.S. Congress, Washington, D.C.

Harder. 2000. RAC Survey Results. Available in electronic form on the SCOR-RAC website in the "Resource Center" area. www4.nas.edu/trb/scor/SCORlibr.nsf/$defaultView.

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TRB. 1994. *Special Report 244: Highway Research: Current Programs and Future Directions.* National Research Council, Washington, D.C.

TRB. 2001. *Special Report 260: Strategic Highway Research: Saving Lives, Reducing Congestion, Improving Quality of Life.* National Research Council, Washington, D.C.

CHAPTER 4

Assessment of the Federal Highway Research and Technology Program

CHAPTER HIGHLIGHTS

- The context for the federal highway research and technology (R&T) program includes an important historical role, numerous stakeholders, many other independent highway research programs, and significant barriers to innovation.
- Eight key characteristics of effective and successful research programs are used to assess the federal highway R&T program.
- Significant accomplishments in the federal program are noted, as well as areas in which improvement would be beneficial to the national highway R&T effort.

This chapter provides an assessment of the federal role in promoting and conducting highway research and technology (R&T) activities. It begins with a review of the institutional and historical context in which the federal highway R&T program operates.[1] The second section describes eight key characteristics that are crucial to the success and effectiveness of a research program and provides the committee's assessment of the current federal highway R&T program in light of these characteristics.

[1] As noted previously, the committee uses the term "federal highway R&T program" to refer to the combined responsibilities and actions of Congress, the administration, and FHWA in funding federal highway research, determining research needs, setting research program priorities, and executing the research program.

Context

Previous chapters have described the scope and organization of the U.S. highway system (Chapter 2) and reviewed highway research activities that serve the system and its users (Chapter 3). The discussion in these chapters encompasses much of the context in which highway research is performed. In summary, four contextual features are important for understanding the federal role—what it is and what it could be:

- *Numerous stakeholders*—Highway users, state and local highway agencies, contractors and suppliers, people and communities served and affected by highways, and many others benefit from highway research. Some, such as state and local highway agencies, are critical to the implementation of innovative products and practices developed through research. Others, such as universities and other research organizations, have a stake in the management, administration, and direction of highway research programs. In addition to responding to these external stakeholders, the R&T program of the Federal Highway Administration (FHWA) must respond to internal customers and stakeholders. The agency's core business units and service business units share responsibility for R&T with its research unit, and also have other responsibilities (for example, policy analysis) that generate research needs. The other modal administrations and federal agencies outside the U.S. Department of Transportation (DOT) are also stakeholders to some extent, especially if they have research programs with common interests and research opportunities.
- *One program among many*—Including the research programs operated by individual state departments of transportation, there are well over 50 programs that sponsor highway research in the United States; many more sponsor highway-related research. The organization of the research in this decentralized manner mirrors the way the highway industry is organized and thereby offers significant advantages, primarily keeping research close to important stakeholders and reflecting diverse perspectives. Nonetheless, the potential exists for significant gaps in research, unnecessary duplication, results that are not transferable, and inadequate follow-up on promising research results. No single research program, even a large one operated by a federal agency, can operate autonomously without sacrificing the overall effectiveness of highway research activities.
- *Barriers to innovation*—Highway innovation is difficult for several reasons, including the fact that the highway sector is a decentralized industry with many components, public-sector procurement practices provide little incentive to innovate, and many public-sector agencies are averse to risk. Research aimed at developing more complete characterizations of system and component performance features can help public officials better manage the risks inherent in

innovation and thereby improve the potential for public-sector acceptance of innovation. Promising products and techniques do not transfer into practice automatically or with ease; therefore, proactive technology transfer activities are needed. Moreover, given the understandable focus of most stakeholders, highway research generally does not address breakthrough innovations that might affect highways in the longer term.

• *Important federal role*—The federal government, acting primarily through FHWA, has for decades been important to the many highway research programs operating in the United States. Federal funds account for about 60 percent of total highway R&T funding. With program staff and technology transfer activities in every state, as well as an international program, FHWA has the connections and resources needed to gather information about research, conduct key research programs, and disseminate information about promising results. Indirectly, because states can spend a portion of their federal-aid highway funds on research and FHWA helps coordinate the research undertaken, the federal program exerts an influence on decisions made by individual state departments of transportation concerning research.

Key Characteristics of an Effective Federal Highway R&T Program

Successful and effective research programs have certain characteristics regardless of the topic area or field in which they are engaged. They also incorporate features that are tailored to the specific context in which they operate. Drawing on both types of features, the committee has identified eight characteristics that are crucial to the success and effectiveness of the federal highway R&T program:

- Clear mission with well-defined goals that complement other R&T programs,
- Significant opportunities for technological progress and innovation,
- Early and sustained external stakeholder involvement,
- Provisions for open competition and merit review to safeguard the federal R&T investment,
- Mechanisms for information management and dissemination,
- Rigorous program evaluation,
- Adequate resources, and
- Appropriate leadership of national highway R&T activities.

The following sections describe these characteristics and provide the committee's assessment of the extent to which they are reflected in R&T activities administered by FHWA.

Clear Mission with Well-Defined Program Goals That Complement Other Programs

Description

A clear mission and well-defined program goals help research programs remain well focused. They provide a basis for keeping the program on course and avoiding diversions that can waste limited resources. Identifying an appropriate role for federal highway R&T, however, is a complex task. Although the role of the program must be based on the nation's vision of its future transportation system, there are uncertainties about the future federal role in the highway program—among members of Congress, DOT officials, state highway officials, and others. The completion of the Interstate highway system, growing demands on the federal highway program by an increasingly diverse group of stakeholders, and FHWA's 1998 reorganization to focus on technology delivery intensify these uncertainties. Nevertheless, the program must pursue research important to FHWA's mission responsibilities, including national transportation policy issues, planning and environmental regulations, intermodal considerations, and many technical issues associated with ensuring that federal-aid highway program funds are used efficiently and effectively. In addition, the program must address the needs of state and local highway agencies responsible for building, operating, and maintaining the nation's highway system, and must serve the full range of stakeholders that use, rely upon, and are affected by the system.

In addition to having a clear mission and well-defined goals, research programs need to complement other programs that have related interests. This is especially true for the federal highway R&T program because, as noted previously, it is but one—although the largest—among many programs, each with its own emphasis areas and relative strengths. For example, although some state highway research addresses long-term issues, these programs tend to emphasize finding immediate solutions to problems, such as materials performance, safety, and traffic operations, faced daily by state agency officials. The National Cooperative Highway Research Program (NCHRP) addresses common problems faced by the states and generally focuses on seeking near-term solutions that are practical and readily usable. Private-sector research tends to be near-term oriented as well, usually aimed at improving competitiveness or creating a new product or service.

Assessment

On the basis of discussions with many senior-level FHWA program managers and information gained through its ongoing review of the agency's R&T

activities, the committee finds that FHWA's R&T mission is not clearly defined, and its role relative to other highway research programs is not well articulated. As a federal agency operating a national program, FHWA has resources that enable it to undertake large-scale research activities and support facilities and laboratories at a level not possible for the states and private-sector programs. In the past, the agency has been able to use these resources and facilities to test concepts, designs, and materials of interest to the states. An example is the recent testing of curved steel bridge members at FHWA's structures laboratory. Such activities are a natural complement to other programs and are an appropriate use of the agency's resources. However, too few of FHWA's R&T activities so clearly complement other highway R&T programs and conform to a mission, implicit or explicit, that reflects the agency's unique capabilities.

In addition, it appears that FHWA's R&T is responsive to the problems of the agency's internal stakeholders and the directors of the core business units, and serves the agency's policy and regulatory interests well. In the committee's view, however, other areas, including fundamental issues related to the needs of the agency's many diverse external stakeholders, are not being addressed.

In a previous report, the committee recommended that FHWA's R&T program seek large payoffs through more exploratory and high-risk research aimed at technological breakthroughs capable of significantly altering the way things are done in the highway industry (TRB 1994). Although such research might be perceived as risky by the other highway R&T programs, it can provide new, fundamental understanding that adds to the effectiveness and cost-efficiency of those other programs. Such research exploits the strengths of a federal agency—a national perspective, significant financial resources and facilities, and direct connections to all highway and other federal agency R&T programs—and addresses topics appropriate for federal agency research (see Box 4-1). FHWA is also well positioned to undertake more research aimed at addressing research gaps not dealt with by other highway R&T programs, as well as emerging issues—stemming from changing demographics, increased demands of a changing economy, and opportunities afforded by new technologies—that can affect the nation's transportation system. Such research activities serve external customers and complement other highway research programs.

Finally, FHWA's research program has long had close ties to the state, NCHRP, and private-sector research programs. However, the opportunity exists to achieve better complementarity by adopting a research mission focused on developing the building blocks these other programs could use.

BOX 4-1

Bases for Federal Involvement in Research and Technology

The National Science and Technology Council (NSTC) of the White House Office of Science and Technology Policy identified certain characteristics that make federal research involvement and funding appropriate. The Research and Technology Coordinating Committee (RTCC) used these characteristics as a basis for determining what it believes should be the focus of FHWA's R&T program:

- Supports long-term, national transportation goals,
- Has benefits that are too diverse for a single company to recover and profit from its investment,
- Is associated with cost or risk that is beyond the capacity of any individual company, and
- Generates benefits that will begin to be realized too far in the future to pass the threshold of private investment criteria.

SOURCE: NSTC (1999, p. v).

Conclusion

FHWA's R&T program is focused too heavily on near-term issues and current problems, making it indistinguishable in this sense from the other highway R&T programs. Although the program addresses important internal goals well, it is missing the opportunity to focus more on fundamental, long-term research while also pursuing research to address gaps not dealt with by other research programs and emerging issues with national implications.

Significant Opportunities for Technological Progress and Innovation

Description

The aim of any applied research program is to develop new technologies, materials, and methods that, when implemented, will help deliver better, more cost-effective services. Highway R&T is aimed at developing innovations for highway practice. Regardless of how well a research program is designed, organized, and funded, however, it is unlikely to fulfill this mission if there are few promising opportunities for innovation. Opportunities must exist to adapt technologies developed from basic research, transfer technologies from other fields, or modify existing practices to incorporate new knowledge or fit new conditions. No one can guarantee that a research initiative will be successful by changing practice or producing benefits that outweigh its costs. But if the opportunities are sufficiently robust and promising, the likely programwide benefits will outweigh total research and development costs.

Assessment

The business of renewing, operating, and managing the nation's highway system provides many opportunities for innovation based on R&T results. The working groups of the National Highway R&T Partnership Forum—ad hoc groups representing scores of highway-related organizations—developed an extensive agenda of research opportunities in the areas of highway safety; operations and mobility; environment; and policy analysis, planning, and system monitoring (Appendix B includes the entire agenda). The following examples illustrate the nature and scope of opportunities for advancing highway practice through federal highway R&T:

- *Applying new knowledge*—There are several ways of finding new knowledge to apply to highway transportation. New knowledge from basic research in such diverse fields as human behavior and materials science has considerable potential in this regard. Research on human factors—how individuals receive and process information—could lead to new standards for in-vehicle displays and road signs that would reduce driver distraction and promote highway safety. Research on the atomic and molecular structure of concrete—a fairly common material used in pavements, bridges, and other highway structures—could lead to breakthroughs in its performance and durability and reduce its cost (see Box 4-2). In addition, the application of known techniques could lead to better understanding of the highly complex interactions among many highway system components. Asphalt research under the Strategic Highway Research Program (SHRP) included important epidemiological studies that led to Superpave®. Similar complexity is found in the areas of concrete performance, crash causation, and the impacts of new intelligent transportation systems (ITS)–based vehicle technologies on travel demand. Research that helps increase understanding of these complexities could lead to significant performance improvements.

BOX 4-2

Proposed Fundamental Research in Concrete Pavements

A committee of the National Research Council's National Materials Advisory Board recently proposed a program of advanced concrete research for FHWA aimed at the development of innovative concrete pavement technology (NRC 1997, p. 9). The committee was asked to look beyond near-term improvements in concrete pavements to identify opportunities for research on innovative and possibly unconventional materials and processes with the potential to accelerate construction, improve the durability of highway pavements and bridges, and enhance the serviceability and longevity of new facilities. The committee estimated that meeting any one of these goals could save billions of dollars in construction and maintenance costs. It concluded that viewing concrete as a single integrated system rather than a conglomerate of parts assembled through a sequence of unit processes could lead to important innovations. The committee recommended research aimed at understanding the development and behavior of the cement matrix and its microstructure at levels—the atomic and molecular—not yet explored. Such understanding is the primary path toward the development of more reliable methods for controlling the micro-, meso-, and macromorphology of concrete that are needed if innovative concrete products are to be developed.

- *Applying and transferring new technologies*—The field of ITS is predicated on the potential for using information and communication technologies to improve the performance and safety of existing transportation systems. New highway traffic control devices, driver information systems, and in-vehicle monitoring and warning devices are emerging, but there is considerably more potential in this area. For example, in-vehicle recording devices, similar to those used in commercial aircraft, can yield operating and performance data that can help researchers develop fundamental knowledge about the causes of crashes. This knowledge, in turn, can lead to improved crash prevention and vehicle crashworthiness. Design practices, construction materials, traffic simulation, and air-quality modeling are other areas in which new technologies and methods might be adapted from other fields for highway application.

- *Adapting to changing conditions and values*—Highway transportation is constantly subject to changes that can affect system performance and the way that performance is perceived. These changes produce a new set of needs and expectations that cannot be addressed without research. For example, growth in urban traffic and congestion means that highway maintenance projects and other sources of nonrecurring congestion, such as crashes and special events, can result in substantial and unexpected delays for travelers. Construction practices and procedures for handling crashes and other incidents can potentially be reengineered to reduce these delays significantly. Likewise, evolving environmental concerns result in research opportunities to develop new environmental assessment and design techniques. And the growth in truck traffic creates the need for new design and operational methods, as well as intermodal transfer facilities, all of which can be developed with the aid of research.
- *Transferring successful highway applications*—Highway agencies and highway-related organizations throughout the world encounter many of the same problems, and the solutions they develop are potentially transferable to other locations and other agencies. Domestically, the Jersey concrete barrier, currently in widespread use throughout the nation, illustrates these opportunities (see Box 1-4 in Chapter 1). These barriers originated with designs developed by General Motors for use on its high-speed test track. Research by the New Jersey Department of Transportation led to a barrier design that greatly improves work zone safety and reduces run-off-the-road crashes. Internationally, the performance of pavements made from stone-matrix asphalt—an open-graded mix used widely in Europe and capable of supporting very heavy loads—impressed a group of U.S. highway engineers visiting their counterparts in Europe in 1990. Such pavements are now used in several states.

Conclusion

There are numerous opportunities for technological progress and innovation in many areas of highway transportation, including human factors, construction materials, design practices, and traffic control systems.

Early and Sustained External Stakeholder Involvement

Description

Research needs to be closely connected to its stakeholders to ensure relevance and program support. Stakeholders are more likely to promote the use of research results if they are involved in the innovation process from the start (TRB 1999). For highway research, the potential stakeholders include the state and local highway agencies that own and operate the highway system; highway users; the companies that furnish the products, services, and equipment needed to build, maintain, and operate the system; and the people and communities that benefit from and are impacted by the system. Many of these stakeholders are responsible for implementing research results.

Research programs of the Construction Industry Institute, the Electric Power Research Institute, and NCHRP amply demonstrate the value of stakeholder involvement. In each of these mission-oriented, pooled-fund programs, stakeholders actively participate in identifying research needs, programming research funds, selecting research performers, and monitoring research progress (TRB 1999). In addition, stakeholders are called upon to build program support, maintain program relevance, and promote the implementation of research results.

However, stakeholder involvement for fundamental, long-term research differs from such involvement for a program of near-term, problem-solving research. Because stakeholders generally are driven by near-term needs and incentives, they can be poor predictors of long-term trends and opportunities.[2] As a result, managing stakeholder involvement for fundamental research involves balancing stakeholder input with the views of external advisors familiar with trends and technological opportunities. Both groups provide essential information for determining which research areas and specific directions hold promise for significant breakthroughs.

Assessment

As noted previously, FHWA's R&T program currently addresses research needs identified primarily by its internal stakeholders, mainly the core business unit directors. Although external stakeholders are far less involved in guiding the program, FHWA's support of the Research and Technology Coordinating Committee (RTCC) for the past decade has led to continuing, strategic-level external guidance on highway R&T opportunities and priorities and occasional examinations of specific research issues. However, a single committee cannot provide broad-based stakeholder input on the full range of potential highway research topics or specific projects on a continuing basis.[3]

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[2] Christensen (1997) illustrated this point for the disk drive industry and for a component of the construction equipment industry.

[3] In a previous report the committee urged FHWA to put in place formal mechanisms for soliciting and employing input from its R&T partners and customers (RTCC 2000a).

The recent activities of the National Highway R&T Partnership Forum and its working groups—with considerable support from FHWA—attest to the interest and willingness of industry stakeholders to be involved in the research program (Box 4-3 provides more information on the forum). These activities represent a promising beginning for improved external stakeholder involvement, but the forum's temporary working groups cannot substitute for a continuous,

BOX 4-3

The National Highway R&T Partnership Forum: Major Infusion of Stakeholder Involvement

The National Highway R&T Partnership Forum was initiated in 1998 by FHWA, the American Association of State Highway and Transportation Officials (AASHTO), and the Transportation Research Board (TRB). Its purpose is to better coordinate investments among highway R&T programs in a manner that involves the diverse array of highway transportation stakeholders. The forum has no official standing and relies entirely on volunteer participation. In 1999 it provided an opportunity for highway stakeholders to participate in identifying national highway R&T needs. Working groups were organized to examine research needs in five areas: highway safety; operations and mobility; infrastructure renewal; environment; and policy analysis, planning, and system monitoring. Each working group prepared a summary report based on inputs from hundreds of individuals and scores of organizations. The working group reports provide a unique catalogue of research needs—identified by volunteer coalitions of highway industry specialists and stakeholders—requiring innovative solutions believed to be achievable through research. The forum's research agenda is included in Appendix B. A synthesis of the working group reports is available at www.trb.org/trb/homepage.nsf/web/r&t_forum.

The activities of the forum and working groups illustrate the potential for broad stakeholder involvement in identifying research needs. The reports of the working groups provide managers of highway R&T programs with valuable information about a wide range of research needs and could form the basis for continuing stakeholder involvement for years to come.

systematic process that encourages and solicits external stakeholder contributions. Moreover, the working groups have merely identified research needs and priorities. Effective external stakeholder involvement also includes participation in R&T funding decisions and in review and evaluation of program results.

Conclusion

FHWA research meets the needs of its internal customers, and the agency's support of the National Highway R&T Partnership Forum is an important step toward engaging its external stakeholders. However, the need remains for a systematic approach to the sustained participation of external stakeholders in determining the direction and research topics for the FHWA program, setting priorities, and making R&T funding decisions.

Provisions for Open Competition and Merit Review to Safeguard the Federal R&T Investment

Description

There is no way to guarantee that research funds will be spent effectively after they have been programmed for a specific purpose. Nevertheless, open competition and merit review are accepted as the best possible safeguards (NRC 1999). Open competition is aimed at attracting the best possible research talent from the widest pool of potential researchers. Merit review involves the review of research proposals by independent technical experts—internal or external—based on predetermined technical criteria.

Independent external expert review helps ensure the quality of research projects and programs. It is recognized as an excellent means of assessing the relevance of research to an agency's mission and considered to be the most effective way of evaluating research programs (NRC 1999).[4] Periodic peer exchanges—modeled on expert reviews and similar to benchmarking activities—are used by state highway agencies for their research program activities (Harder 2001).

Assessment

Historically, the majority of FHWA's contract research program has been based on open competition and merit review by agency staff. These methods are

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[4] The peer review process for evaluating research proposals used by the National Science Foundation has proven to be a successful approach to external review.

viewed favorably by the General Accounting Office as the basis for research contract awards and used in many federal agency research programs, as well as state highway research programs and NCHRP (GAO 1999). Nevertheless, FHWA could enhance these methods for its program by including independent external experts on the review panels. In addition, providing an opportunity for researchers to submit unsolicited proposals, to be judged on the basis of merit, would be desirable.[5]

At the same time, an increasing share of FHWA-administered research is not awarded on the basis of open competition and merit review, primarily because Congress has chosen to designate more research projects and research performers. In 2001 such designations amounted to 51 percent of FHWA's research funding. With new designations being made each year as part of the congressional appropriations process, FHWA not only has fewer resources for sustaining a competitively awarded, merit-based highway research program, but also cannot predict accurately in advance the level of resources that will be available for such a program. Finally, such designations reduce the agency's ability to direct its research to areas of consensus-based national emphasis.

Conclusion

Including independent external experts on research proposal and project review panels would enhance FHWA's current approach to management of contract research. The trend toward increasing congressional designation of research projects and research performers and away from competitively awarded, merit-based highway research reduces the agency's ability to utilize the nation's best research talent and to conduct research on topics that represent the consensus of the highway system's stakeholders on research needs.

Mechanisms for Information Management and Dissemination

Description

Mechanisms for information management and dissemination address two closely related activities. The first is gathering information about research needs, activities, and products, as well as other innovations with potential for implementation. The second is disseminating information about research activities under

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[5] The committee has previously endorsed alternative approaches to solicitation of research topics and research contracting suggested by FHWA (1993).

way, promising innovations, and best practices. Research programs can share this information to better coordinate their own activities and minimize unnecessary duplication of effort across programs. Such information can also indicate opportunities for increased collaboration and partnering among research programs. In light of the decentralized nature of highway research, information management and dissemination are particularly important, requiring connections to state and local highway agency personnel; state, private-sector, and university researchers; and managers of other federal and international R&T programs.

Assessment

FHWA undertakes many activities in support of the management and dissemination of research information. The agency, together with other federal agencies, state departments of transportation, and other sponsors, provides funding that supports the core activities of TRB. These activities include nearly 200 committees comprising thousands of transportation professionals from all over the world; the TRB Annual Meeting, at which more than 1,500 technical presentations are made; numerous technical conferences throughout the year; several series of publications on transportation research; and an online bibliographic database that now contains more than 500,000 abstracts and citations of completed and in-progress transportation research. FHWA also partners with other organizations, including ITS America, the Civil Engineering Research Foundation, and the Institute for Transportation Engineers, to promote highway innovation. Since 1990, FHWA, working with AASHTO and other organizations, has organized 44 international technology-scanning tours aimed at identifying and evaluating innovative technologies and methods in other countries for potential application in the U.S. highway system. FHWA also funds the Local Technical Assistance Program, the largest coordinated national transportation technology transfer activity, with centers in every state, Puerto Rico, and eight Indian reservations.

The potential for improving FHWA's technology transfer activities, as reported previously by this committee, remains (TRB 1999). As noted earlier, FHWA reorganized in 1998 to focus more on technology delivery, creating four resource centers that provide technical and program assistance, training, and technology delivery to the agency's division offices, state and local highway agencies, and others.[6] Together, FHWA's headquarters office, resource centers, and division offices position the agency to gather information on national highway research needs and

[6] The resource centers are located in Atlanta, Baltimore, Olympia Fields (Illinois), and San Francisco. There is an FHWA division office in each state.

activities in the United States and worldwide, and to disseminate this information to other researchers and those who implement research results.

The committee previously recommended that FHWA monitor its individual technology transfer activities, including information gathering and dissemination, and assess their performance to learn what does and does not work for highway technology transfer (TRB 1999). Doing so is particularly important for research results involving highly innovative and breakthrough technologies, which, as noted earlier, the committee has urged FHWA to pursue. To build upon such research results, researchers and engineers will need considerable guidance and direction so they can adopt these technologies and adapt them to their needs.

Conclusion

Although FHWA has engaged successfully in many technology transfer activities in the past, the agency needs to determine what technology transfer practices are most effective to achieve the needed changes in transportation practices by state and local agencies.

Rigorous Program Evaluation

Description

The 1993 Government Performance and Results Act (GPRA) focused attention on the performance and evaluation of federal government activities, including research.[7] Research program evaluation can show where progress is being made and orient agency and program staff to the need to document practical research outcomes.[8] It can also lead to change in the research direction or termination of research activities because the potential benefits cannot justify the resources being expended. Input from customers and stakeholders is important to research program evaluation. Such evaluation is inherently difficult because the potential benefits of the research are often years away, difficult to predict, and attributable to multiple research initiatives. Nonetheless, expert evaluation—which includes quality review, relevance review, and benchmarking—provides an effective

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[7] GPRA requires federal agencies to develop a strategic plan that sets goals and objectives for at least a 5-year period, an annual performance plan that translates the goals of the strategic plan into annual targets, and an annual performance report that demonstrates whether the targets have been met.

[8] Potential measures include the number of projects aimed at test and evaluation, the number of state or other highway agencies that adopt research results, and new standards resulting from the research.

mechanism for assessing research programs by focusing on the documentation of specific practical outcomes and measurement of progress toward their achievement (NRC 1999).

Assessment

FHWA currently addresses program evaluation in several ways. First, the agency participates in the development of an annual DOT strategic plan, which is the cornerstone of the department's response to GPRA requirements. Second, FHWA's Office of Research, Development, and Technology is preparing an internal program evaluation based on the Baldridge Award criteria.[9] That office also has initiated an external assessment of the research facilities at FHWA's Turner-Fairbank Highway Research Center. Third, the agency supports this committee's ongoing efforts aimed at evaluating the strategic direction of its R&T program. These are significant steps toward program evaluation. Nevertheless, the agency has yet to identify the appropriate mix of external customers, stakeholders, and experts for all stages of this evaluation process—a matter of considerable importance if the agency's focus is to become oriented toward more fundamental, long-term research.

Conclusion

FHWA has initiated several efforts aimed at program evaluation. Additional attention needs to be given to identifying the appropriate mix of external customers, stakeholders, and experts for all stages of the evaluation, especially if the agency is to focus on more fundamental, long-term research.

Adequate Resources

Description

A successful highway R&T program requires adequate and stable funding to achieve desired results. Without such funding, some important research cannot be undertaken, and opportunities for potentially high payoffs will be missed.

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[9] The criteria for the Baldridge National Quality Award are leadership, strategic planning, information and analysis, human resources development and management, process management, business results, and customer focus and satisfaction. Congress established the award program in 1987 to recognize U.S. organizations for their achievements in quality and business performance and to raise awareness about the importance of quality and performance excellence as a competitive edge (see www.quality.nist.gov/).

Inadequate research funding also can affect the quality and usefulness of research facilities.[10] Finally, since federal funding is essential to the state, NCHRP, and university transportation R&T programs, consideration of the adequacy of resources applies to these programs as well.

Assessment

The RTCC reported in 1994 that total funding for highway R&T was low, and there has been little change since then (TRB 1994). Current annual highway R&T funding represents less than 0.6 percent of annual total public spending on highways. This level of funding is low in light of several factors: the asset value of the highway system; annual public-sector spending on highway construction, maintenance, and operation; and annual highway user spending for owning and operating highway vehicles. The RTCC believes important research needs, including many previously identified by the committee as key environmental, economic, and social issues related to the highway system, are not currently being addressed (TRB 1997). Funding to pursue the potentially high-payoff advanced concrete research described in Box 4-1, for example, is currently unavailable. The reports of the working groups of the National Highway R&T Partnership Forum identify additional examples that would require funding.

Conclusion

Total funding for federal highway R&T is low, with the result that important research needs are not being addressed despite the potential for high payoffs.

Appropriate Leadership of National Highway R&T Activities

Description

Leadership is vital to the national highway R&T effort because of the importance of the highway system and the potential for research to provide much-needed innovations. The decentralized nature of highway R&T, coupled with the large number of interrelated but independent programs, calls for leadership that influences—rather than sets research directions in—all the individual programs, with the objective of achieving mutual research goals. As noted earlier,

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[10] In a recent assessment of FHWA's Federal Outdoor Impact Laboratory, the committee noted that inadequate funding prevented upgrading the laboratory facilities and limited the researchers' ability to address important emerging research needs (RTCC 2000b).

private-sector decision makers often look to federal programs for direction and leadership; absent such leadership, they are reluctant to commit corporate funds for highway R&T.

Assessment

There are several reasons to expect FHWA to serve as the leader of the national highway R&T effort. FHWA is the federal mission agency responsible for the nation's highway transportation system and has the largest single highway R&T program. Its responsibilities include advancing national highway policy, administering the federal-aid highway program, and developing and enforcing many highway regulations. Moreover, an important part of the agency's mission is to support innovation through technology transfer, education and training, and technical support. In addition, FHWA has direct connections to all the state and many local highway agencies, as well as the other federal, state, private-sector, and university R&T programs.

Examples of how FHWA currently supports the other highway R&T programs have been discussed in Chapter 3 (many of these examples are listed in Table 3-2). Although such support suggests the agency's leadership potential, this potential is constrained by the federal program's current performance relative to several other assessment criteria, as discussed above. FHWA needs to establish a strong identity for its R&T program, one that complements the other highway R&T programs. The agency also needs to adopt a systematic approach to external stakeholder involvement and to increase significantly the proportion of the program that is competed openly and awarded on merit. In addition, leadership requires a comprehensive vision of how the highway transportation system can evolve. Such a vision has yet to be developed and presented. The committee's specific program recommendations are presented in the next chapter.

Conclusion

As the federal mission agency responsible for the federal-aid highway program, FHWA is well positioned to be the leader for the national highway R&T effort by influencing rather than directing other programs. The agency has supported the national highway R&T effort in many ways in the past. An appropriate leadership role for FHWA includes becoming the national leader in fundamental, long-term highway research. Continued support of the state, NCHRP, university, and private-sector research programs would enhance this leadership role. Examples of such support include characterizing national highway technology needs, evaluating the public costs and benefits of new highway technologies, and monitoring federal agency and international R&T programs for new technologies. (Table 3-2 lists additional examples.)

Summary

Table 4-1 summarizes the committee's assessment of the current federal highway R&T program against the characteristics discussed above.

Table 4-1 **Assessment of FHWA's Highway R&T Program According to Key Characteristics**

Key Characteristics	Assessment
Clear mission with well-defined program goals that complement other R&T programs	The current program is focused too heavily on near-term issues and current problems and is not easily distinguishable from the other highway R&T programs. It is missing the opportunity to focus on fundamental, long-term research.
Significant opportunities for technological progress and innovation	There is a potential for significant progress and technological breakthroughs in many areas, including human factors, construction materials, design practices, and traffic control systems.
Early and sustained external stakeholder involvement	Although the program appears to serve FHWA's internal stakeholders adequately, it lacks a systematic approach for the sustained participation of external stakeholders in determining the program's direction and research topics, setting priorities, and making R&T funding decisions.
Provisions for open competition and merit review to safeguard the federal R&T investment	Historically, the Federal Highway Contract Research Program has been based largely on open competition and merit review by agency staff. These procedures would be enhanced by more involvement of external experts and openness to unsolicited proposals from qualified researchers. The share of the program subject to these controls (now about 49 percent) is decreasing because Congress has designated many research projects and researchers.

continued

Table 4-1 *(continued)* **Assessment of FHWA's Highway R&T Program According to Key Characteristics**

Key Characteristics	Assessment
Mechanisms for information management and dissemination	The program is somewhat successful at gathering, sharing, and disseminating information about research needs, activities, and innovations and at supporting the other highway R&T activities and programs. FHWA needs to examine and evaluate what does and does not work for information gathering and dissemination.
Rigorous program evaluation	FHWA has taken several steps aimed at research program evaluation, but a wider range of external stakeholders could be involved in the evaluation process.
Adequate resources	Total funding for federal highway R&T is low—less than 0.5 percent of total annual highway program expenditures—with the result that important research needs are not addressed despite the potential for high payoffs.
Appropriate leadership of national highway R&T activities	As the federal mission agency responsible for the federal-aid highway program, FHWA is well positioned to be the leader for the national highway R&T effort by influencing rather than directing other programs but has yet to capitalize on this positioning. The agency has supported the national highway R&T effort in many ways in the past. An appropriate leadership role for FHWA includes becoming the national leader in fundamental, long-term highway research. Continued support of the other highway R&T programs would enhance this leadership role, as would articulation and presentation of a vision of the nation's future highway transportation system.

References

Abbreviations

FHWA	Federal Highway Administration
GAO	General Accounting Office

NRC	National Research Council
NSTC	National Science and Technology Council
RTCC	Research and Technology Coordinating Committee
TRB	Transportation Research Board

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CHAPTER 5

Recommendations

The nation's economy and the lifestyles of its citizens depend heavily on a safe and efficient highway system. More than 90 percent of all trips in the United States are made by private automobile; highway vehicle-miles traveled are increasing about 3 percent every year. Trucks move more than 14,000 ton-miles of freight each year for every person in the country, and this usage is also increasing about 3 percent each year. At the same time, the highway system faces unprecedented challenges. Congestion, by any measure, is getting worse as the total number of drivers and the amount of travel outstrip growth in capacity. Despite numerous improvements in both vehicles and highways, more than 40,000 people lose their lives in traffic crashes each year. Environmental challenges are at the heart of contentious debates about where, how, and even whether to add new capacity. The providers of highway transportation face many problems that require innovative solutions.

The federal role in highway research and technology (R&T) is vital to highway innovation. Only the federal government has the resources to undertake and sustain high-risk—but potentially high-payoff—research, and only the federal government has the incentives to invest in long-term, fundamental research. In the committee's judgment, the R&T program of the Federal Highway Administration (FHWA) is missing an opportunity to address this critical federal responsibility. This chapter presents recommendations for improving and strengthening the federal highway R&T program.

FHWA's R&T program should focus on fundamental, long-term research aimed at achieving breakthroughs in the understanding of transportation-related phenomena. In the judgment of the committee, at least one-quarter of FHWA's R&T research expenditure should be invested in such research.[1]

Fundamental, long-term research goes beyond solving problems incrementally. It involves and draws upon basic research results to provide a better understanding of problems and develop innovative solutions. For example, fundamental research aimed at improving understanding of the properties of pavement materials at the molecular level could lead to better asphalt and concrete pavements by improving the predictability of the life-cycle performance of different pavement designs. Similarly, fundamental research on individual travel behavior, lifestyle choices, and household activity patterns could lead to the development of better predictive models of regional travel demand to replace current descriptive models calibrated with aggregate data. Such research has the potential for high payoffs, even though it tends to be risky and typically requires longer to complete. Current expenditures for fundamental, long-term research at FHWA are less than 0.5 percent of the agency's R&T budget. The consensus of the committee is that this funding level is too low for such an important activity that is appropriate to a federal agency, especially since the state and private-sector highway R&T programs are unlikely to undertake this type of research.

FHWA's R&T program should undertake research aimed at (*a*) significant highway research gaps not addressed in other highway R&T programs and (*b*) emerging issues with national implications.

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[1] This recommendation for more fundamental, long-term research is consistent with a previous committee recommendation (TRB 1994). The amount recommended here, one-quarter of FHWA's R&T budget, is approximately $52 million in terms of its Fiscal Year 2001 budget and less than 8 percent of annual expenditures for highway R&T in all programs.

State, private-sector, and university highway R&T programs encompass successful problem-solving efforts, but they do not invest in certain kinds of research for several reasons, including scope, scale, and time frame. For example, although the private sector has undertaken research on how to produce improved retroreflective pavement markings, it has had little interest in pursuing research to develop a mobile retroreflectometer that would enable public agencies to determine whether existing markings meet safety standards. Such research has been undertaken by the public sector. Similarly, research on emerging issues is appropriate for federal agencies. For example, the federal government could examine how traffic diversion due to increased congestion on urban freeways can affect the performance of alternative routes not built to Interstate design standards.

The committee recommends that FHWA adopt the goal of allocating approximately one-half of its R&T resources to topics addressing significant gaps in other highway R&T programs and emerging issues with national implications.[2]

This share would leave one-quarter of FHWA's R&T resources for other activities related to the agency's federal mission responsibilities, including research related to policy and regulations, technology transfer and field applications, education and training, and technical support.

FHWA's R&T program should be more responsive to and influenced by the major stakeholders in highway innovation.

These stakeholders include the federal, state, and local government agencies that construct, maintain, and administer the nation's public highways; the private companies that supply materials, equipment, and services used by these agencies; and a wide array of highway users, communities, and public interest groups. FHWA's recent solicitation of highway research needs through the National Highway R&T Partnership Forum activity is a noteworthy first step toward obtaining broad stakeholder input. Although the forum has produced useful information on research needs, more substantive stakeholder involvement in the decision making, priority setting, and resource allocation for FHWA's research program is essential to ensure that the program addresses the problems faced by

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[2] The combination of this recommended research with the fundamental, long-term research recommended earlier is needed to change the current focus of FHWA's R&T program on short-term, problem-solving research.

those building, maintaining, using, and affected by the nation's highways. A significant challenge for the agency is informing Congress about stakeholder perceptions of highway research needs and priorities.

Although a systematic approach to stakeholder involvement begins with problem identification, such involvement must carry through to implementation.

To maintain an appropriate program focus on fundamental, long-term research, decisions about what research to pursue should balance stakeholder problem identification with expert external technical review regarding which research areas and specific research directions hold promise for significant breakthroughs. Such decisions should also reflect a strategic vision for the national transportation system. FHWA's R&T program should be based on open competition, merit review, and systematic evaluation of outcomes.

Competition for funds and merit review of proposals are the best ways of ensuring the maximum return on investment of research funding and addressing strategic national transportation system goals. Designation of specific projects or research institutions without open competition occurs at the expense of missing creative proposals prepared by the most-qualified individuals and organizations throughout the nation and does not reflect the consensus of national highway stakeholders on research needs.

Merit review and evaluation should include panels of external stakeholders and technical experts. To ensure nationwide representation on such panels, Congress should provide FHWA with funds and the authorization to meet this need.

Travel expenses for external stakeholders and technical experts involved in merit review and evaluation panels can be considerable. It is important that Congress recognize these costs and provide administrative funds for their reimbursement.

FHWA's highway R&T program should promote innovation by surveying research and practice worldwide, with the aim of identifying promising technologies, processes, and methods for use in the United States. The information from such surveys should be disseminated to the full range of highway stakeholders.

FHWA's research managers are well positioned to assume this role because of their extensive interactions with state highway agencies, private industry, other federal agencies, universities, and key highway research organizations throughout the world. They can leverage these interactions to undertake and promote the identification of promising innovations and disseminate this knowledge to all highway stakeholders. The agency's research on pedestrian safety measures used in Europe, for example, suggested several methods of crosswalk marking, signal operation, and traffic calming with application in the United States.

Two key elements of the federal highway R&T program are the University Transportation Centers (UTC) program and the State Planning and Research (SP&R) program. The UTC program is one of few opportunities for highway and transportation researchers to pursue investigator-initiated research. Although the amount of funding made available to individuals is quite modest, such funds are vital for attracting and supporting some of the nation's best young minds to highway and transportation research and thereby play an important role in graduate education.

University transportation research funded under the UTC program should be subject to the same guidelines as FHWA's R&T program—open competition, merit review, stakeholder involvement, and continuing assessment of outcomes—to ensure maximum return on the funds invested.

The SP&R program, which originated more than 60 years ago, has become an important component of the national highway R&T effort. Congress should continue to authorize this program.

The research portion of the SP&R program is the centerpiece of state highway agency R&T programs. The federal SP&R research funds, which amounted to $185 million in 2001, are matched by state funds on at least a 20:80 (state-to-federal) basis; although this contribution to research is significant, some states spend additional state funds on highway research. The SP&R program not only facilitates individual state highway R&T programs but also fosters research collaboration and partnering among the states in pooled-fund projects.

The committee endorses the findings and recommendations of the congressionally requested study to determine the need for and focus of a Future Strategic Highway Research Program (known as F-SHRP).

The report of that study [titled *Strategic Highway Research: Saving Lives, Reducing Congestion, Improving Quality of Life* (TRB 2001)], which is being released concurrently with this report, calls for a large-scale, fixed-duration strategic research initiative aimed at the most important problems currently facing public highway agencies. F-SHRP is designed to yield research products for immediate use. It will provide a natural complement to a federal highway R&T program focused on fundamental, long-term research. F-SHRP is aimed at making substantial progress toward four critical research goals:

- Developing a consistent, systematic approach to performing highway renewal that is rapid, causes minimum disruption, and produces long-lived facilities;
- Preventing or reducing the severity of highway crashes through more accurate knowledge of crash factors and of the cost-effectiveness of selected countermeasures in addressing these factors;
- Providing highway users with reliable travel times by preventing and reducing the impact of nonrecurring incidents; and
- Developing approaches and tools for systematically integrating environmental, economic, and community requirements into the analysis, planning, and design of new highway capacity.

It is important that the proposed funding for the F-SHRP research—derived from federal-aid highway program allocations to the states that would otherwise be spent on construction, maintenance, and other authorized activities—not be viewed as a substitute for funding for other state and federal highway R&T programs.

The above recommendations call for a strong federal highway R&T program designed to maximize the investment of public funds in a research effort that is vital to the nation's economy and the quality of life of all its citizens. The recommendations directed at FHWA call for strong leadership, clear vision, stakeholder involvement, and accountability in all facets of the program. If these reforms are implemented, the committee would support a significant increase in the agency's R&T budget.

An FHWA R&T budget of twice the current level, while significant, would nonetheless amount to only about 1 percent of annual total public highway expenditures. Even this increase would leave the funding low compared with research expenditures in other important sectors of the economy or other federal mission agencies.

Finally, the committee recognizes that reforming the federal highway R&T program in accordance with the above recommendations will require the cooperation and contributions of Congress, FHWA, and highway R&T stakeholders. Congress provides the funding and funding flexibility; FHWA manages the program and conducts research; and highway R&T stakeholders contribute in many ways, including implementing innovations.

Therefore, if Congress agrees with the committee's recommendations for an improved federal highway R&T program, it should provide FHWA with the funding and funding flexibility needed to undertake the recommended changes. Without such changes in its R&T funding and funding flexibility, FHWA will be unable to reform its R&T program as the committee has recommended. If FHWA's highway R&T program cannot be reformed, highway R&T stakeholders should explore with Congress other mechanisms for carrying out federal highway research.

Highway transportation is too important, the stresses on the system too severe, and innovation too critical to do anything less.

References

Abbreviation

TRB	Transportation Research Board

TRB. 1994. *Special Report 244: Highway Research: Current Programs and Future Directions.* National Research Council, Washington, D.C.

TRB. 2001. *Special Report 260: Strategic Highway Research: Saving Lives, Reducing Congestion, Improving Quality of Life.* National Research Council, Washington, D.C.

Appendix A

Background on the U.S. Highway System

The U.S. highway system is owned, operated, and maintained by public-sector agencies that contract with private construction companies for most highway construction and some highway maintenance. The system is financed by federal, state, and local taxes. Private individuals and companies own and operate automobiles, buses, and trucks that use the system and make decisions about where, when, and how they travel. The public sector is also a major highway user and makes travel choices for military mobilization, school transportation, public safety, and the like. The highway system and the public–private highway industry that supports it stem from a federal–state intergovernmental partnership established early in the 20th century. This partnership and its fundamental principles have served the system and nation well. Although these principles are a consequence of history, they can change as a matter of public policy.

This appendix presents information about the origins and current characteristics of the nation's highway system. It also describes the industry components—public and private—that own, construct, operate, and maintain highways. The significance of highway transportation to the nation's economy, its energy and environmental consequences, and its role in defense mobilization are then addressed.

Origins and Current Characteristics

During the 19th century, organized road building was essentially a state-initiated activity to meet the needs of postal delivery and to join farms to markets. Although interest in highways grew during the latter half of the century, highway development was overshadowed by railroad expansion (Rae 1971). The popularity of bicycles, stimulated by the speed and mobility of the safety bicycle—a design with wheels of equal size and pneumatic tires—led to late-19th-century efforts aimed at improving roads. Groups such as the League of American Wheelmen,[1] founded in 1880, and bicycle manufacturers, who by 1890 were producing more than a million bicycles each year, began urging state legislatures to provide better roads (Weingroff 1993).[2] The National League for Good Roads was founded in 1892 and convened a Good Roads Convention in Washington, D.C., the following year.

In 1893 Congress established the Office of Road Inquiry (ORI) in the Department of Agriculture to assist states and localities in their road-building activities. ORI focused on gathering information on highway laws, suitable road-building materials, and rail rates for hauling such materials. ORI's instructions from the Secretary of Agriculture, reflecting contemporary political sentiment, emphasized that "the actual expense in the construction of highways is to be borne by the localities and states in which they lie."

The appearance of motor vehicles at the turn of the century added to the pressure for road building that continued to grow in the early 20th century. In 1913 Congress passed the landmark Federal Aid Road Act and appropriated $75 million over a 5-year period for the improvement of rural post roads. The funds were to be spent through state highway departments, a provision that required states without highway departments to create them. Funds were provided on a 50-50 matching basis, not exceeding $10,000 per mile, for projects approved by the Bureau of Public Roads (BPR), the successor to ORI that later became the Federal Highway Administration (FHWA). The legislation put Congress on record as recognizing that better roads were essential to the national welfare and a national as well as a local responsibility.

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[1] Now the League of American Bicyclists.

[2] Many manufacturers of buggies and bicycles were also involved in the manufacture of early motor vehicles.

Initially, federal and state highway programs were financed from general revenues. The states were first to adopt user taxes for highways; as early as 1916, such taxes made up about $26 million of the $87 million in state highway spending. In 1932 the federal government followed the states by imposing a tax on gasoline fuels, and although the revenue thus collected was not formally earmarked for highway programs until 1956, federal spending and gasoline tax revenues tracked closely in the intervening years. After the Highway Trust Fund was established in 1956, user financing became a basic principle of the federal-aid highway program.

U.S. mobilization for World War I underscored the need for the nation to develop a systematic network of trunk highways instead of pursuing piecemeal improvement of local roads. The Federal Highway Act of 1921 recognized this need by requiring federal highway aid to be concentrated on "such projects as will expedite the completion of an adequate and connected system of highways, interstate in character." Each state was required to designate 7 percent of its road mileage as primary, and this mileage alone was eligible for federal-aid matching funds. This legislation marked the beginning of a genuine national highway system.

The 1913 and 1921 acts formed the basis for a national, federally assisted state highway program with state and local ownership and responsibility for planning, designing, constructing, and maintaining highways. The federal role was established as one of financial assistance to ensure a high-quality, uniform system across the states and technical assistance to promote innovation in the highway industry.[3] The result is a system of essentially free highways whose variations are nearly transparent to highway users because of the high degree of system uniformity regardless of state ownership. Such uniformity stems from programmatic efforts by BPR and FHWA, as well as the assistance and cooperation of state and local highway agencies. Federal highway funding is based on legislated formulas with factors intended to balance national and state needs, another important characteristic that follows from the way the system is organized. The priorities of the federal-aid highway program follow a functional classification of highways—rural Interstate highways, principal rural arterials, local rural highways, urban Interstates, local urban collectors, and others—that reflects differences in highway and pavement design.

[3] The federal role in highway transportation does not involve ownership of any part of the public road system outside federal property.

Between 1921 and 1956, federal highway legislation continued to provide funds to the states for highway construction. The Federal-Aid Highway Act of 1956 changed some of the fundamental aspects of this assistance by creating a new class of highways and a new funding mechanism. The act laid out a new network of express highways (expressways) that would connect the major cities in the United States, reflecting proposals originating in the early 1930s. The 41,000-mile network now known as the Eisenhower System of Interstate and Defense Highways was to be toll free, although provision was made for incorporating about 2,300 miles of toll roads in the system. A new financing mechanism, the Highway Trust Fund, was established, based on receipts from federal user taxes on motor fuels, tires and tubes, new buses, and trucks and trailers and a use tax on heavy trucks. Through the Highway Trust Fund, the federal government contributed 90 percent of the highway construction costs for the new Interstate system.

The Interstate highway system provided a truly national system of highways that supported the growth of the nation's economy by reducing vehicle operating costs and travel time for motor vehicle passengers and freight. The controlled-access, grade-separated, divided highways of the Interstate system became the standard for other highway construction as well. The system, in conjunction with other factors such as a thriving economy, a growing population, cheap land, and the home mortgage tax deduction, had a profound impact on the way communities grew and expanded.

The Interstate highway program has not been without its problems. Early in the program there were allegations of waste and mismanagement, but BPR acted quickly and decisively to standardize contracting procedures and undertook contract audits and investigations. Construction costs climbed past initial and revised estimates, and user fees were raised to ensure that the Highway Trust Fund would meet the obligations posed by the system. Planners and critics citing potential adverse environmental impacts and community disruption urged suspension of all urban Interstate construction until the full impact of the system could be identified. Such criticisms led to the requirement in the 1962 Federal-Aid Highway Act that metropolitan areas with populations of more than 50,000 implement a formal transportation planning process that was continuing, cooperative, and comprehensive. This was followed by a provision in the 1973 Federal-Aid Highway Act that authorized withdrawal of controversial Interstate segments and substitution of urban mass transportation projects. Today's concerns about urban air pollution and traffic congestion are linked to commuting patterns that resulted in part from urban Interstate construction.

Extent of the U.S. Highway System

The U.S. highway system is the nation's largest public infrastructure system, consisting of almost 3.9 million miles of roadways (79 percent of which is in rural areas), 583,000 bridges and other related structures, and a wide range of traffic control and safety systems and equipment. All public roads and streets in the United States are functionally classified by type and use. There are three key functional subsystems—arterials (including Interstates), collectors, and local roads—broadly defined on the basis of the traffic they serve (statewide or Interstate, metropolitan or local). These subsystems are further subdivided into rural and urban.

In 1995, legislation designated about 159,000 miles of roadways (98 percent of which has already been built) as the National Highway System (NHS). This network serves major population centers, international border crossings, ports, airports, public transportation facilities, and other key transportation facilities; meets national defense requirements; and serves interstate and interregional travel. Although representing only about 4 percent of the nation's highways, the NHS carries more than 40 percent of all highway traffic, 75 percent of heavy-truck traffic, and 90 percent of tourist traffic. It forms the basis for the majority of current federal aid for highways. The NHS legislation was designed to focus attention on and provide additional federal resources for the nation's most important roads.

U.S. highways represent an asset value estimated at greater than $1,300 billion, more than 87 percent of the nation's infrastructure assets. The United States spends about $117 billion annually on highway transportation infrastructure—more than two-thirds of the nation's total spending on transportation infrastructure (Buechner 1999).

Federal Legislation and Government Roles in Highway Transportation

By creating a new class of highways and a new highway funding mechanism, the Federal-Aid Highway Act of 1956 significantly affected the governmental roles in highway transportation. Subsequent legislation continues to refine these roles. States have always viewed the Highway Trust Fund as state money collected by the federal government for distribution back to the states. The distribution formulas set by Congress redistribute trust fund contributions to address national highway goals, with the result that some states receive more trust fund dollars than they contribute, while others receive less. Congress occasionally changes the distribution formulas and has considered proposals to eliminate federal highway taxes, leaving the states responsible for generating needed highway funds directly. Following debate on this issue for the 1998 highway reauthorization bill, Congress decided to continue the Highway Trust Fund and added the requirement that each state must receive at least 90.5 percent of its contribution.

Other highway legislation has affected the federal-state relationship. Between 1966 and 1970, several new laws were passed addressing vehicle standards, traffic operations, and highway design, firmly establishing a federal interest in highway safety. In 1966 the National Traffic and Motor Vehicle Safety Act and the Highway Safety Act authorized the first federal motor vehicle and highway safety regulations. Although the initial regulations were aimed at vehicle crashworthiness and crash avoidance, they were followed by a new emphasis on driver-, vehicle-, and highway-related safety research, as well as by regulations based on research and science that affected several aspects of highway management and operation. FHWA has sole responsibility for three highway-related safety areas—identification and surveillance of crash locations; highway design, construction, and maintenance; and traffic engineering—and shares responsibility for a fourth—pedestrian safety—with the National Highway Traffic Safety Administration.

In 1970 Congress broadened the federal-aid highway program to cover several highway maintenance categories and created a program of federal aid for bridge rehabilitation. In 1976 federal funds were made available for restoration, resurfacing, and rehabilitation on federal-aid highways, called the 3R program. These changes were made in response to the growing maintenance needs of the Interstate system and state concerns about the costs involved.[4] Although the changes shifted the financial burden of such projects, they also altered the responsibilities of the federal government and the states and extended federal control of the trust fund revenues. This expansion of the federal role was paid for in part by reducing spending on construction elements of the federal program.

The Surface Transportation Assistance Act of 1982 (STAA) added reconstruction (a fourth R) to the 3R program. It also responded to growing concerns about motor carrier safety and the compatibility of large trucks with the nation's highway system by expanding the federal role in regulating the size of commercial motor vehicles. Federal law now establishes truck size and weight limits on a

[4] Congress changed the distinction between construction and maintenance by amending the U.S. Code to include resurfacing, restoration, and rehabilitation within the definition of construction as the term was used in the federal-aid highway program (TRB 1987).

federally designated, 190,000-mile network of major roads, and affects where certain large motor carriers can operate off this network of highways designed to safely accommodate the larger vehicles permitted under STAA.

The Surface Transportation and Uniform Relocation Assistance Act of 1987 reauthorized the federal-aid highway program in much the same form as it had taken throughout the 1980s; the act also extended authorization for completing the Interstate highway system through 1993. Federal spending for operations and maintenance covering research, safety, and 4R activities now represents just over 40 percent of all federal highway aid. Moreover, the federal interest in operational issues was extended further through new federal priorities favoring projects that incorporate safety-effective design features and through federal studies of operations and maintenance problems (FHWA 1988).

Congress has further revised the federal role in highway transportation by passing (then repealing) a national speed limit; passing (then repealing) a motorcycle helmet law; and requiring states to pass legislation that mandates seat belt use, sets the minimum drinking age at 21, and establishes zero tolerance for underage drinking and driving violations. The Transportation Equity Act for the 21st Century requires states to set new impaired-driving requirements regarding possession or consumption of alcohol in open containers in a motor vehicle, as well as repeat offenses against drinking and driving laws. Although the states are free to enact their own legislation, failure to do so results in redirection of a portion of their federal-aid highway construction funds to highway safety programs. Mandating such regulations often creates tension between the federal government and the states and affects the relationships between FHWA and state highway agencies, especially if the mandates are unfunded or federal aid to the states is affected.

Other federal mandates address highway program administration. They include provisions that impose federal guidelines on wages paid on federal-aid projects and direct that a portion of federal funds be set aside for contracting with minority, disadvantaged, and woman-owned business enterprises.

Role of the Federal Highway Administration

FHWA is the mission agency within the U.S. Department of Transportation (DOT) responsible for the federal-aid highway system and for the development of regulations, policies, and guidelines for achieving national highway goals through its programs. FHWA dispersed about $26 billion in 1999 to the states, primarily from the Highway Trust Fund. Specifically, FHWA's mission is to "provide the best highway system in the world by continually improving the quality of the system and its intermodal connections" and "in cooperation with all [its] partners to enhance the country's economic vitality, quality of life, and the environment." To this end, the agency's strategic goals focus on safety, mobility, productivity, the human and natural environment, and national security (see Table A-1).

State and Local Roles

State and local governments are responsible for owning, constructing, operating, and maintaining the highway system. Each of the 50 states, plus Washington, D.C., and the Commonwealth of Puerto Rico, has an independent highway agency. These agencies are responsible for the segments of the federal Interstate

Table A-1 **Strategic Goals of the Federal Highway Administration**

Strategic Goal	Description
Mobility	Ensure improved access to and increased mobility on the highway system (this can include redistributing resources among states or regions to ensure a minimum national standard of highway service).
Safety	Provide a safer highway transportation system (all levels of government have a responsibility to ensure that highways are constructed, operated, and maintained in a safe and rational manner).
Productivity	Foster economic growth and productivity through efficient and effective performance and regulation of the highway system.
Human and natural environment	Promote the protection and enhancement of the human and natural environment within the highway program.
National security	Provide a primary national highway network with uniform minimum standards for military and emergency movements (national defense preparedness is and will remain an important national priority).

SOURCES: DOT and FHWA publications.

highway and primary highway systems that lie within their borders, as well as their own networks of state highways. The states own more than 20 percent of the nation's highways. An average state owns 23.7 percent of the highways within its borders, with state ownership ranging from 8.5 percent in North Dakota to 91.5 percent in West Virginia. In 1999 the states provided $62 billion for highway-related purposes through a range of means, including vehicle and driver licensing fees and fuel taxes. States also provide direct assistance to local governments by performing construction and maintenance on locally owned roads and by distributing state revenues to local governments as grants for highway purposes.

At the local level, the nation's more than 2,800 counties collectively own and manage about 1.7 million miles of highway (an average of about 600 miles each), or 44 percent of all highways. More than 35,000 municipalities, towns, and townships own and manage nearly 25 percent of the nation's highways. Localities spent about $30 billion on highways in 1999.

Highway Industry Characteristics

From the very beginning, the organization of highway agencies in states, counties, and municipalities made highway building a local enterprise. This enterprise spawned a large number of highway contractors and construction companies that serve local markets, as well as a few that extend outside state boundaries. Further affecting the limited market reach of much of the highway industry are the large quantities of low-cost materials used in highway building; such materials are costly if transported long distances. Moreover, state statutes have historically made it difficult to spend state funds outside the state, a benefit for local highway builders and suppliers of materials. Although some of these restrictions and limitations have been relaxed over time, both the highway system and the industry that serves it remain highly decentralized and fragmented.

Much of the construction, maintenance, and rehabilitation of the highway system is performed or supported by a highly diversified industry consisting of thousands of engineering firms, commodity suppliers, construction companies, contractors, and equipment manufacturers and suppliers. The companies vary in size, but many have fewer than 20 employees, although industry consolidation is changing this situation. More than 80 percent of the companies work only in a single state, and the majority derive all their income from in-state projects.

Economic Significance of Highway Transportation

The following statement summarizes how transportation affects the economy.

> Transportation is an indispensable component of any economy and society. It can increase the value of goods by moving them to locations where they are worth more. It allows people to commute to places of employment where their time has value. By extending the spatial boundaries of commodity and labor markets, transportation encourages competition and production; transportation stimulates demand for various goods and services, thereby contributing to U.S. economic growth. To meet this demand, the transportation sector employs millions of workers. (BTS 1997)

Within the nation's transportation system, highways account for 2.7 trillion vehicle-miles traveled (VMT) annually; this figure encompasses all motor vehicles, including heavy-duty trucks (FHWA 1999). Growth in VMT was about 13 percent between 1990 and 1995, or 2.5 percent per year, and is not diminishing. Outlays for passenger transportation in the United States in 1997 were $833 billion, 4 percent more than in 1996. Automobile transportation outlays dominated at about $688 billion, or 82.5 percent of the total.

More than $504 billion was spent in 1997 for freight transportation in the United States, an increase of about 8 percent over 1996. Expenditures for truck freight in 1997 amounted to $402 billion, 79 percent of the total freight transportation market. Small-package delivery revenues for for-hire trucking rose 96 percent in a decade to $15.7 billion in 1997. Business outlays for highway transportation–related equipment (trucks, trailers, buses, and automobiles) rose to $125.6 billion in 1997, representing 20 percent of all business expenditures for nonresidential durable equipment of all types.

The highway system supports the nation's economy and highly mobile lifestyle. By enabling a wide range of travel options for personal and business travel, the system affects how the nation conducts its business and its citizens carry out their daily lives. As a result, human activities and highway transportation are closely connected. The commute to work—a complex interaction of travel demand, land use patterns, job and work locations, and individual travel decision making (Pisarsky 1987)—illustrates the contribution of highways to the economy, as well as some of the problems of highway dependency.

The 1970s and 1980s witnessed a substantial surge in commute-to-work travel, predominantly by automobile, as a result of increases in the number of jobs, women in the workforce, and total worker population. In addition, during the 1980s, the increase in the number of drivers (22 million) was greater than that in the number of people (19 million). Geographic patterns in the work commute continue to change, with suburban locations now being the primary destinations of work trips, and cross-suburb commuting increasing at an even greater pace than suburban commuting in general. All these changes put considerable pressure on a highway system that was planned and constructed when the work commute was primarily from suburb to central city and that has not seen an appreciable increase in mileage in the past two decades.

Meanwhile, growth in highway use for other categories of passenger and freight travel also continues, even though it is not as well documented as growth in the work commute. Truck traffic has changed considerably in the past two decades, especially since deregulation of the trucking industry in 1979. Factors such as global competition, e-commerce,[5] and worldwide component sourcing in all types of manufacturing have increased the demand to move product components and products more quickly on highways. Although truck trip data are scarce, evidence of overall growth in truck traffic is provided by several sources. The number of large trucks (Class 8) nearly doubled from 1982 to 1997. In addition, revenues of all intercity commercial carriers increased considerably between 1986 and 1996. For example, revenues for United Parcel Service shipments more than doubled, from $7.4 billion to greater than $16 billion during the period. Domestic air freight, which often includes truck pickup and delivery trips, increased more than threefold, from $3.5 billion to $11.3 billion. Among all truck trips, 81 percent are less than 50 miles in length, but they represent 66 percent of revenues carried. Concurrently, there is evidence that in response to increasing congestion in urban areas and on certain urban bypass and intercity routes, some businesses have relocated to avoid exposure to uncertain or continuing highway congestion delays.[6]

The significant public-sector investment in highways also leverages substantial investments by road users.[7] The largest portion of personal assets held by the American public other than their homes is the vehicle fleet. This fleet includes 130 million automobiles, 76 million trucks, 3.8 million motorcycles, and about 0.7 million buses. In 1996, Americans spent more than $225 million on new automobiles and trucks.

[5] E-commerce is defined as "any transaction completed over a computer-mediated network that involves the transfer of ownership or rights to use goods and services" (Fraumeni 2001).

[6] Personal communication with Paul Roberts, consultant, January 2000.

[7] Of the total adult population, 88 percent is licensed to drive.

How the highway system performs also affects the nation's economy. Road users gauge system performance primarily by the smoothness of roads and the extent of roads, congestion, and delays. A study of mobility and congestion in 68 urban areas led to the conclusion that overall congestion resulted in 4.3 billion hours of traveler delay, 6.6 billion gallons of wasted fuel, and $72 billion in lost time and fuel costs in 1997.[8] However, from 1994 to 1997, of the total lane-miles needed to avoid further increases in the level of congestion, only 4 percent was added in the 68 urban areas (although other steps might have been taken).

Congestion and delay are not the only negative outcomes of highway transportation. In 2000 there were about 11 million vehicle crashes, more than 3 million injuries, and more than 42,000 deaths associated with highway transportation. Moreover, highway vehicles are the largest source of transportation-related emissions for nearly every type of air pollutant. In total, they contribute slightly more than one-third of nationwide emissions of the Environmental Protection Agency's six criteria pollutants for measuring air quality (TRB 1995).

The benefits of public investment in highway infrastructure accrue to the private sector in the form of greater mobility, improved access, reduced travel time and trip length, and less wear and tear on vehicles. Trucking company executives confirm this when they condition support for increased user taxes on exclusive use of such revenues for highway improvements. Achieving future cost reductions or performance improvements through new technology will ultimately depend on investment in research and technology.

Energy and Environmental Considerations

Motor vehicle transportation accounts for most of the energy consumed and pollutants emitted in U.S. transportation. If motor vehicle travel grows at even half the rate experienced during the past half-century, the amount of travel by motor vehicle on the nation's highways will more than double before the middle of this century (TRB 1995). Urban air pollution is one of the nation's most vexing environmental problems, a highly visible side effect of motor vehicle use that has become a public health concern for millions of Americans living in and around metropolitan areas. Many of its adverse consequences are known to the public, and it has become the subject of research, regulations, and combined public-private efforts to better understand and manage it.

The greatest immediate need of transportation policy makers and administrators is for environmental information and analysis in support of programs

[8] Congestion as a measure compares travel time during peak periods with travel time during unrestricted flow conditions (TTI 2001).

undertaken to comply with federal clean air regulations, although water quality, noise, and land use issues related to transportation are also of concern (TRB 1997a). Two long-term environmental issues associated with motor vehicle transportation are the risk of global climate change and the risk of losses in biological diversity and ecosystem functioning. The long-term buildup of greenhouse gases in the atmosphere, including carbon dioxide and other greenhouse gases emitted from fuels used in transportation, contributes to the risk of global climate change. Changes in air, water, and soil chemistry resulting from the chemicals emitted into the atmosphere by motor vehicles and from the gradual changes in habitats and natural processes caused by road systems and other transportation infrastructure affect the risk of losses in biological diversity and ecosystem functions (TRB 1997b).

Energy is important to highway transportation in several ways (Greene 1996). The current dependence of U.S. highway transportation on petroleum-based fuels is important because such fuels are the source of much U.S. air pollution, and continued dependency on foreign sources of petroleum can create strategic problems.[9] Although alternative fuels are available for motor vehicles, they currently cost more than, and lack the supply infrastructure of, traditional gasoline and diesel fuels. Alternative fuels and alternative power sources could become more widely available if the price of petroleum-based fuels should rise.

Another issue related to energy and transportation fuels is the current dependence of highway financing on federal and state fuel taxes. Changes in motor vehicle use, motor vehicle fuels, and vehicle fuel efficiency have an impact on tax revenues.

The Highway System and National Defense Issues

DOT and FHWA address national security through the strategic goal of "advancing the Nation's vital security interests by ensuring that the transportation system is secure and available for defense mobility and that our borders are safe from illegal intrusion." Recently both DOT and FHWA have recognized an increasing number of terrorist threats, the growing dependence of transportation on petroleum and information technology, and the need to ensure defense mobility. Information systems could prove highly vulnerable to attacks focused on the introduction of false information into the system or interference with computer and communication systems. As transportation systems become

[9] The oil export boycott by Arab members of the Organization of Petroleum Exporting Countries in 1974 is the most dramatic example of such problems.

increasingly integrated with information systems, the potential for widespread system disruption and personal injury as a result of such security breaches grows. There is a critical need to ensure that the nation's transportation systems and infrastructure are capable of providing adequate defense mobility and sustaining military mobilizations.

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Abbreviations

BTS	Bureau of Transportation Statistics
FHWA	Federal Highway Administration
TRB	Transportation Research Board
TTI	Texas Transportation Institute

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Appendix B

Agenda for Highway Research Prepared by the Working Groups of the National Highway Research and Technology Partnership Forum

Table B-1 Safety Working Group

Theme	Emphasis Area
1. Safety management and data systems	• Recommendations for implementing research and evaluation results • Case studies and guidelines for safety management practices and principles • Collection, management, and analysis of crash data • Crash causation research
2. Driver competency	• Novice drivers • Countermeasures for managing inattention • Safe mobility for older drivers • Learning opportunities and resources to improve driver skills
3. High-risk driving	• Impaired driving by targeted drivers (e.g., high blood-alcohol content) • Child and adult restraint system use • Automated enforcement equipment • Drivers without licenses or with revoked licenses • Aggressive driving • Understanding of risk-taking characteristics
4. Light-duty vehicle safety	• Crash avoidance capabilities—vehicle handling and stability, braking and traction control, conspicuity, lighting, and signaling • Human-machine interface in light-duty vehicles • Restraint system designs and passenger compartment integrity • Vehicle compatibility • Biomechanics evaluation protocols and crash dummies • Driver fitness monitoring technology • Child safety • Performance of vehicles
5. Highway infrastructure and operations	• Human factor safety guidelines • Consequences of leaving the road • Intersection safety • Intelligent infrastructure initiative • Work zones • Inclusion of safety in highway design process

Table B-1 (continued) **Safety Working Group**

Theme	Emphasis Area
6. Vulnerable road users	• Crash and use data regarding walking, bicycling, and motorcycling • Safer road sharing for pedestrians and bicyclists • Off-road facilities for pedestrians and bicyclists • Visibility and conspicuity • Educational materials
7. Heavy truck and bus safety	• Truck and bus crashes and their precursors • Driver errors • Heavy-vehicle safety equipment and technologies • Enforcement of commercial motor carrier safety regulations • High-risk carriers and drivers • Commercial driver training and performance management • Driver alertness and fatigue management • Driver physical and medical fitness • Highway infrastructure and operations
8. Postcrash management	• Emergency medical systems interventions for motor vehicle crash victims • Trauma system effectiveness • Interventions and technologies • Intelligent vehicle systems • Simulated patient training using emerging electronic technology

Table B-2 **Infrastructure Renewal Working Group (Asset Management)**

Theme	Emphasis Areas
1. Information management	• Data systems integration • Legacy systems preservation • Data standards for measurement, accuracy, and precision
2. Decision support tools	• Probabilistic life-cycle scenario analysis • Valuation analysis (inherent value of asset and economic value of mobility benefits) • Benefits determination • Performance measures for integrating customer and organizational goals • Presentation of asset management results
3. Implementation	• Organizational commitment • Barriers to implementation
4. Education	• Operational training for collecting and managing data, applying analytical tools, and interpreting and presenting results • Organizational training for broad spectrum of functions and levels • Outreach (awareness) training

Table B-3 Infrastructure Renewal Working Group (Pavements)

Theme	Emphasis Areas
1. Designs and materials	• Prediction of pavement performance • Quantification of total life-cycle costs • Long-term durability of paving materials
2. Construction and maintenance techniques and technologies	• Road user cost data for traffic congestion and delays • Impact of nontraditional contracting practices on construction time • Long-term durability of construction materials • Specialized construction and nondestructive testing equipment
3. Safer, environmentally friendly pavements	• Long-term performance of recycled pavement materials • Pavement surface properties and characteristics related to noise, safety, and vehicle-pavement interaction
4. Education, communication, and job training	• Existing and new educational program improvements • Deployment of new technologies into research efforts
5. Promotion and delivery of innovation	• Converting research results into implementable products • Management techniques for product delivery

Table B-4 **Infrastructure Renewal Working Group (Highway Structures)**

Theme	Emphasis Areas
1. Enhanced materials, structural systems, and technologies	• Properties and characteristics of materials • Fiber-reinforced polymer composites • High-performance concrete and steel • Advanced corrosion protection systems
2. Efficient maintenance, rehabilitation, and construction	• Cost benefits of design-build approach • Maintenance outsourcing and contract maintenance • Cost benefits of preventive maintenance • Life-cycle costs of innovative prefabricated systems
3. Safety assurance of highway structures for extreme events	• Acceptable risk under extreme events • Bridge instrumentation program implementation • Structure performance specifications
4. Assessment and management of bridges and other structures	• Enhancements such as the inclusion of geographic information systems data • Adaptation of bridge management system frameworks for structures other than bridges • Nondestructive testing technologies • Databases to support bridge management systems • Risk management and capital investment strategies
5. Enhanced specifications for improved structural performance	• High-performance materials specifications • Fiber-reinforced polymer composite materials specifications • Rapid replacement and repair specifications • Specifications for structures other than bridges and for other transportation modes • Load resistance factor design–based geotechnical engineering research and validation studies
6. Information and automation for structures design, construction, and maintenance	• Computer-integrated management system for bid estimating, project management, and construction • Computer-integrated–automated project delivery system • Data to link related design components • Protocols for storing and managing project data • Interactive Internet modules related to load and resistance factor design, bridge management systems, and inspection • Protocols for online access to AASHTO specifications and transportation guides • Automation support of design and analysis tools • Software verification-validation

AASHTO = American Association of State Highway and Transportation Officials.

Table B-5 Operations and Mobility Working Group

Theme	Emphasis Areas
1. Customers, customer expectations, and customer needs	• Customer expectations • Impacts of competing services • System operation warrants • Performance measures • Training in meeting customer needs • Crosscutting issues
2. Maximizing efficiency and minimizing congestion	• Performance objectives • Impact of operations on behavior of travelers • Evaluating performance • Predictive transportation management • Monitoring facility performance • Operational management • Incident management • Personnel and agency organization • Interagency relationships and regional transportation management • Work zone and social events management • Weather response • Travel demand management • Legal and regulatory barriers • Trade-offs between operational and infrastructure improvements • Relationships between transportation management and alternate modes of transportation • Crosscutting issues
3. Information needs and requirements	• Information requirements of users • Relationship between information and traveler behavior • Data needs of agency personnel • Low-cost data-collection techniques • Rural characteristic and information needs • Institutional issues associated with data sharing • Information presentation needs of disabled people • Crosscutting issues
4. Transportation safety	• Strategies for incident response • Advanced technology applications • Grade crossing and work zone safety • Photo enforcement

continued

Table B-5 (continued) **Operations and Mobility Working Group**

Theme	Emphasis Areas
	• Combine enforcement with improved operations • Communicating successful practices • Pedestrian safety • Speed regulation • Crosscutting issues
5. Environmental issues	• Environmental science • Analysis tools • Impacts of operational measures • Best practices • Relationship between operations and environment of neighborhoods and communities • Crosscutting issues
6. Intermodal interfaces and efficiencies	• Goods movement • Supply-chain management concepts • Impact of teletravel on access to services and transportation mobility • Institutional and cultural response to increased emphasis on operations • Crosscutting issues
7. Research programs and processes	(None)

Table B-6 Policy Analysis, Planning, and Systems Monitoring Working Group

Theme	Emphasis Areas
1. Improving understanding of interactions between transportation and society	• Demographic interactions • Economic interactions • Technology interactions
2. Enhancing data-driven decision-making tools	• Linkage between investment and benefits • Performance measures • Innovative financing approaches • Alternative revenue and tax sources • Traditional highway user funding • Public-private partnerships
3. Improving monitoring of evolving trends	• Sustainable data collection • More responsive analytical tools • Continuing, coordinated, comprehensive system monitoring
4. Advancing multimodal transportation planning	• Performance-based planning • Collaborative planning and partnerships • Management and operations • Planning and programming • Multimodal and intermodal planning • Goods movement planning • Technology • Environment and sustainability

Table B-7 Crosscutting Topics

Topic	Working Group	Theme or Emphasis Area
Safety	Safety	All
	Infrastructure	Work zone safety
		Safer pavements
		Safety assurance of structures
	Operations	Incident management
		Work zone management
		Advanced technologies
		Grade crossings
		Enforcement
		Pedestrians
Environment	Infrastructure	Environmentally friendly pavements
	Operations	Environmental issues
		Weather response
	Policy	Analytical tools
		System monitoring
		Partnerships
		Goods movement
		Environment and sustainability
Planning	Safety	Safety management and data systems
		Off-road facilities for pedestrians and bicyclists
	Infrastructure	Information management
		Decision support tools
		Less disruptive construction and maintenance
		Cost benefits of design-build approach
		Cost benefits of preventive maintenance
		Bridge management systems
	Policy	All
Information and data	Safety	Safety management and data systems
		Crash data for vulnerable road users
	Infrastructure	Information management
		Training for collecting and managing data
		Road user cost data
		Information and automation for structures
	Operations	User information needs
	Policy	Technology interactions
		Innovative finance
		Sustainable data collection

Table B-7 (continued) Crosscutting Topics

Topic	Working Group	Theme or Emphasis Area
Performance measures	Infrastructure	Integrating customer and organizational goals Pavement performance
	Operations	Performance of operational activities User and community goals Cost-effectiveness of performance measuring systems Monitoring facility performance
	Policy	Performance measures Performance-based planning Multimodal and intermodal planning
Workforce training	Infrastructure Operations Safety	Asset management Educational programs—pavements Meeting customer needs Driver skills Driver-fitness monitoring

APPENDIX C

University Transportation Research Centers

Part 1: University Transportation Centers

These centers were designated in the Transportation Equity Act for the 21st Century (TEA-21) or competed as regional centers to receive TEA-21 funding. Federal funding is matched on a 50:50 basis and is subject to a variable obligation limitation ceiling, which reduced the amounts shown by approximately 12 percent in Fiscal Year 2000.

Table C-1 Group A: Ten Regional Centers Competitively Selected

Location	Theme
Massachusetts Institute of Technology (Region 1)	Strategic management of transportation systems
City College of New York (Region 2)	Regional mobility and accessibility investment strategies
Pennsylvania State University (Region 3)	Advanced technologies in transportation operations and management
University of Tennessee (Region 4)	Transportation safety
University of Wisconsin–Madison (Region 5)	Transportation investment and operations
Texas A&M University (Region 6)	Sustainable transportation for mobility and economic strength
Iowa State University (Region 7)	Transportation management systems and operations[a]
North Dakota State University (Region 8)	Rural and nonmetropolitan transportation
University of California, Berkeley (Region 9)	Improving accessibility for all
University of Washington (Region 10)	Management and planning of intermodal operations

NOTE: Each receives $1 million per year from 1998 to 2003.

[a] From 1988 to 1995, the theme was intelligent transportation systems and geographic information systems; from 1995 to 1999, the center operated without federal funding.

Table C-2 Group B: Eight Congressionally Designated Centers

Location	Theme
Assumption College	Transportation and environmental education for 21st century
Purdue University	Safe, quiet, and durable highways
Rutgers University	Advanced infrastructure and transportation
South Carolina State University	Transportation intermodalism
University of Central Florida	Advanced transportation simulation
University of Denver and Mississippi State University	Intermodal transportation—planning, design, and assessment
University of Southern California and California State University, Long Beach	Metropolitan transportation research

NOTE: Each received $300,000 per year in 1998 and 1999 and $500,000 in 2000 and 2001; limited competition with Group C centers for fifth and sixth years.

Table C-3 **Group C: Nine Congressionally Designated Centers**

Location	Theme
Morgan State University	Transportation safety and efficiency through management, research, and development
New Jersey Institute of Technology	Productivity improvements through transportation
North Carolina A&T State University	Urban transit
North Carolina State University	Transportation and environment
San Jose State University	Surface transportation policy studies
University of Alabama	Management and safety of transportation systems
University of Arkansas	Rural transportation
University of Idaho	Advanced transportation technology
University of South Florida	Urban transportation

NOTE: Each received $750,000 per year between 1998 and 2001; limited competition with Group B centers for fifth and sixth years.

Table C-4 Group D: Six Congressionally Designated Centers

Location	Theme
George Mason University (with University of Virginia and Virginia Polytechnic Institute and State University)	Intelligent transportation systems
Marshall University	Economic growth and productivity in rural Appalachia through transportation
Montana State University, Bozeman	Rural transportation
Northwestern University	Infrastructure technology
University of Minnesota	Intelligent transportation systems
University of Rhode Island	Advanced transportation infrastructure and systems

NOTE: Each receives $2 million per year from 1998 to 2003.

Part 2: Programs Designated in TEA-21 and Funded from Federal Highway Administration Surface Transportation Research Program Funds

Funding is on an 80:20, federal-to-other matching basis; federal funds are subject to an obligation limitation ceiling (approximately 12 percent reduction in Fiscal Year 2000).

Table C-5 Programs Funded Through FHWA Surface Transportation Research Program

Program	Location (Federal Funds)	Term
Seismic Research	University of California, San Diego ($4 million)	1999–2002
Global Climate Research	University of Alabama at Huntsville ($1 million)	1999–2003
Asphalt Pavement Research	Auburn University ($0.5 million)	1999–2000
Seismic Research Program	National Center for Earthquake Engineering at State University of New York—Buffalo ($12 million)	1998–2003
Fundamental Properties of Asphalt and Modified Asphalt	Western Research Institute at University of Wyoming ($16 million)	1998–2003
Intelligent Infrastructure Research	Drexel University ($10 million)	1999–2003
Recycled Materials Research Center	University of New Hampshire ($9 million per year)	1998–2003
Intermodal Transportation Simulation System and National Center for Aviation and Transportation	Dowling College ($2 million) and Auburn University (minimum of $0.5 million in Fiscal Year 2000)	Fiscal Year 2000
	(Total: $136.5 million)[a]	

[a] Includes $94 million to other designated programs for undesignated recipients during the term of 1998 to 2003.

Part 3: Programs Designated in TEA-21 and Funded from FHWA Technology Deployment Initiatives and Partnerships Program

Funding is on an 80:20 federal-to-other matching basis; federal funds are subject to an obligation limitation ceiling (approximately 12 percent reduction in Fiscal Year 2000).

Table C-6 **Programs Funded Through FHWA Technology Deployment Initiatives and Partnerships Program**

Program	Location (Federal Funds)	Term
Advanced Vehicle Research	University of Alabama at Tuscaloosa ($2 million)	1999–2003
Geothermal Heat Pump Smart Bridge Research	Oklahoma State University ($3.5 million)	1999–2002
Intelligent Stiffener for Bridge Stress Reduction	University of Oklahoma ($2.5 million)	1999–2001
Advanced Trauma Care	University of Alabama at Birmingham ($3.75 million)	1999–2003
Center for Transportation Injury Research	Calspan of Buffalo Research Center ($12 million)	1998–2003
Head and Spinal Cord Injury Research	Louisiana State University ($1 million) and George Washington University ($1.5 million)	1999–2003
Motor Vehicle Safety Warning System	Georgia Technical Institute Research Center ($2.1 million)	1998–2000
Intelligent Transportation Infrastructure	State of Pennsylvania ($10.2 million)	1998–2003
Advanced Traffic Monitoring and Response Center	Pennsylvania Transportation Institute with Pennsylvania Turnpike Commission ($10 million)	1998–2003
Transportation Economics and Land Use	New Jersey Institute of Technology ($6 million)	1998–2003

Part 4: Designated Programs (Recipients) in Fiscal Year 2000 Highway Appropriations Funded at 50 Percent of Conference Earmark

Table C-7 Programs Funded at 50 Percent of Conference Earmark in FY 2000

Program	Location	Funding
Geosynthetic Materials	Montana State University	$200,000
Polymer Binders	South Carolina State University and Clemson University	$625,000
Advanced Engineering/ Wood Composites	San Diego State University and University of Maine	$600,000
Center for Excellence for Structures and Pavements	West Virginia University	$1,000,000
Native Vegetation Center	University of Northern Iowa	$150,000
National Environmental Respiratory Center	University of New Mexico	$25,000

APPENDIX D

International Highway Research and Development Activities

There is considerable variation among countries in highway research activities and funding. Little published information exists on funding for these activities, which comes from many different government sources. Moreover, many countries have separate organizational and funding arrangements for highway infrastructure and highway safety.

In addition to national highway research and development programs, European and other member countries of the Organization for Economic Cooperation and Development (OECD) participate in a range of international cooperative research activities. The OECD Road Transport Research (RTR) Program was established in 1967 to improve the performance and reduce the costs associated with highway transportation in member countries (OECD 1997). The program uses expert working groups to review the state of the art and state of practice in member countries, identify research gaps, and make suggestions for technical and policy improvements on topics of common interest. Several research projects have been undertaken under the direction of special committees using separate earmarked grants. The RTR program also manages two databases for technology transfer and information exchange—the International Road Research Documentation and the International Road Traffic and Accident databases.

The Cooperation on Science and Technology (COST) Program is a voluntary, nationally funded cooperative research program aimed at coordinating national research projects across (mostly) European countries. COST actions (projects) are generally concerned with precompetitive scientific and technical research addressing specific objectives of interest to participating countries. In most cases, COST actions are used to coordinate existing or proposed national research. COST has no specified research program structure or set of priorities. A key characteristic of the COST concept is freedom of participation for each country; a commitment to participate by at least five countries is required to initiate a COST action.

The Research and Technological Development (RTD) Program of the European Commission addresses high-level, Europe-wide objectives that cannot be attained at a national level. Such research makes use of the broad range of skills within the European Community and spreads the costs and risks involved. The current program, termed the Fifth Framework for Research and Technological Development, has a budget of about $14.6 billion for a wide range of scientific and technical activities during the period 1998 to 2002. Current thematic initiatives address transportation-related projects: competitive and sustainable growth; sustainable mobility and intermodality; land and marine transport; aeronautics; and research in materials, production technology, standards, and technology. The RTD program includes a transportation research component and a road transport research program with the following themes: sustainable mobility; road safety; traffic, transport, and information management; and road infrastructure design and maintenance. The budget for this portion of the program is about $30 million (Cordis 2000).

The European Research Coordination Agency (EUREKA) initiative was launched in 1985 to enhance European competitiveness in high-technology fields. Since then the 20-plus member nations have allocated up to $10 billion annually to a wide range of projects, including some addressing transportation issues. EUREKA currently funds 44 transport projects on such topics as alternative fuels, intelligent transportation systems, advanced materials, and material recycling at a total funding level of about $200 million (EUREKA 2000).

References

Abbreviations

EUREKA	European Research Coordination Agency
OECD	Organization for Economic Cooperation and Development

Cordis. 2000. www.cordis/lu/fp5/home.html.
EUREKA. 2000. www.eureka.belsp.be (click on Project Portfolio, then click on Transport).
OECD. 1997. *Road Transport Research Outlook 2000.* Paris.

Appendix E

Worksheet for Estimating Percentage of Congressional Designations for the Federal Highway Administration's Research and Technology Program

Table E-1 **Item 1: FHWA R&T Funding by Category as Authorized in TEA-21 ($ millions)**

Program Category	1999	2000	2001
Surface transportation R&T deployment	132.0	137.0	143.0
Intelligent transportation systems R&D	40.7	47.0	48.3
University Transportation Centers	25.65	27.275	27.25
Training and education	15.0	16.0	18.0
Total	213.35	227.775	236.35

NOTE: FHWA = Federal Highway Administration; R&T = research and technology; R&D = research and development; TEA-21 = Transportation Equity Act for the 21st Century.

Table E-2 Item 2: Designated FHWA R&T Funding by Category as Authorized in TEA-21 ($ millions)

Program Category	1999	2000	2001
Surface transportation R&T deployment	56.4	59.4	59.4
Intelligent transportation systems R&D	0.5	0.5	0.5
University Transportation Centers	15.65	17.275	17.25
Training and education	0	0	0
Total	72.55	77.175	77.15

Table E-3 Item 3: Additional Designated FHWA R&T Funding by Category: Specified in Annual Appropriations ($ millions)

Program Category	1999	2000	2001
Surface transportation R&T deployment	21.6	19.1	39.6
Intelligent transportation systems R&D	0	0	5
University Transportation Centers	0	0	0
Training and education	0	0	0
Total	21.6	19.1	44.6

Table E-4 Item 4: Total Designated FHWA R&T Funding by Category, Authorized in TEA-21 and Specified in Annual Authorizations (Sum of Items 2 and 3; $ millions)

Program Category	1999	2000	2001
Surface transportation R&T deployment	78.0	78.5	99.0
Intelligent transportation systems R&D	0.5	0.5	5.5
University Transportation Centers	15.65	17.275	17.25
Training and education	0	0	0
Total	94.15	96.275	121.75

Table E-5 **Items 5-8: Estimating Percentage of Congressional Designations ($ millions)**

Item	Description	1999	2000	2001
5	Obligation limit on FHWA R&T funding	0.883	0.871	0.879
6	Total FHWA R&T funding after obligation limit is applied	188.4	197.96	207.93
7	Total designated FHWA R&T funding after the obligation limit is applied[a]	83.13	83.86	107.02
8	Percentage of FHWA R&T funding subject to congressional designations[b]	44.0	42.0	51.0

[a] By category, authorized in TEA-21 and specified in annual authorizations.

[b] For specific research projects or research performers (based on Item 7 totals divided by Item 6 totals).

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