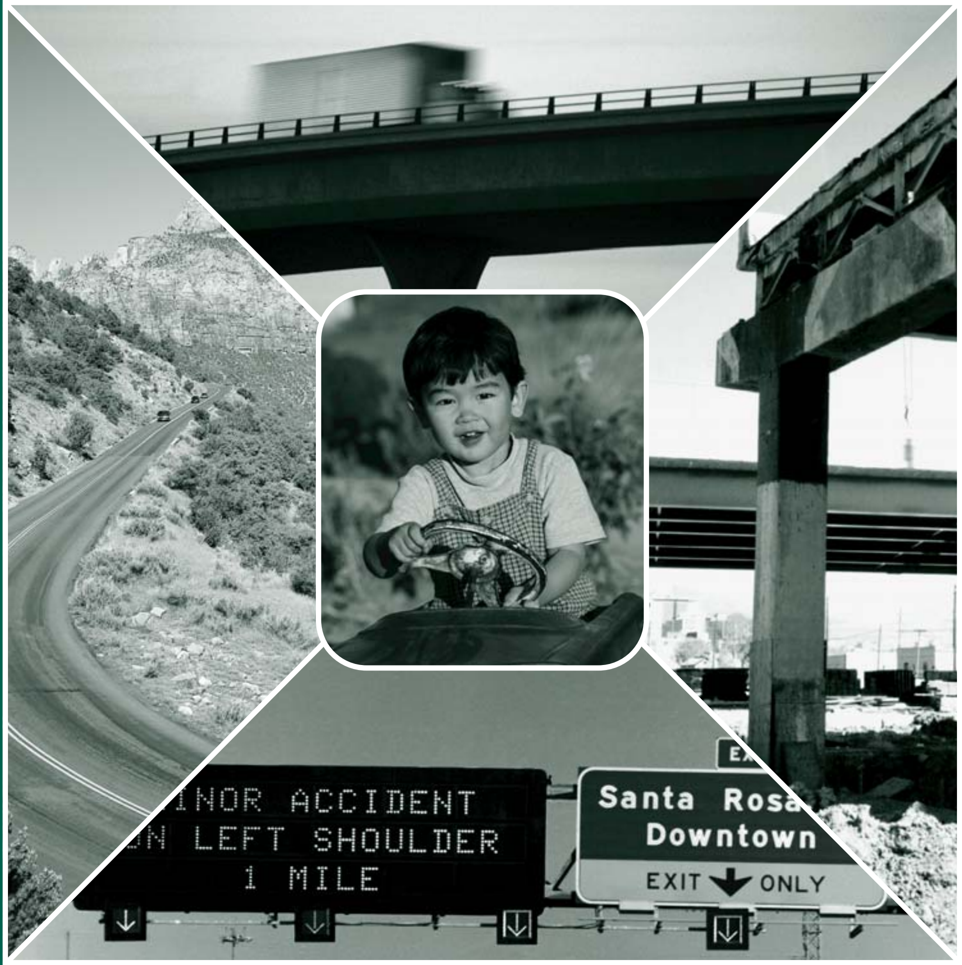
Strategic Highway Research

SAVING LIVES
REDUCING CONGESTION
IMPROVING QUALITY OF LIFE



SPECIAL REPORT 260

Transportation Research Board

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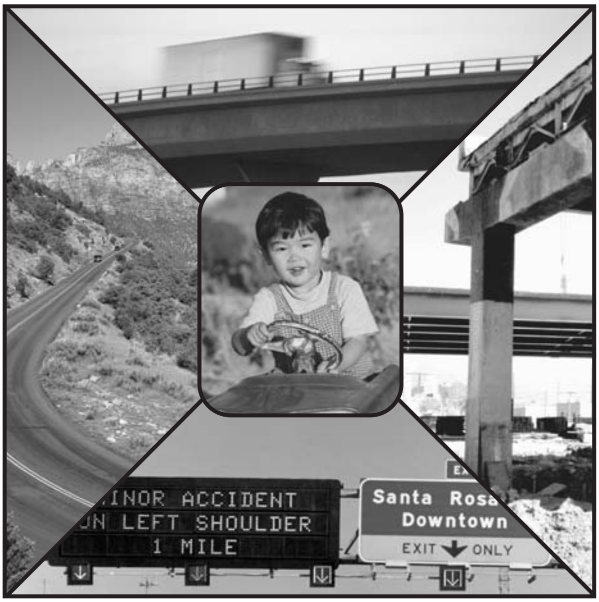

Committee for a Study for a Future Strategic Highway Research Program

TRANSPORTATION RESEARCH BOARD

National Research Council

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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

In June 1998, the United States Congress passed the Transportation Equity Act for the 21st Century (TEA-21). This bill, which reauthorized the federal-aid highway program, called for the Transportation Research Board (TRB) "to conduct a study to determine the goals, purposes, research agenda and projects, administrative structure, and fiscal needs for a new strategic highway research program to replace the program established under [the section of the United States Code establishing the first Strategic Highway Research Program] or a similar effort."[1] The committee interpreted this charge to imply that the new program was to follow a model for the conduct of highway research that was initiated with the first Strategic Highway Research Program (SHRP), authorized by Congress in 1987. This model can be characterized as a focused, time-constrained, management-driven program designed to complement existing highway research programs.[2]

To carry out this congressional request, TRB established a committee of leaders from the highway community, chaired by C. Michael Walton of The University of Texas at Austin, with Bradley L. Mallory of the Pennsylvania Department of Transportation as vice chair. The primary task of the Committee for a Study for a Future Strategic Highway Research Program (F-SHRP) was to propose a research program aimed at strategic highway needs; therefore, the committee members were chosen for their demonstrated ability to provide strategic leadership in public agencies, private-sector firms, academia, and user and stakeholder associations within the highway community. Brief biographies of the committee members are given at the end of this report (see Study Committee Biographical Information). The committee also benefited

[1] Transportation Equity Act for the 21st Century, Public Law 105-178, Section 5112, "Study of a Future Strategic Highway Research Program."
[2] It can be argued, with good reason, that the American Association of State Highway Officials Road Test, conducted in the late 1950s, also possessed many of these characteristics.

from the contributions of liaisons from the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA), who coordinated the committee's work with their organizations and facilitated outreach to their members throughout the study.

This study was carried out in close cooperation with the National Research Council's (NRC) Research and Technology Coordinating Committee (RTCC), which performs a continuing review of FHWA's research and technology programs. RTCC's report *The Federal Role in Highway Research and Technology* (TRB 2001) provides a helpful context for the present study, including an overview of the highway industry, highway research and technology programs, and national priorities for highway research. In addition to the RTCC members who were also members of the F-SHRP committee, the following individuals served on RTCC during the development of this report: Allan L. Abbott, Director of Public Works and Utilities, City of Lincoln, Nebraska; Dwight M. Bower, Director, Idaho Transportation Department; Richard P. Braun, Minnesota Guidestar; John E. Breen, Nasser I. Al-Rashid Chair in Civil Engineering, The University of Texas; Forrest M. Council, Highway Safety Research Center, University of North Carolina; Reid Ewing, Research Director, Surface Transportation Policy Project; Irwin Feller, Director and Professor of Economics, Institute for Policy Research and Evaluation, Pennsylvania State University; Larry R. Goode, Director of Transportation Planning, Policy and Finance, Institute of Transportation Research and Education, North Carolina State University; Jack Kay, Transportation Advisor, Science Applications International Corporation; Leon Kenison, Commissioner, New Hampshire Department of Transportation; Joe P. Mahoney, Professor of Civil Engineering, University of Washington; Karen M. Miller, Commissioner, District I Commission for Boone County, Missouri; James E. Roberts, Chief Deputy Director, California Department of Transportation; Sandra Rosenbloom, Director, The Drachman Institute for Land and Regional Development, University of Arizona; Michael M. Ryan, Deputy Secretary for Highway Administration, Pennsylvania Department of Transportation; David Spivey, Executive Vice President, Asphalt Paving Association of Washington, Inc.; and Dale F. Stein, President Emeritus, Michigan Technological University.

The study was conducted under the overall supervision of Stephen R. Godwin, Director of TRB's Studies and Information Services Division. Ann M. Brach served as study director and wrote the report under the direction of the committee.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

Appreciation is expressed to the following individuals for their review of this report: Richard E. Balzhiser, Electric Power Research Institute, Inc., Palo Alto, California; Randall Erikson, North Oaks, Minnesota; Robert A. Frosch, Harvard University, Cambridge, Massachusetts; Thomas D. Larson, Lemont, Pennsylvania; Michael D. Meyer, Georgia Institute of Technology, Atlanta; Alison Smiley, Human Factors North, Inc., Toronto, Canada; and James W. van Loben Sels, Parsons Brinckerhoff, Columbia, South Carolina. Although these reviewers provided many constructive comments and suggestions, they were not asked to endorse the report's findings and conclusions, nor did they see the final draft before its release.

The review of this report was overseen by Alexander H. Flax, Potomac, Maryland, and Lester A. Hoel, University of Virginia, Charlottesville. Appointed by NRC, 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.

Suzanne Schneider, Assistant Executive Director of TRB, managed the report review process. The report was edited and prepared for publication under the supervision of Nancy Ackerman, Director of Reports and Editorial Services. Rona Briere edited the report with support from Kristin Motley. Alisa Decatur prepared the manuscript. John McCracken, Joy Kelly, and Sally Hoffmaster of FHWA provided photographs for the cover. Special thanks go to Marion Johnson, Frances E. Holland, and Jocelyn Sands for assistance with meeting arrangements, communications with committee members, and administrative matters.

The proposed research in this report reflects the insights and cooperation of hundreds of people who responded to the committee's requests for information and input. Appendix A describes the outreach process used and lists

many of the participants. Special thanks are due to AASHTO technical committees and staff, FHWA staff, TRB committees and staff, the working groups of the National Research and Technology Partnership Forum, and many academicians and private consultants who generously contributed their time and expertise. Their willingness to support this effort is a testimony to the importance of research and technology in transportation and the best predictor of the success of the proposed program.

Reference

ABBREVIATION

TRB Transportation Research Board

TRB. 2001. *Special Report 261: The Federal Role in Highway Research and Technology.* National Research Council, Washington, D.C.

Contents

Executive Summary

Tens of thousands of lives lost and millions of injuries each year on America's highways; deteriorating bridges and pavements; hours of congestion and delay due to highway construction work zones, crashes, and other incidents; insufficient capacity to meet the needs of a growing population and expanding economy—these critical highway transportation problems demand solutions as we enter the third millennium. In this report a Future Strategic Highway Research Program (F-SHRP) aimed at addressing these problems is outlined.

Purpose

The highway network is the backbone of America's transportation system, making it possible to meet the mobility and economic needs of communities, regions, and the nation as a whole. Americans use the highway system to make more than 90 percent of passenger trips and move 69 percent of total freight value; highways also accommodate buses, bicycles, and pedestrians. In addition, highways provide vital links among all modes of transportation; thus the influence of their physical and operational condition extends well beyond the impacts experienced directly by highway users.

The problems outlined above are therefore pervasive, with wide-ranging impacts on the nation's economy and quality of life. The first Strategic Highway Research Program (SHRP), conducted in the late 1980s and early 1990s, focused on a few critical infrastructure and operations problems faced by state transportation agencies. Given the success of SHRP and the pressing need to find solutions for the problems challenging the highway system today, the Congress requested in 1998 that the Transportation Research Board (TRB) "conduct a study to determine the goals, purposes, research agenda and projects, administrative structure, and fiscal needs for a new strategic highway research program." Accordingly, TRB formed a committee of leaders from the public, private, and academic sectors of the highway community to carry out the study that resulted in this report.

Strategic highway problems and promising avenues of research and technology for addressing these problems are identified in this report. Rather than detailed research plans, an overall direction for those who may be charged with developing such plans is provided. As discussed below, the committee recommends that an interim planning stage take place between the publication of this report and the commencement of the research program. In the event that such an interim effort cannot be carried out, it will need to be the first step taken once the research has been funded. This report is intended to keep such a planning effort focused on the identified strategic needs, without unduly constraining researchers and research managers in exploring and developing the most promising research tasks and technologies.

Approach

The F-SHRP committee began its work by articulating an overarching theme to guide the study. This theme is grounded in the fact that everyone is a customer of the highway system in some way. Customers expect high levels of service throughout the economy, and highway transportation is no exception. With this in mind, the committee identified as the theme of the study *providing outstanding customer service for the 21st century.*

In accordance with the congressional request, the study approach adhered to the SHRP model of a special-purpose, time-constrained research program in which a concentration of resources is used to accelerate progress toward a few high-priority objectives. The committee also decided that its approach to the study should have three characteristics: it should address highway needs from a systems perspective; it should be open to research in nontraditional highway-related areas; and it should explicitly acknowledge the interdependence of highway research and technology programs.

In keeping with the overarching theme of providing outstanding customer service for the 21st century, the committee decided to conduct an extensive outreach process to identify highway needs and research opportunities. Stakeholders representing user groups, the private sector, various interest groups, and universities, as well as federal and local agencies and all state departments of transportation, received letters soliciting their input. Scores of presentations, briefings, and focus group sessions also took place. An interactive website was developed as well to allow for electronic input and provide periodic updates on the progress of the study.

The outreach process identified hundreds of highway needs and research opportunities. From this vast array of possibilities, the committee had to select a limited number of focus areas for the F-SHRP research, as well as specific topics on which to concentrate the work in each area. In thus defining the scope of the program, the committee was mindful of the pitfalls of trying to do too much and thereby compromising what could be accomplished. Therefore, through a multistage, iterative process, the committee selected a small number of topics that met the following criteria for inclusion in a new, focused, independent research program:

- *Significance of the issue*—Each topic addresses a national transportation need and represents a critical issue faced by most, if not all, departments of transportation.
- *Appropriateness for a SHRP-style research program*—Each topic requires a concentration of dedicated resources, at a large scale, over several years to accelerate progress toward implementable goals in a relatively short time frame. Each also requires an integrated approach involving coordination among many disciplines and numerous stakeholders.
- *Effectiveness and expected impact of research*—For each topic, research and technology hold promise for delivering results that will have a significant impact on highway system performance in ways that matter to customers. These results include increased safety; reduced delay; more effective and quicker highway renewal, yielding longer-lasting, higher-quality facilities; and enhancement of the economy, the environment, and communities.

F-SHRP Strategic Focus Areas and Research Programs

Through the iterative process described above, the committee concluded that F-SHRP should comprise research programs addressing the four strategic focus areas described below.

Renewal: Accelerating the Renewal of America's Highways

Overall research program goal: To develop a consistent, systematic approach to performing highway renewal that is rapid, causes minimum disruption, and produces long-lived facilities.

Challenges and Opportunities in Highway Transportation

In meeting customer expectations, the transportation community faces both challenges and opportunities that require new ways of thinking about moving people and goods. The challenges represent a broadening set of performance demands on the highway system, including technical, environmental, economic, safety, social, and political requirements. Population growth, economic expansion, and changing demographics (the aging population, the baby "boomlet," immigration) characterize the customer base well into the future and necessitate new approaches to the planning, design, and operation of the highway system. Transportation professionals must respond to the new economy (which is global, rapidly changing, and customer-focused), the desire for greater environmental sustainability, a demand for ever-improving quality of life, the public's expectations for greater involvement in transportation decision making, and the need for technologies and expertise not traditionally associated with highway engineering. Demand for passenger travel and goods movement is expected to increase significantly during the next two decades, even as Americans continue to place a high value on the privacy and flexibility of personal automobile travel. Strict reliability requirements for freight movement, enabled by information and communication technologies, must be met by an increasingly congested highway system. Yet the capacity of the system is not likely to expand as rapidly as demand, so more efficient operation of existing capacity is paramount. At the same time, selected capacity improvements will continue and must be planned, designed, and built to meet customer expectations.

Research and technology advances offer opportunities to address these challenges. For example, human factors research and new data collection technologies can help in better understanding and addressing factors associated with highway safety. Sensors, high-performance materials, and new approaches to construction and contracting can contribute to the renewal of highway infrastructure that supports mobility and the economy. Communication and traffic control technologies can help in operating the existing system more efficiently and more safely. Better economic and environmental models and improved planning and design approaches can make it possible to provide new infrastructure that enhances the economy, safety, and the human and natural environments.

Background: After decades of constant use, often exceeding facilities' original design life, much of the highway system is in need of extensive renewal. Because of the indispensable role of these facilities, however, renewal work, in contrast to the construction of new highways, must be performed while the facilities remain in service, introducing significant safety, mobility, and economic concerns. The public demands that this work be done quickly, with as little social and economic disruption as possible, and in such a way as to reduce future interventions to a minimum. The safety, economic, financial, management, environmental, aesthetic, and technological challenges of facing this situation on an individual project are formidable enough. Meeting these challenges on a nationwide scale will require the development of an entirely new way of approaching highway renewal.

Description: Under F-SHRP, a systematic method of analyzing renewal needs and evaluating alternative strategies and technologies will be produced, and the tools highway agencies need to implement a new model of highway renewal will be developed. Research may be performed in such areas as construction methods, materials, and equipment; innovative management and contracting techniques; work zone safety and traffic analysis and techniques; performance measures; and advanced information technologies.

Potential impact:[1] The results of this research would translate into user savings in several ways: smoother pavements would lead to reduced vehicle wear and tear and fuel usage; faster rehabilitation would mean less restriction of access to commercial and residential areas; and rapid, less-disruptive renewal techniques would reduce delay due to work zones. The reduced delay would be achieved not only during renewal activities, as a consequence of better management of work zones, but also over the life of facilities through the use of long-lived materials and methods. In a study of 68 urban areas, the cost of delay to highway users was estimated at about $78 billion in 1999. About 54 percent of this delay was due to nonrecurring incidents, such as construction work, disabled vehicles, and crashes. If implementation of the results of this proposed research, together with the results of the travel

[1] The estimates of potential impact used in this executive summary and throughout the report are intended to serve as quantitative economic indicators of the extent of the problems addressed by the proposed research and, correspondingly, the magnitude of potential benefits associated with even small improvements resulting from the research. The estimates are not intended to imply that these are the only or the most important potential benefits of the research, nor are they a claim that a particular order of benefit will be achieved. More precise estimates of the specific types and magnitude of benefits to be derived from applying the results of the proposed research can be derived once specific implementable products of the research have been identified.

time reliability research described below, reduced such incident-related delay in these urban areas by just 5 percent, the result would be annual savings of about $2.1 billion.

Safety: Making a Significant Improvement in Highway Safety

Overall research program goal: To prevent or reduce the severity of highway crashes through more accurate knowledge of crash factors and of the cost-effectiveness of selected countermeasures in addressing these factors.

Background: While providing indispensable service, highway travel also exacts a high cost in terms of fatalities, injuries, and property damage. Tremendous progress has been made in highway safety during the last several decades, but increases in vehicle-miles traveled threaten to drive up the absolute numbers of fatalities and injuries even as fatality and injury rates fall. Current safety practices and incremental improvements, as important as they are, are not sufficient to break through the safety impasse. To make a significant improvement in highway safety, it is necessary first to develop a much more fundamental understanding of the factors contributing to crashes and the cost-effectiveness of crash countermeasures. A number of advanced technologies make it possible to gather new and more accurate data from which this understanding can be gained.

Description: Under F-SHRP, a combination of traditional crash analysis methods and advanced data collection technologies will be used to understand the importance of various factors in highway crashes and to assess the cost-effectiveness of existing crash countermeasures.

Potential impact: Application of more fundamental knowledge of crash factors and the effectiveness of countermeasures could lead to sizable reductions in deaths and injuries, making it possible to outstrip the anticipated growth in vehicle-miles traveled. Every 1 percent improvement in highway safety resulting from application of the results of this research would mean more than 400 lives saved, 30,000 injuries averted, and $1.8 billion in economic costs avoided annually.

Reliability: Providing a Highway System with Reliable Travel Times

Overall research program goal: To provide highway users with reliable travel times by preventing and reducing the impact of nonrecurring incidents.

Background: As noted above, dependence on the highway system to help Americans achieve a wide variety of business, personal, and professional goals has led to a significant increase in vehicle-miles traveled, while capacity increases have remained quite small. The result has been increased congestion and delay. Moreover, such a heavily used highway system is more susceptible to unforeseen variations in travel time due to nonrecurring incidents such as crashes, disabled vehicles, construction work zones, hazardous materials spills, and special events. At the same time, users have become more sensitive to such unforeseen variations in travel time, making highway system reliability a paramount customer need.

Description: Under F-SHRP, strategies and tactics for reducing the impacts of particular types of nonrecurring incidents will be developed. This will be accomplished by studying the likelihood of occurrence of such incidents, the impacts on users, and associated customer expectations, and by applying the many tools and technologies available for managing and responding to highway incidents.

Potential impact: More reliable travel times would mean reductions in unexpected delay, which would in turn translate into significant user savings. As noted above, if implementation of the results of this research in combination with those of the proposed renewal research reduced incident-related delay in 68 urban areas by just 5 percent, the result would be annual savings of about $2.1 billion.

Capacity: Providing Highway Capacity in Support of the Nation's Economic, Environmental, and Social Goals

Overall research program goal: To develop approaches and tools for systematically integrating environmental, economic, and community requirements into the analysis, planning, and design of new highway capacity.

Background: The existing highway system is straining to handle the current demand in many locations. Given the anticipated growth in vehicle-miles traveled, selected additions to highway capacity are warranted. During the decades spent building and operating the Interstate highway system, much was learned about the complex set of relationships between highways and the economy, communities, and the environment, and much remains to be learned. Any effort to provide new highway capacity must incorporate explicit consideration of these relationships from the earliest planning and design stages so the highway system will simultaneously contribute to national goals in the areas of safety, mobility, productivity, and environment.

Description: Under F-SHRP, an integrated, systems-oriented approach to highway development will be formulated that encompasses engineering, economic, environmental, social, and aesthetic considerations and uses appropriate tools and technologies to integrate these considerations in a systematic way throughout the highway development process.

Potential impact: The principal impact of this research is expected to be the provision of new capacity where it is needed, along with all the economic and quality-of-life benefits associated with that capacity, in a way that responds to the full range of customer requirements: highways that are aesthetically pleasing, enhance historical and community values, and contribute to a healthier economy and environment. These types of benefits are difficult to quantify. However, one set of estimates for selected environmental impacts—the costs of road dust, highway runoff, and road noise—indicates that a 5 percent reduction in these costs due to more environmentally sensitive designs would translate to savings of approximately $180 million per year.

Recommendations

Research Program

Recommendation 1: A Future Strategic Highway Research Program should be established.

Given the significant needs and problem areas identified through the outreach process conducted for this study, the opportunities to address these needs through research and technology, and the limited ability of existing programs to exploit these opportunities, the F-SHRP committee concludes that a large-scale, special-purpose, time-constrained research program, modeled after the first SHRP, is justified if the highway system is to meet its customers' demands over the next several decades. The research conducted under F-SHRP should be focused in the four areas described above.

Administration and Funding

Recommendation 2: The administrative structure of F-SHRP should meet the following criteria: (*a*) it should possess essential quality control mechanisms (including open solicitation and merit-based selection of research proposals, appropriate review procedures during the conduct of research, and mechanisms for redirecting research as needed on the basis of results); (*b*) it should have the characteristics required to carry out a large contract research program (including appropriate management, administra-

tive, and contract support capabilities and the ability to attract and retain talented staff and other resources); (*c*) it should have focused core staff and secure funding over the program's time frame (including a reasonably predictable budget that can be managed on a multiyear, program basis, not subject to annual programming decisions or competition with other research priorities); and (*d*) it should have the flexibility to institute stakeholder governance mechanisms at both the executive, overall program level and the technical, component program level.

The choice of administrative structure should be made during the interim work stage (see Recommendation 5). The details of the mechanisms to be used to meet the above four criteria should be developed during the interim stage as well. The organizational design should address the fundamental aspects of the F-SHRP philosophy: it should support a customer orientation, a systems approach to research, the incorporation of nontraditional research, and coordination with existing highway (and other appropriate) research and technology programs. The committee notes that the National Research Council meets these criteria and successfully administered the first SHRP.

Recommendation 3: The same funding mechanism used for SHRP is recommended for F-SHRP: a takedown of 0.25 percent of the federal-aid highway funds apportioned under the next surface transportation authorizing legislation.

On the basis of the federal-aid highway funding levels of the Transportation Equity Act for the 21st Century and an assumed reauthorization period of 6 years, this recommended funding mechanism can be expected to produce approximately $450 million to $500 million. Given the relative scope and complexity of the required activities, the distribution of funding among the four research areas should be approximately 25 percent for the infrastructure renewal research; 40 percent for the safety research; 20 percent for the travel time reliability research; and 15 percent for the research on tools for providing new capacity in an environmentally, economically, and socially responsive manner. During the interim planning stage, detailed cost estimates should be developed and the total funding requirement, distribution, and percentage takedown modified as necessary.

Implementation

Recommendation 4: F-SHRP should address the need for implementation of program results from the initial planning stages throughout the management and conduct of the program.

Recommendation 4*a*: A determination should be made as early as possible regarding where the long-term responsibility for coordination and facilitation of implementation will lie.

Recommendation 4*b*: A portion of the research funding should be devoted to implementation-related activities appropriate to the research stage; additional funding for full-scale implementation activities will be required once the research program has been completed.

Interim Work

Recommendation 5: A strategic direction for F-SHRP is provided in this report; additional detailed planning is necessary before the research can be carried out. The American Association of State Highway and Transportation Officials and the Federal Highway Administration should consider funding and overseeing the development of detailed research work plans during the period immediately preceding initiation of the research program proper (which is assumed to take place at the beginning of the next surface transportation authorization period).

This interim work should include extensive outreach, a broad range of technical expertise appropriate to each research program, and review of relevant international efforts.

Characteristics of a Future Strategic Highway Research Program

The committee has identified various criteria and characteristics to help define different aspects of F-SHRP: the four strategic focus areas, specific research programs, and the overall program's administrative structure. Taken together, the following characteristics describe what F-SHRP should look like and provide a guide for further development of the program:

- Focused on a few topics of national significance for which a research program of critical mass and continuity is expected to achieve breakthrough impacts in highway practice
- Time-constrained
- Driven by stakeholders at the highest management and technical levels
- Complementary to and interdependent with other highway research and technology programs
- Customer service–oriented
- Systems-oriented
- Open to research in nontraditional highway-related areas
- Implementation-oriented from the research planning stages through adoption of research results

1 CHAPTER *Introduction*

Everyone in American society is a customer of the nation's highway system in one way or another. Customers in every segment of the economy expect high levels of service, and highway transportation is no exception. In meeting customer expectations, the transportation community faces both challenges and opportunities that frequently require new ways of thinking about moving people and goods. The challenges represent a broadening set of performance demands on the highway system, including technical, environmental, economic, safety, social, and political requirements.

In the context of these challenges and opportunities, the Transportation Equity Act for the 21st Century (TEA-21), passed in June 1998, called on the Transportation Research Board (TRB) "to conduct a study to determine the goals, purposes, research agenda and projects, administrative structure, and fiscal needs for a new strategic highway research program."[1] The Committee for a Future Strategic Highway Research Program (F-SHRP) was formed to undertake this study.[2] The results of the committee's work are documented in this report.

Context for a Future Strategic Highway Research Program

The first Strategic Highway Research Program (SHRP, or "Sharp"), conducted during the late 1980s and early 1990s, was a highly successful effort by Congress, state departments of transportation (DOTs), and highway industry leaders to address critical needs facing the industry at the time. Today, at the beginning of the 21st century, a number of new and emerging factors influence highway programs. Some of these factors are described here

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[1] Transportation Equity Act for the 21st Century, Public Law 105-178, Section 5112, "Study of a Future Strategic Highway Research Program."

[2] See Study Committee Biographical Information at the end of this report for biographies of the committee members.

as representative of the context within which F-SHRP must be conducted.[3] The factors are grouped into five categories for ease of description, but each category interacts closely with the others. Some trends reinforce each other, while others conflict. In many cases, highway transportation both enables the trends (such as economic growth) and is influenced by them. No attempt is made here to articulate precise relationships among the factors (in most cases these are areas ripe for research); what is presented is simply a description of the most salient factors and trends that characterize the highway environment.

Demographics

Several trends in the demographics of the United States will have significant implications for both levels and patterns of highway demand. First, despite a decreasing rate of population growth, the absolute numbers of persons added to the total population during the next few decades will be large: the U.S. population is expected to grow by more than 50 million in the next two decades (Bureau of the Census 1999, Tables 2 and 3). Population growth will be concentrated in particular areas, such as the South and the West, placing proportionally higher demands on the transportation systems of those regions.

Certain sectors of the population will grow more rapidly than others. Of particular importance is the rising proportion of older persons. As people retire, their travel patterns include more nonwork trips. Aging also brings changes in physical and cognitive skills, with implications for highway safety that are not yet well understood. In addition, the mobility needs of the very old, especially those no longer able to drive, will need to be addressed more aggressively in the coming years. At the same time, there will be an increase in the number of younger drivers as the children of baby boomers reach driving age. Safety and licensing issues for these new drivers will be another priority. Finally, immigration constitutes a large portion of population growth, and minorities represent an increasing percentage of the total population. As these groups advance economically, they constitute a source of travel growth and increased car ownership.

Other social trends affect transportation. For example, population growth rates in rural areas are approaching growth rates in the major metropolitan

[3] Special acknowledgment is due to Alan Pisarski and Martin Wachs for their discussion of these issues at the committee's June 2000 meeting. The ideas in this section are synthesized from their work and other sources listed in the Additional Sources at the end of the chapter. Citations for specific statements and data are included in the discussions of each research program in Chapters 4 through 7.

centers to which much of the transportation system has historically been oriented. Recent emphasis on urban revitalization may reverse this trend, but in general transportation needs to respond to changes in housing and other lifestyle choices. Moreover, the increase in the number of women in the workplace has resulted in more work trips. It has also led to more trip chaining (stopping for such purposes as child care and household errands on the way to or from work) as women continue to handle most child care and home management responsibilities in addition to working outside the home.

Economics

Economic growth has been rapid during the last decade, and despite recent slowdowns, healthy economic growth is expected in the coming decades. Economic growth, like population growth, is not evenly distributed and does not necessarily have the same characteristics and transportation implications in every region. Total vehicle-miles traveled (VMT) is projected to increase by 50 percent to more than 4 trillion by 2020.[4] Domestic manufacturing output and international trade have increased, so that there are more goods to be moved physically through the economy. An increasing percentage of freight consists of higher-value, lighter-weight goods that are most likely to be transported by truck or air rather than by rail. At the same time, freight movement overall is increasingly intermodal, placing particular importance on intermodal connections that almost always involve a highway component. This is especially true for global trade, in which connections must be made at air and water ports and land borders. Moreover, trends such as just-in-time manufacturing, rapid delivery, and mass customization of goods demand very tight travel time tolerances for freight movement.

Electronic commerce is another important economic development that is expected to have significant impacts on transportation, although it is not yet clear exactly what these impacts will be. E-commerce may reduce some types of shopping trips but may increase goods movement. This goods movement may involve more trips by smaller trucks into residential neighborhoods or more large trucks traveling on residential streets that were never designed for such traffic.

Tourism, which obviously involves a large transportation component, is another increasingly important part of the economy. Customer requirements

[4] U.S. Department of Energy, www.eia.doe.gov/oiaf/aeo/aeotab_7.htm.

for leisure travel, in terms of travel time, travel patterns, and travel-related amenities (signage, roadside aesthetics, and rest areas, for example) are likely to differ from requirements for commuting and other ordinary daily travel activities.

Environment and Energy

There is increasing public concern about a wide range of issues related to the natural environment, including air and water quality, noise, habitat and endangered species protection, and global climate change. "Environment" more broadly understood can also include cultural, historic, and social components. Historically, the impact of highways on all these components of the environment has not been given sufficient consideration in either research or practice, although there are some notable exceptions, such as the construction of certain national park roads. The construction of the Interstate system, for example, like the urban renewal efforts of the time, occasioned unforeseen damage to some neighborhoods and habitats.

In recent decades, environmental issues have been the focus of significant and increasing regulation, and much of the response to these issues by the highway sector has resulted from legal and regulatory actions. While much progress has been made, the contentious spirit of these activities may have impeded more creative and effective solutions.

Current activities point to trends such as more emphasis on environmental stewardship, environmental and community enhancement through highway-related activities, more areawide analysis of environmental issues instead of an exclusive focus on project-level impacts, and streamlining of environmental analysis and review processes. The concept of sustainability is also gaining ground, though consensus is still lacking on what sustainability entails in practice.[5] Environmental justice is another emerging area that requires additional definition.[6] A number of additional challenges will continue, including

[5] A commonly used definition of sustainability was adopted by the United Nations World Commission on Environment and Development (Brundtland Commission) in 1987: "A sustainable condition for this planet is one in which there is stability for both social and physical systems, achieved through meeting the needs of the present without compromising the ability of future generations to meet their own needs."

[6] The Federal Highway Administration defines three fundamental environmental justice principles: (*a*) to avoid, minimize, or mitigate disproportionately high and adverse human health and environmental effects, including social and economic effects, on minority populations and low-income populations; (*b*) to ensure full and fair participation by all potentially affected communities in the transportation decision-making process; and (*c*) to prevent the denial of, reduction in, or significant delay in the receipt of benefits by minority and low-income populations.

the demand for more highway mobility, coupled with an increase in not-in-my-backyard sentiment.

Energy resources, particularly petroleum, are a key element in assessing the context of transportation research. Political and technological developments can significantly affect both the supply of and demand for energy in transportation. An increase in gasoline prices, for example, may motivate greater efficiency in fuel utilization, which in turn could lead to growth in demand for smaller, lighter vehicles that could reverse the recent popularity of sport utility vehicles. The need to decrease emissions from motor vehicles can also contribute to changes in vehicle and fuel technologies. Such changes can have impacts on safety as well as fuel efficiency and emissions.

Institutions

During the last few years, a number of institutional issues have emerged that will demand resolution in the near future. Perhaps the most fundamental of these issues relates to the changing roles of highway-related institutions, especially government institutions. Recent years have seen a trend toward devolving authority from the federal to the state level, and in many cases further within the states to local governments. Consideration is being given to new forms of regional government to address important issues, such as environmental impacts, economic growth, and land use, that affect areas that do not correspond to traditional governmental jurisdictions. The role of the private sector is also evolving as government agencies outsource greater proportions of their work and generally take more of a partnering approach to their relationships with private firms.

DOTs are experiencing significant changes in the nature and focus of their work. They are increasingly customer-oriented in the way they conceive of their mission. Moreover, they are gradually shifting from a focus on projects, facilities, and construction to a more programmatic, systemwide operations perspective. Most DOTs are actively engaged as well in strategic planning and various levels of performance measurement. There is a growing effort to introduce comprehensive asset management into the way business is conducted. At the same time, many states are handling special, large-scale projects that require whole new ways of doing business almost overnight. In all cases, state DOTs must address a broader set of issues—engineering, environmental, economic, financial, technological, and social—in all their activities and decision making.

The range of issues to be addressed necessitates in turn a broader mix of disciplines and expertise than was needed to build the Interstate highway system. DOTs and private-sector firms are struggling to attract, train, and retain a diverse and highly skilled workforce. Most DOTs have also suffered from reductions in the size of the workforce and from the retirement of large numbers of experienced personnel. Declining enrollments in highway-related fields, such as civil engineering, mean a reduced supply of new talent. At the same time, the workload of DOTs has increased significantly as a result of the influx of funds from the last two highway authorizing bills (the Intermodal Surface Transportation Efficiency Act of 1991 and TEA-21) and the increase in regulatory requirements. In short, DOTs are handling a larger and more complex workload with fewer human resources precisely at a moment when creative and skilled personnel are more critical than ever to their mission.

Although highway funding has increased in recent years, some serious questions will arise in the future about how the highway system will be financed. The traditional user fees, derived largely from per-gallon charges on fuel, are potentially threatened by the increasing energy efficiency of highway vehicles, the special tax treatment accorded alternative fuels, and the fact that the user fees are not linked to inflation. Proposals for addressing this issue (such as indexing fuel taxes to inflation or charging a fee based on miles traveled) are in their infancy and are likely to face significant political barriers, at least in the short term. At the same time, innovative financing methods have been introduced, including leveraging of private resources, increased use of tolls, and debt financing. While this issue is not currently at a critical level, it will need to be addressed in the very near future if significant problems are to be averted in the next two decades.

Another institutional issue is the trend toward greater public involvement in the highway development process. While public involvement may have begun as a response to regulatory requirements, it is increasingly becoming a part of the customer-oriented focus of transportation agencies. There is much work to be done in developing effective methods of communication and public participation in highway planning, design, and overall decision making. Public participation from a customer-oriented perspective involves more than responses to particular transportation needs, however. State DOTs and the Federal Highway Administration (FHWA) survey the public from time to time to measure levels of satisfaction and identify areas for improvement. Selected results of FHWA customer surveys are presented in Box 1-1.

Box 1-1

Selected Results of FHWA Customer Satisfaction Surveys

In February 2001, FHWA published the results of three customer surveys conducted in 2000. Several of the findings of these surveys reinforce the results of the F-SHRP committee's efforts to identify strategic highway research focus areas. First, the surveys indicate the importance of highways and transportation to customers:

- Most customers (65 percent) are satisfied with the major highways they use most often.
- Most respondents (80+ percent) believe the transportation system supports important community values, such as livability, economic well-being, and environmental well-being.

At the same time, several areas of dissatisfaction reflect the need for customer-oriented improvements in the areas identified by the F-SHRP committee:

- Customers are less satisfied with traffic flow now than they were in 1995 because of increases in congestion and travel delays.
- Thirty-two percent of respondents were dissatisfied with work zones, the second-highest indicator of dissatisfaction after traffic flow.
- Respondents perceived heavy traffic to be the largest contributor to delay, followed by work zones.
- While there was some support (just under 40 percent) for building new highways, support was much stronger (more than 60 percent) for expanding existing transportation facilities, including highways, and providing better traffic information.

Respondents favored improvements to traffic flow, safety, and pavement conditions as areas in which to focus resources. They also supported the following approaches to overcoming traffic delays: using more durable paving materials, making repairs during off-peak hours, reducing repair times, improving traffic signal timing, clearing accidents quickly, and adding travel lanes. Customers also supported short-term road closures for long-lasting repairs.

Source: FHWA (2001).

Technology

While the issues described above may appear daunting, technology advances offer opportunities for addressing these issues through efforts such as F-SHRP. Some of the more salient of these developments are briefly described here.

Advances in information and communication technologies offer opportunities for significant improvements in highway performance. Such technologies include computers, the Global Positioning System, cellular telephones and other telecommunications technologies, and geographic information systems. The field of intelligent transportation systems (ITS) is built on these technologies, which can contribute to safety (crash avoidance and automatic contacting of emergency personnel, for example), the development of onboard navigation systems, systemwide operations, more efficient traffic control, and better communication with users, among other things. These technologies are usually combined with sensing technologies, described later.

At the same time, information and communication technologies pose some issues that the highway community has not fully addressed, such as the safety implications of putting advanced technologies (navigation systems, cell phones) in vehicles and the privacy issues that arise when vehicles are equipped with technology that makes their location known to other parties. Transportation agencies are also faced with the expense of acquiring and maintaining the technologies, plus the difficulty of attracting or training and retaining technically skilled staff to operate them. These issues are all on the transportation supply side. In addition, communication technologies have potential demand implications that are not well understood. Telecommuting, teleconferencing, videoconferencing, and other such capabilities were originally thought to be substitutes for travel. However, they may simply increase the opportunities for interaction; replace business travel with other travel; or facilitate people's living farther from work so that when they do commute, they travel longer distances. Likewise, e-commerce has a number of potential impacts, discussed earlier.

New materials for both vehicles and infrastructure will be important in efforts to meet safety, operations, and infrastructure performance goals. High-performance materials, including concretes, steels, aluminum, and composites, can now be designed for greater durability, higher strength, and increased corrosion resistance. These characteristics can make infrastructure components last longer, requiring fewer maintenance and repair interventions. Some high-performance materials are designed for rapid setup in the field so that repair and rehabilitation activities will cause minimal lane closure and disruption to traffic. Emerging smart materials and structures combine sensing and communication technologies with advanced materials to create facilities that are self-monitoring. This allows for optimal maintenance intervention and may even contribute to system operations if, for instance, traffic- or weather-sensing technologies are embedded in the materials.

Equipment and sensing technologies also have promising highway applications. Automated and robotic equipment can reduce the need to place highway personnel in the dangerous situations sometimes encountered in bridge inspection or maintenance and repair of facilities that are open to traffic. Better equipment can also speed construction and rehabilitation activities and increase the quality of some procedures. Sensing technologies can be used, as mentioned above, to monitor the physical condition of facilities (stresses and strains in a bridge or cracks in a pavement), their operational performance (the volume and speed of traffic or the length of a backup), or their condition due to inclement weather (the presence of snow or ice). These technologies can be used as well to determine the quality of newly constructed elements in the field, allowing facilities to be opened to traffic at the earliest opportunity (instead of relying on traditional testing methods that usually require a sample to be transported to a laboratory for testing before a facility can be opened).

Advances in data systems and analysis tools are also critical for addressing the challenges facing highway professionals. Much more efficient means of gathering, storing, analyzing, and communicating data have been developed. Agencies still face questions such as what data are needed, how often they should be updated, and how they can be used to benefit operational, environmental, engineering, and safety objectives. However, simulation and prediction models and various types of analytical tools, including some that use artificial intelligence techniques, are available to help address these issues.

Potential changes in vehicle technologies, driven by the energy and environmental concerns mentioned above, may have impacts on the highway system. Electric or hybrid vehicles may have infrastructure needs, including fueling and highway services, different from those of today's vehicles. Lighter lead acid batteries are being considered by some trucking firms as a cost-effective approach for weight reduction and improved fuel efficiency. Such vehicle and fuel developments may also influence revenues from fuel-based user fees, demand for freight movement by truck, and overall growth in VMT.

Study Approach

Overarching Theme

From the outset of this study, the F-SHRP committee recognized the central importance of meeting customer needs for any future program of strategic highway research. Accordingly, the committee articulated the following overarching theme for F-SHRP:

Providing outstanding customer service for the 21st century

This theme informed all of the committee's work, as well as the proposed research program that resulted from those efforts. Customer needs or requirements are invoked throughout the report in support of the committee's recommendations. Because it was not possible within the scope and resources of this study for the committee to conduct its own customer survey, the following sources were used as the basis for inferences regarding customer expectations:

- The FHWA customer survey summarized in Box 1-1 (FHWA 2001). This survey strongly supports the renewal and reliability strategic focus areas.
- Two studies of West Coast trucking firms (Regan and Golob 2000; Loudon and Layden 2000), which strongly support the reliability strategic focus area.
- Information derived from transportation agency personnel on the committee and through the outreach process. This input was assumed to reflect customer needs, at least indirectly. Frequently, respondents and committee members cited their own states' customer surveys, as well as input received through public involvement activities at the state level. These sources of customer input support all four strategic focus areas but reveal in particular customer interest in safety, aesthetics, additional capacity, and environmental and social concerns, which is reflected in the safety and capacity strategic focus areas.
- Committee members and members of the Research and Technology Coordinating Committee who represent user and customer groups, including motorists, truckers, and community and environmental interest groups. Information gathered from these sources support in particular customer needs in the safety, reliability, and capacity strategic focus areas.
- Committee judgment about future needs based on the trends summarized earlier, such as projected increases in VMT; patterns of population

growth; and trends in safety, technology, and the economy. Customer surveys may not reveal such future needs since they typically ask customers to comment on current conditions and immediate actions to be taken. The committee considered as part of its responsibility making judgments about future needs since the proposed research is intended to produce results for eventual implementation.

In addition, the renewal and reliability research programs described in Chapters 4 and 6, respectively, include identification of specific requirements for various types of highway customers among the recommended research tasks.

Overall Philosophy

In accordance with the committee's interpretation of the congressional request for this study (that the new program should replace or be similar to the first SHRP), the F-SHRP study approach adheres to the principal features of the SHRP model—a focused, time-constrained, management-driven program designed to complement existing research programs. As noted, the study approach is also based on a decidedly customer-oriented view of highway needs. In addition, the approach has the following characteristics:

- It addresses highway needs from a systems perspective.
- It is open to research in nontraditional highway-related areas.
- It explicitly acknowledges the interdependence of highway research and technology programs.

Each of these characteristics is described below.

Systems Approach

Highways are not isolated facilities. They form part of local, regional, and national highway systems and the global economy; they are an integral part of intermodal transportation systems; and they operate within a broader context, or system, of social, environmental, and economic issues. All of the challenges described above reflect the complexity of the systems within which highways are situated. Numerous stakeholders in the public and private sectors bring a wide variety of perspectives to these challenges. Many disciplines—engineering, environmental science, the social sciences, and law, to name a few—must be involved in finding solutions. The F-SHRP committee acknowledged this complexity both in its outreach process, which sought insights from a wide array of highway stakeholders (as discussed below), and in its choice of research topics for the program, each of which represents an attempt to take a broad view of the problems at hand, to apply a combination of tools and approaches, and to take a spectrum of potential impacts into account.

Nontraditional Research Areas

Traditional research for highways is typically in the areas of materials, design, roadside hardware, traffic operations, and planning. While the repertoire of highway research has broadened in recent years to include human factors, the environment, and other topics, some of these areas are still not well integrated into the set of tools used by highway professionals. In the research proposed for F-SHRP, some emphasis is given to areas that are relatively neglected by the highway community from a research point of view. These areas may be characterized as falling within the purview of business, economics, and other social sciences. For example, the proposed research on highway renewal and system reliability includes identifying customer performance requirements, relating these requirements to system performance, and quantifying and assessing user impacts. The proposed work on highway travel time reliability also includes study of the institutional issues that are so critical to highway operations, especially with regard to incident management and response. Research under the safety topic will need to address legal and privacy issues. And the proposed research on providing new capacity will address environmental and economic impacts and community involvement. Research on all four topics will need to address management and workforce issues as they relate to proposed solutions to major highway challenges.

Finally, the inclusion of these topics in a highway research program will necessitate the involvement of new players in developing and guiding the research and will draw new research talent from other fields into the highway arena. It may be hoped that the cross-pollination of ideas and experiences resulting from this approach will extend beyond the conduct of F-SHRP.

Interdependence of Highway Research and Technology Programs

The history of the highway system in the United States has been characterized by a steady flow of research and technology development that has supported national and local highway needs since the 19th century. The major programs involved in highway research and technology on an ongoing basis are the National Cooperative Highway Research Program (NCHRP); FHWA's research and technology program; state DOT research programs; and university transportation research programs. These programs have differing missions. With the exception of some of the university programs, which can be more focused, each must address a large number of issues to support highway agencies and cannot afford to focus all its resources on a small number of topics to the neglect of all others. The programs also focus on differing time frames: state DOTs tend to solve very short-term problems, while NCHRP and FHWA address issues that have relatively longer-term horizons. The types of work typically conducted differ as well: states do the most applied work, involving technology transfer and addressing state-specific operational needs; NCHRP addresses issues that are being faced by a large number of states; FHWA covers a broad range of disciplines and technologies focused on issues of national concern; and universities perform independent research, as well as research in cooperation with the other programs. Corresponding to these differences in type of work and time horizon are differences in stakeholders and in the amount of resources and types of expertise required.

One of the lessons from SHRP was that an occasional infusion of additional resources into a focused, independent research program can accelerate significant improvements in strategically chosen areas. An earlier example of this approach is the American Association of State Highway Officials (AASHO) Road Test, performed in the late 1950s, under which the pavement design standards for the Interstate highway system were developed. This model is implicitly founded on the existence of the ongoing highway research programs mentioned above that advance the state of the art, although at a more moderate pace, across a broader spectrum of highway needs. The missions of these programs are not altered by the existence of selected high-profile, focused programs. Pavement and bridge research, for example, did not cease to be conducted by NCHRP, FHWA, state DOTs, and universities simply because SHRP focused some additional resources on particular aspects of this research. Many infrastructure issues not addressed by SHRP continued to be pursued by these other programs, and dozens of other areas not covered by SHRP were advanced.

Just as neither SHRP nor the AASHO Road Test obviated the need for the various ongoing programs, F-SHRP is not in competition with the latter programs; it thereby adheres to the program model discussed earlier in complementing existing highway research. In fact, while all of the research topics proposed for F-SHRP are broad and integrated in nature, each is highly dependent on the vitality of established highway research and technology programs for many of the technical elements of the solutions to be sought. In many cases, F-SHRP will perform only selected types of research whose results will be integrated with the products of other programs to accelerate the latter's effective implementation. Chapters 4 through 7, describing the four F-SHRP research topics, delineate this approach in more detail.

Outreach and Information Gathering

One of the first priorities of the F-SHRP committee was to gather as much input as possible from the highway community. There were several reasons for developing a comprehensive outreach and information-gathering plan for this study. First, because of the success of the first SHRP (see Chapter 2), expectations for and interest in this project are high; people want to be informed about the study and to have the opportunity to provide input. Second, a potentially wide range of research topics was under consideration; expertise in many more areas than could be represented on a committee was required to make effective decisions about the topics to be included in the program. Third, the impact of the committee's recommendations is potentially quite broad: highway owners, builders, users, regulators, suppliers, and others will all be affected by the results of the program.

The outreach process had three main objectives: to identify strategic highway needs that can be advanced by research, to develop a research program that can address those needs, and to build support for the program by achieving consensus on needs and by soliciting stakeholder involvement in the process of program development. The first two objectives pertain to the types of information sought directly by the committee; the third is a more indirect, but nonetheless critical, result of an effective outreach program.

In addition to the research topics to be included in F-SHRP, the committee received input on appropriate criteria for screening proposed research topics. Input was obtained as well on administrative and funding aspects of the proposed research program.

The outreach process was conducted in three stages:

Stage 1—Develop the themes of the research program. This was the broadest level of outreach, in which input was sought across the highway stakeholder community to help identify strategic areas of focus for the proposed research program. Approximately 700 letters were sent to public, private, and academic organizations to solicit their input. Nearly 50 presentations on the F-SHRP development effort were made to various stakeholder groups, and 25 presentations on strategic highway needs were made by stakeholders at committee meetings. An interactive website was also established so that input could be provided electronically and stakeholders could track the study's progress. Approximately 120 formal responses were received. The input obtained during this first stage served as the foundation for the vision, overarching theme, and strategic focus areas of F-SHRP.

Stage 2—Identify the specific research programs within the strategic focus areas. In this stage, input was sought from technical experts on specific types of research that would best address the strategic focus areas. Again, public, private, and academic input was solicited—from American Association of State Highway and Transportation Officials (AASHTO) committees; TRB technical committees; the working groups of the National Research and Technology (R&T) Partnership Forum;[7] and technical experts representing universities, industry, private consultants, and federal agencies. The result of this stage was a reduced number of research program areas from which the F-SHRP committee formulated its recommendations.

Stage 3—Broadly define the research agenda. This stage was even more focused as it contributed to the agenda under each research program. Input for this stage was received through small meetings, focus groups, and e-mail exchanges. The results of this stage helped the committee define the research programs proposed in this report.

All told, more than 240 individuals and groups representing thousands of highway stakeholders responded in some way to the outreach efforts. More detail on the outreach process can be found in Appendix A.

[7] The National R&T Partnership Forum is an ad hoc effort by AASHTO, FHWA, TRB, and other highway stakeholders to develop a comprehensive agenda of highway research and technology needs. Five working groups were formed to address safety, infrastructure, planning and environment, operations, and policy and system monitoring. The F-SHRP outreach effort was conducted in close cooperation with these working groups, which provided valuable input. While the Partnership Forum focuses more on influencing established highway research programs, the research topics proposed by F-SHRP nevertheless reflect the priorities identified by the Forum's stakeholders, addressing these priorities through research efforts more in line with the SHRP model discussed in this report. For more information about the R&T Partnership Forum and the priorities it identified, see "R&T Forum" at www.TRB.org.

Development of Selection Criteria

Many avenues of research could be pursued to support the vision and strategic focus areas arising from the outreach process described above. Following the SHRP model and adding some further considerations, the committee developed a set of criteria to help select among hundreds of excellent research ideas. These criteria were used at each stage of the outreach process: to develop strategic focus areas in Stage 1; to narrow down the specific research topics in Stage 2; and to guide the development of the research agenda in Stage 3. The major steps in the development of the strategic focus areas and research topics are documented in Appendix B. Three categories of criteria were used:

1. Significance of the issue
   - The research addresses one or more national transportation goals: safety, mobility, economic growth and trade, human and natural environment, and national security.
   - It reflects a major concern of state DOTs and other state and local agencies that will continue well into the future.
2. Appropriateness for a SHRP-style research program
   - A research program of critical mass and continuity is necessary to achieve the program goals.
   - An integrated systems approach is needed, involving multiple players (industry, government, academia) and issues (technology, aesthetics, management, institutional issues).
   - The area is receiving insufficient attention (in scope or scale) in existing research programs because of a lack of funding, incompatibility with the missions of those programs, or other institutional constraints.
   - The area has a significant component of public-sector responsibility.
3. Effectiveness or expected impact of the research
   - There is a reasonable prospect for significant improvements, rather than just incremental improvements, from the research.
   - Results are likely to have a major impact (benefit/cost) if successful.
   - Research results would be forthcoming within a reasonable time frame.
   - Barriers to innovation are likely to yield to implementation efforts within a realistic time frame.
   - The research community has the potential to address the topic.

– The implementing community has the potential to implement the results of the research (including the capacity to cooperate at the research and development stage to the extent necessary for effective implementation).

Organization of This Report

Historical background on SHRP, a brief analysis of its success, and a summary of lessons learned from the program are provided in Chapter 2. A brief review of the results of the committee's study, including a general description of the overall proposed research program, its strategic vision and focus areas, and the four component research programs, is presented in Chapter 3. In Chapters 4 through 7 the component research programs are described in more detail, including the challenges that must be addressed for each, a general outline of the research tasks, and other considerations for the effective conduct and implementation of the research. The administration and funding of the overall program are addressed in Chapter 8. Finally, the committee's recommendations are presented in Chapter 9.

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ABBREVIATIONS
AASHO American Association of State Highway Officials
DOT U.S. Department of Transportation
NAP National Academy Press
TRB Transportation Research Board

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CHAPTER 2

The First Strategic Highway Research Program

In the early 1980s, highway research was extremely underfunded as compared with other industries. Most highway research was funded by federal and state agencies and performed in relatively small programs at the federal and state levels, at universities, and in some private-sector firms and associations. The major highway research programs were (and still are) those of FHWA; the individual state DOTs; and NCHRP, in which the state DOTs pool some of their research funds to address problems of mutual concern. Each of these programs addresses a wide variety of research in support of the missions of the sponsoring agencies (see Chapter 1). Their research agendas are determined largely through a bottom-up process in which technical experts in each area work together to identify the most important research needs in that area, and submit these needs to a management or decision-making body that allocates the available research funding. This approach ensures that each of the many disciplines that support the highway enterprise (such as structural and pavement design, materials engineering, hydraulics, safety, and numerous others) receives attention in the research agendas. However, it also means that these programs have difficulty tackling large, multifaceted problems requiring a large and consistent flow of resources over several years.

During this period, state DOTs faced several problems of this sort. The quality of asphalt and the integrity and longevity of pavements, for instance, were major problems. The economic and highway safety and overall impacts of winter storms affected almost every state. Concrete bridge decks and other bridge components were deteriorating prematurely for reasons that were not entirely clear. Several reports drawing attention to the deteriorating condition of America's infrastructure were widely publicized and moved highway officials to address the problem actively. Although existing research programs were focused on aspects of these problems, none could concentrate sufficient resources to produce implementable solutions in an accelerated time frame.

A small group of leaders from within highway agencies and the transportation research community began to articulate an approach to address this situation, consisting of a highly focused, time-constrained research program aimed at critical needs recognized by those within the highway industry, particularly the state DOTs. This approach was designed to complement existing research programs by utilizing additional funding over a prescribed time frame. The other programs would continue to pursue their broad mission-oriented agendas, coordinating with the new program as appropriate.

The Strategic Transportation Research Study

The new program was described in *Special Report 202: America's Highways: Accelerating the Search for Innovation* (TRB 1984), also known as the Strategic Transportation Research Study or the STRS ("Stars") report. A steering committee of highway leaders, much like the F-SHRP committee, directed the STRS work. The committee focused on developing a national research program aimed at high priorities that were not being adequately addressed by existing programs. They compared the distribution of highway agency expenditures with that of highway research expenditures to identify research areas that were being neglected relative to their importance to the agencies. Materials, paving technology, and maintenance emerged as areas of high agency investment that were being relatively neglected in research. The committee chose six research areas in which focused, accelerated, results-oriented research promised significant benefits. These areas are listed below, along with the research objective cited in the STRS report for each (TRB 1984):

- Asphalt—"Objective: To improve pavement performance through a research program that will provide increased understanding of the chemical and physical properties of asphalt cements and asphalt concretes. The research results would be used to develop specifications, tests, and construction procedures needed to achieve and control the pavement performance desired."
- Long-term pavement performance (LTPP)—"Objective: [To] increase pavement life by the investigation of long-term performance of various designs of pavement structures and rehabilitated pavement structures, using different materials and under different loads, environments, subgrade soils, and maintenance practices."
- Maintenance cost-effectiveness—"Objective: To improve the cost-effectiveness of maintenance through research that will provide technologi-

cal improvements in equipment, materials, and processes and will improve the administration of maintenance programs, in the areas of budget development, program management, and resource allocation."

- Protection of concrete bridge components—"Objective: To prevent the deterioration of chloride-contaminated concrete components in existing bridges and to protect new, uncontaminated bridge components from chlorides."
- Cement and concrete in highway pavements and structures—"Objective: To improve the economy, versatility, and durability of concrete in highway pavements and structures through an increased understanding of the chemistry of cement hydration and the properties of concrete."
- Chemical control of snow and ice on highways—"Objective: To avoid costly deterioration of bridges, pavements, and vehicles and other adverse environmental effects by reducing the dependence on chlorides for snow and ice control; improving mechanical, thermal, and other removal techniques; and producing environmentally safe alternative chemicals."

The committee recommended that $150 million be spent over 5 years, funded by 0.25 percent of federal-aid highway funds. The committee also presented a brief assessment of several administrative options under which the proposed program could be managed.

Transition from STRS to SHRP

The STRS report provided a vision of a focused, management-driven, time-constrained research program and a general outline of what needed to be done in each of the above six research areas. However, substantial work was needed to translate this vision and outline into the detailed plans required to execute a research program.

NCHRP and FHWA provided funds to conduct the interim planning activities (called "pre-implementation" at the time). This effort was led by an interim executive director and was performed by contractors who worked under the guidance of a committee structure. In all, more than 200 individuals representing major highway stakeholder groups were involved in the pre-implementation efforts in the course of less than 2 years. The result of their work was the final report *Strategic Highway Research Program: Research Plans* (TRB 1986).

At the same time, AASHTO agreed to a 0.25 percent "takedown" from the federal-aid highway funds to carry out the research program during the 5-year period to be covered by the 1987 highway authorizing legislation. Since this money would otherwise have gone to the states for their highway construction programs, state DOT support for the research program and its funding mechanism was an essential requirement for the program to go forward. AASHTO also supported the establishment of a new unit of the National Research Council (NRC) to carry out the program. Legislative language was subsequently developed to support these decisions.

Strategic Highway Research Program

In 1987 Congress passed the Surface Transportation and Uniform Relocation Act, which authorized SHRP. The program content and funding amount and source followed the recommendations of the STRS report.[1] The administrative structure followed the recommendations of the *Research Plans* report; that is, it became a new unit of NRC. An executive director and additional management and technical staff were recruited or borrowed from other organizations. Thus SHRP began.

An extensive committee structure continued to guide the SHRP work. Overall guidance was provided by an executive committee with 14 members (plus ex officio members), including chief executive officers and chief engineers from AASHTO member departments and other representatives of the private and academic sectors. The six major research areas were condensed to four, and an advisory committee was formed for each. Expert task groups reviewed research proposals and provided advice to the executive committee, which made final decisions about contract awards.

Close cooperation with AASHTO leadership and other stakeholders was a salient feature of SHRP during both the research phase and the subsequent implementation phase. SHRP research or implementation was regularly on the agenda of the AASHTO Board of Directors and the Standing Committee on Highways at their semiannual meetings. The SHRP newsletter, *Focus,* was widely distributed to the highway community.

SHRP developed a large number of "products." The following are examples of these products:

- Asphalt—The best-known product of SHRP is Superpave®, which is actually a system involving a large number of individual SHRP products.

[1] Specifically, the funding was a takedown of 0.25 percent from all programs apportioned to the states, before the apportionment was made.

Superpave allows pavement designers to tailor asphalt mixes to specific traffic loads and climates, thus producing pavements that are more durable and less likely to rut in extremely hot weather or to crack in extremely cold weather. The Superpave system consists of three elements: a process for selecting the most appropriate asphalt binder, a laboratory procedure for optimizing the mix design, and tests for predicting how well the mix will perform in real-world conditions.

- Maintenance cost-effectiveness—Asphalt and concrete pavement repair methods and materials were evaluated, and manuals and guidelines for pavement repairs that are durable and cost-effective were produced.
- Cement and concrete in highway pavements and structures—Improved concrete materials for bridges and pavements, methods for protecting reinforcing bars from corrosion, and new test methods and guidelines for increasing the service life of concrete pavements and structures were evaluated and developed.
- Chemical control of snow and ice on highways—An approach to winter maintenance that involves a combination of anti-icing strategies and road weather information systems (RWIS) was promoted. Anti-icing involves treating the pavement with salt or other chemicals that lower the freezing point of water prior to a storm to prevent ice from forming on the pavement. RWIS is a network of sensors that lets the agency know pavement and atmospheric conditions; temperature; rate of snowfall, rain, or sleet; and amount of chemicals remaining on the pavement from previous applications. This system allows the agency to be prepared for storms and to deploy materials, crews, and equipment in appropriate amounts.
- Work zone safety—Several products resulted from SHRP research on work zone safety, including a flashing stop/slow paddle, opposing traffic lane divider, direction indicator barricade, truck-mounted attenuator for chemical spreaders, queue detector, intrusion alarm, portable rumble strip, and all-terrain sign and stand. These products help protect both workers and motorists by warning workers of vehicles that may enter a work zone and helping motorists navigate through the zone.

SHRP Implementation

SHRP was designed to be a focused, short-term research program, performed by a special-purpose organization that would cease to exist once its mission had been accomplished. To gain the intended practical benefits from any research program, however, many implementation activities are required. Little funding for implementation was budgeted in the SHRP program; funding for significant implementation activities required additional legislation.

In December 1991, Congress passed the Intermodal Surface Transportation Efficiency Act (ISTEA), which included special funding for SHRP implementation. This funding was administered by FHWA, and coordination and oversight of SHRP implementation activities became a major focus of the agency's technology transfer activities. In addition to ISTEA funding specifically allocated for SHRP implementation, many states used a portion of their State Planning and Research funds, state funds, and in-kind activities to support SHRP implementation. Rough estimates indicate that these direct state contributions to SHRP implementation at least matched the investments provided for in ISTEA. In addition, industry was actively involved in SHRP implementation activities. Highlights of SHRP implementation activities include the following initiatives:

- SHRP and LTPP state coordinators, who continue to coordinate the implementation of SHRP and the execution of LTPP in their respective states;
- Staff loaned by state DOTs to the SHRP program;
- AASHTO's efforts to develop specifications for SHRP products;
- The Lead States program, in which a small number of states became proficient with particular SHRP technologies and then coached other states to facilitate their implementation efforts;
- The AASHTO SHRP Implementation Task Force, which was so successful that it was leveraged into a new Senior-Level AASHTO Steering Group for Technology Deployment; and
- The TRB Superpave and LTPP Committees, which provide stakeholder and peer review of the technical development of these two components of SHRP.

Assessment of SHRP

Benefits

The best indicators of the success of SHRP are the extent and pace of implementation of SHRP results and the consequent impact on the condition and operation of the nation's highway system. In 1997, the Texas Transportation Institute (TTI) estimated potential benefits from SHRP based on various implementation scenarios (Little et al. 1997).[2] Box 2-1 shows ranges of benefit/cost ratios projected by the TTI study. In addition, FHWA conducted a study in which state DOTs were surveyed about actual benefits received from implementation of SHRP products. The following examples are taken from the results of these studies and from additional interviews.

Asphalt

In 1999, 45 percent of the hot-mix asphalt tonnage in the nation (on state roads and in the District of Columbia and Puerto Rico) was designed to the Superpave standards developed under SHRP (Mack and Dunn 2000).[3]

Box 2-1

Estimated Benefits of SHRP Projects

TTI projected the following benefits to transportation agencies and to users from implementation of SHRP products. The numbers shown represent dollars of benefit for each dollar invested in research, development, and implementation.

Asphalt products (Superpave):	26–43 for agencies
	72–116 for users
Snow and ice control products:	15–29 for agencies
	62–124 for users
Six selected concrete products:	1–3 for agencies (benefits to users not estimated)
Portland cement concrete pavements:	3–11 for agencies
	9–33 for users
Pavement maintenance products:	36–131 for agencies
	47–173 for users
Work zone safety products:	1–2 for agencies
	6–12 for users

Source: Little et al. (1997).

[2] The TTI study of economic benefits used a 20-year analysis period and projected savings or benefits for "slow," "moderate," and "fast" implementation scenarios. The analyses for each category of SHRP projects involved different sets of assumptions, which can be found in the study itself or in the *RoadSavers* series (FHWA 1997).

[3] This degree of research implementation so soon after research results became available and in the absence of any regulatory mandate is unusual in the highway industry for several reasons, such as the decentralized and fragmented nature of the industry, the procurement systems generally used in the public sector, risk aversion, and other institutional issues (Bernstein and Lemer 1996; TRB 1998; TRB 1994; TRB 1996; Brach 1999).

Superpave is expected to increase the life of an asphalt overlay from approximately 8 to approximately 12 years. This increased life means agency savings from reduced pavement maintenance and rehabilitation, and user savings from both smoother pavements (which reduce fuel consumption and vehicle wear and tear) and fewer traffic disruptions from road work. The TTI analysis projected annual highway agency savings nationally of almost $750 million if Superpave were fully and quickly implemented.[4] Projected annual user savings (reduced delay because of fewer pavement repairs and reduced vehicle operating costs because of smoother pavements) were estimated at more than $2 billion nationwide. Pavement management has evolved to a much more sophisticated level as a result of the states' participation in SHRP. Improved pavement management means states are making better decisions about the types and timing of pavement maintenance and rehabilitation activities, and the ultimate result is more efficient use of public funds and higher-quality roads.

Maintenance Cost-Effectiveness

The TTI analysis projected that state and local highway agencies collectively could save $24 million to $89 million per year in pothole repair costs, depending on how quickly they implemented the associated SHRP products. Pavement preservation techniques were projected to yield nationwide annual savings to highway agencies of $102 million to $385 million, depending on how quickly the new preventive maintenance strategies were adopted. Motorists would face fewer delays and less wear and tear on vehicles and could thus save $167 million to $627 million annually in user costs. South Carolina found that the spray-injection pothole repair method evaluated by SHRP takes less time, requires fewer workers, and lasts longer than the state's traditional method.[5] North Carolina expects the crack-sealing method endorsed by SHRP to increase the life of crack seals by 40 percent—from 5 to 7 years.

Cement and Concrete in Highway Pavements and Structures

On the basis of six of the SHRP products in this category, TTI forecast potential savings to highway agencies nationwide of $4.1 million to $15.5 million per year (over a 20-year period), depending on the pace of implementation.

[4] For this projection, the study assumed a more conservative increase in pavement life from 8 to 10 years, rather than 12 years.

[5] State-specific examples of successful implementation of SHRP products are from the RoadSavers website: www.fhwa.dot.gov/winter/roadsvr/casehome.htm.

These savings would result from lower testing and maintenance costs and extended service life. Alaska saves $1,400 per bridge using a new test for evaluating chloride content. In a year and a half, this test saved the state $95,000. Idaho gets rapid results from a new test designed to detect alkali-silica reactivity, which causes severe cracking in concrete, at about one-tenth the cost of old tests. Oregon has preserved three landmark bridges and saved $50 million using cathodic protection technology evaluated by SHRP. Electrochemical chloride extraction, another test evaluated by SHRP, has increased the lives of two Virginia bridges by 12 to 15 years at a lower cost and with less disruption as compared with replacement or rehabilitation. A SHRP-developed specification for high-performance concrete (HPC) encouraged the use of this material on bridges, allowing them to be built lighter and stronger. Dozens of bridges have been built with HPC to date. There are several potential benefits: in some cases there are overall savings in materials since less HPC is required in comparison with ordinary concrete; longer spans mean fewer bridge piers, which can pose obstructions to rivers, traffic, and environmentally sensitive areas beneath the bridge; and lighter bridge decks, for example, can allow older bridges to be rehabilitated without the need for weight restrictions, which can be an impediment to commercial traffic.

Chemical Control of Snow and Ice on Highways

Winter maintenance activities (snow and ice control) have changed radically as a result of SHRP. New technologies and methods have resulted in direct savings to highway agencies from reduced personnel and material requirements. Users and communities have avoided billions of dollars in economic losses because their highways have remained open during storms or been quickly returned to operation if closed. In addition, improved winter maintenance techniques can reduce the use of salt and abrasives, thereby minimizing environmental impacts. Estimated savings per agency are $1,300 to $30,000 per truck route,[6] depending on the severity of the storm. User savings from increased safety (reduced accident costs) are estimated to range from $12,000 to $107,000 per truck route. Nevada expects its expanding

[6] "Truck route" refers to the segmentation of the highway network that agencies use to deploy equipment for winter maintenance efficiently and effectively. Usually a truck equipped with a plow and/or anti-icing or deicing materials is assigned to a specific route on the network. This route often forms the basis for winter maintenance budgeting and is therefore a reasonable unit of analysis for calculating benefits from SHRP winter maintenance products.

RWIS network to provide motorists and shippers with safer, more reliable travel conditions; save $7 million in labor, materials, and other costs during the next 25 years; and protect the environment by reducing the amount of chemicals and abrasives used. In Colorado, an anti-icing/RWIS strategy is helping to improve air quality by reducing the use of sand and other abrasives, which are responsible for about 20 percent of Denver's persistent winter air quality problems.

Work Zone Safety
In addition to saving lives, the work zone safety devices developed under SHRP save money. Experts in the TTI study estimated that use of the flashing stop/slow paddle and the opposing traffic lane divider alone could reduce work zone crashes by approximately 5 percent, leading to nationwide annual savings of $2.1 million to $4.1 million for agencies and $15 million to $30 million for highway users.

Success Factors

Early in the present study, the F-SHRP committee invited individuals familiar with SHRP to share their experiences and assessment of the program. From these discussions and from the broad outreach process described in Chapter 1, the following were identified as success factors for SHRP:

- SHRP focused on a small number of high-priority national needs.
- SHRP complemented existing programs instead of competing with them.
- The administrative structure of the program encouraged accelerated research within a fixed time frame; kept the work from being caught up in the politics or bureaucracy of any existing program or organization; and avoided any incentive to establish a longer-term interest for those involved, which could have had an adverse influence on the conduct of the research.
- The program was founded on a clear vision of the importance of research for the vitality of the highway industry and society and on the argument that research funding for highways was extremely inadequate in comparison with funding for other industries and with highway research funding in other countries.
- The program was carried out through a process involving clear stakeholder—especially state—ownership. State DOT personnel chaired and served on SHRP committees, and DOTs were permitted to spend federal-aid money on SHRP implementation.

- Close cooperation with industry was a key feature of SHRP. Industry members served on the executive committee and various technical committees and participated in pilot tests and training.
- SHRP was a centrally administered program, but the individual research projects were awarded on a competitive basis through a process that was open to all qualified researchers.
- The research proposals were reviewed by experts to ensure that the highest-quality proposals would be selected.
- The program and administrative structure allowed sufficient flexibility to implement midcourse corrections to the research plan on the basis of interim results. The willingness and ability to change course when confronted with compelling evidence kept the program focused on achieving results more than on fulfilling plans.

Lessons Learned

It is important to review the SHRP experience to find ways of duplicating its successes and avoiding its problems. Assessment of the SHRP experience yields some important lessons that the F-SHRP committee attempted to apply in carrying out this study. Among these lessons are the following:

- Relatively few individuals were directly involved with the STRS study, which led to the conceptual design for SHRP. While this situation was appropriate at the time, especially given the innovative nature of the STRS approach, the very success of SHRP necessitates broader involvement in the development of F-SHRP. This is the case because many in the highway community who were not involved in SHRP are now aware of the potential impacts of such a program and are interested in contributing to its direction. For this reason, the F-SHRP committee engaged in an extensive outreach process for almost 2 years to obtain as much input as possible from across the spectrum of highway stakeholders (see Chapter 1 and Appendix A).
- Implementation of research results and the significant funding required for this purpose were not incorporated in SHRP itself, but were seen as a future need to be met as products became available. In addition, no particular party was assigned responsibility for implementation. SHRP assumed this responsibility during the second half of the research phase, in coordination with a number of FHWA programs. FHWA expanded this responsibility and received legislative funding for the purpose as the SHRP research phase was ending. While it is unrealistic to assume in advance that

each research activity will yield a product meriting an organized implementation effort, it is important for the overall program to have the resources required to proceed with vigorous implementation when warranted. Implementation issues are addressed in more detail in Chapter 8.

• While the establishment of a new organization to run SHRP had many benefits, the time and costs associated with start-up and close-down of the SHRP organization introduced some inefficiencies. This concern is addressed in the discussion of administrative structure in Chapter 8.

Concluding Comments

In summary, the SHRP experience demonstrated that a focused, time-constrained research program can be a highly effective complement to existing traditional highway research programs. While the latter programs address a wide variety of needs, continually moving the highway industry forward, the occasional concentration of additional resources in a few strategic focus areas can accelerate progress toward implementable solutions and advance the state of the art for the entire industry. In this report, the F-SHRP committee recommends a program of research and technology that can provide solutions for some of the most pressing problems faced by the highway community now and well into the future.

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ABBREVIATIONS

FHWA	Federal Highway Administration
TRB	Transportation Research Board

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ABBREVIATIONS

FHWA	Federal Highway Administration
NCHRP	National Cooperative Highway Research Program
SHRP	Strategic Highway Research Program
TRB	Transportation Research Board

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CHAPTER 3 A Future Strategic Highway Research Program: Overview

The outcome of the F-SHRP committee's study confirms the need for a future strategic highway research program, as requested by Congress. Both the context described in Chapter 1 and the results of the committee's outreach process clearly reveal the many significant issues facing the highway industry now and into the next two decades—issues often characterized by two or more significant trends that in concert produce a challenge that cannot be addressed without raising the industry's response to a higher plane. For example, the increasing number of highway facilities in need of major renewal, together with decreasing economic and social tolerance for disruptions resulting from renewal work, requires that highway agencies undertake such renewal in a manner that is more responsive to user concerns. Increases in vehicle-miles traveled, along with inadequately decreasing fatality and injury rates, necessitate entirely new approaches to highway safety to prevent the number of deaths and injuries from rising. Growing congestion and the consequent increase in the impact of incidents on reliability, combined with greater user demand for travel time reliability, make incident management and response a more critical element of highway operations. And demand for more and more quickly provided capacity in the context of increasingly stringent environmental and social requirements calls for an altogether new way of planning and designing highways.

Developments in several areas of research and technology, discussed in the previous chapter, offer opportunities to address the above issues if sufficient resources can be concentrated within a relatively short time frame. The fact that these opportunities exist is due to decades of research in fields outside the highway enterprise and to the further development of these ideas and technologies by traditional highway research and technology programs. However, these traditional programs are usually unable to dedicate sufficient resources to a few well-defined problems of large magnitude over a relatively short period of time. This kind of intense, large-scale focus, requiring the integration of multiple fields of research and technology, is not suited to the broad, mission-oriented, discipline-based research programs that have been the mainstay of the highway industry for half a century.

Given these considerations—significant highway needs, opportunities provided by research and technology, and constraints on existing research programs—the committee concludes that a large-scale, special-purpose, time-constrained research program is justified if the highway industry is to meet its customers' demands over the next several decades. The success of this approach in the first SHRP reinforces the committee's conclusion. The proposed program should be problem-oriented rather than discipline-oriented; it should include close attention to implementation considerations from its initiation; and it should possess the characteristics and meet the criteria described in Chapter 1.

In the remainder of this chapter, the vision guiding the development of the proposed research program is presented, and an overview is provided of the strategic focus areas resulting from the outreach process described in Chapter 1 and the overall goals of the four proposed research programs. The four programs are then described in detail in Chapters 4 through 7.

Vision

One of the results of the F-SHRP outreach process was the committee's development of a vision for the highway system that captures the aspirations expressed by the outreach respondents. This vision guided the development of the F-SHRP program:

> *A highway system that actively contributes to improved quality of life for all Americans by providing safe, efficient mobility in an economically, socially, and environmentally responsible manner.*

This vision arises from a recognition that the mobility of persons and goods is a key part of the foundation of the nation's economic system and quality of life, that the highway system has historically played a critical role in providing mobility and fostering economic growth, and that this system promises still further advancement for all citizens.

Strategic Focus Areas and Proposed Research Programs

To realize the above vision, the committee contemplates the creation of a research program that, when implemented, will lead to measurable improvement in the overall responsiveness of the highway system. Building on the results of the outreach process and using the selection criteria outlined in Chapter 1, the committee established four strategic focus areas for F-SHRP:

- *Renewal*—Accelerate the renewal of America's highways. The overall goal of this research is to develop a consistent, systematic approach to performing highway renewal that is rapid, causes minimum disruption, and produces long-lived facilities (see Chapter 4).
- *Safety*—Make a significant improvement in highway safety. The overall goal of this research is to prevent or reduce the severity of highway crashes through more accurate knowledge of crash factors and of the cost-effectiveness of selected countermeasures in addressing these factors (see Chapter 5).
- *Reliability*—Provide a highway system with reliable travel times. The overall goal of this research is to provide highway users with reliable travel times by preventing and reducing the impact of nonrecurring incidents (see Chapter 6).
- *Capacity*—Provide highway capacity in support of the nation's economic, environmental, and social goals. The overall goal of this research is to develop approaches and tools for systematically integrating environmental, economic, and community requirements into the analysis, planning, and design of new highway capacity (see Chapter 7).

In this report, strategic highway problems and promising avenues of research and technology for addressing these problems are identified. Detailed research plans are not proposed; instead, overall direction for those who may be charged with developing such plans is provided. The committee recommends that an interim planning stage take place between the publication of this report and the commencement of the research program (see Chapter 8). In the event that such an interim effort cannot be carried out, it will need to be the first step taken once the research has been funded. The descriptions of the four research programs in Chapter 4 through 7 are intended to keep such a planning effort focused on the identified strategic needs, without unduly constraining researchers and research managers in exploring and developing the most promising research tasks and technologies.

CHAPTER 4

Renewal: Accelerating the Renewal of America's Highways

Overall research program goal: To develop a consistent, systematic approach to performing highway renewal that is rapid, causes minimum disruption, and produces long-lived facilities.

Challenge of Highway Renewal

America's highway system comprises more than 3.9 million miles of highways, arterials, local roads, and streets (FHWA 2001, Table VM-2). These roads are critical to meeting the mobility and economic needs of local communities, regions, and the nation as a whole. They carry more than 90 percent of passenger trips (BTS 1999b, p. 14) and 69 percent of freight value (BTS 1999a, Table 1-43). In additional to commercial and private vehicles, they accommodate buses, bicycles, and pedestrians. They also provide vital links to all other modes of transportation, so that the influence of their physical and operational condition extends well beyond the impacts experienced directly by highway users.

Overall Challenge

The Interstate highway system—which accounts for about 2.5 percent of total lane-miles (BTS 1999a, Table 1-5) but 23 percent of vehicle-miles traveled (VMT) (BTS 1999a, Table 1-29)—was built primarily during the 1960s and 1970s and is approaching or has exceeded its design life. Significant portions of the system are carrying traffic well in excess of their design capacity. Other classes of roads, particularly urban street networks and urban arterials in heavily congested areas, face a similar predicament. Therefore, the renewal of roads so that the highway system can continue to provide its intended economic and social benefits is a pressing local and national concern. As noted, however, it is precisely because of the important role of the highway system that renewal work must usually be done while facilities remain in use or with as little closure as possible. In the short term, while critical renewal activities are being carried out, users will experience disruption. The challenge is finding a way to achieve the much-needed infrastructure renewal with as little disruption as possible. Examples of the criticality of this issue exist throughout the country; Box 4-1 describes one example—the southeast freeway system in Wisconsin.

The challenge of highway renewal has been the subject of a number of workshops and industry task forces. Among the most notable are the 1998 Workshop on Pavement Renewal for Urban Freeways, sponsored by FHWA, the California Department of Transportation, and TRB, during which workshop participants developed alternative approaches to a real urban freeway renewal project on California's Interstate 710 (see Box 4-2), and the TRB Task Force on Accelerating Opportunities for Innovation in the Highway Industry, which has chosen accelerated highway construction as the first focus of its efforts.[1]

Renewal is not limited to restoring roads to their original design characteristics; it frequently means meeting even higher customer demand. Although demands on the highway system have grown significantly, very little new capacity has been provided. VMT on the nation's highways increased by 76 percent between 1980 and 1999 [FHWA 2001, Tables VM-202 (1980–1995) and VM-2 (1996–1999)], whereas the capacity of the system in lane-miles increased by only 3 percent [BTS 1999a, Table 1-5 (1908–1995); FHWA 2001, Table HM-60 (1996–1999)]. While relatively little additional capacity is planned for the next two decades, significant growth in highway demand is expected to continue. As mentioned in Chapter 1, VMT is projected to increase 50 percent by 2020. In the same time frame, truck volume is projected to double from 8.0 billion tons in 1998 to 16.8 billion tons.[2] Not only has highway demand increased quantitatively, but customer expectations have changed in nature during the last several years. The public wants roads that not only are smooth and safe, but also support community goals, enhance the

[1] This task force was formed in response to a recommendation in *Special Report 249: Building Momentum for Change* (TRB 1996). The purpose of the task force is to accelerate opportunities to implement innovations in the highway industry by advocating continuous improvement, facilitating removal of barriers to innovation, encouraging development of beneficial strategies, and creating a framework for informed consideration of innovation. The task force's first workshop, on the topic of accelerated construction, was held November 16–17, 2000.

[2] Results of FHWA study, presentation available at www.ops.fhwa.dot.gov/freight/wefa.ppt (Slide 18).

Box 4-1

Southeast Freeway System, Wisconsin

The freeway system in southern Wisconsin represents only 8 percent of the state's road miles, but 36 percent of weekday vehicle-miles traveled. Most of the system was built 30 or more years ago and is very much in need of rehabilitation or reconstruction. However, it is critical to keep this system operating: almost 60 percent of Wisconsin's residents live in eastern counties served by these roads; 65 percent of the state's manufacturing jobs are in the area; and southeastern freeways provide intermodal connections to General Mitchell International Airport, the Milwaukee Amtrak depot, and the Port of Milwaukee, while also serving as an important tourist connection. The Marquette Interchange in Milwaukee, a particularly important component of the freeway system, is deteriorating as a result of high traffic volumes, today's heavier vehicles, road salt, and studded tires. An outdated design, ill-suited to the current types and volumes of vehicles, has led to serious safety concerns. However, the interchange links three Interstate highways and carries more than 300,000 vehicles per day. This kind of situation is found throughout the country and calls for serious attention to new ways of providing for freeway renewal.

Source: Wisconsin Department of Transportation (2001).

Box 4-2

Get In, Get Out, Stay Out! Workshop on Pavement Renewal for Urban Freeways, California

In February 1998, 44 highway system experts—designers, contractors, construction managers, maintenance engineers, traffic managers, and senior engineering officials—gathered in Irvine, California, to develop innovative approaches to urban freeway renewal. Workshop participants were presented with a real renewal project: the Long Beach Freeway (Interstate 710) in southern California. Each of four teams had to develop a renewal plan that met the following criteria: long service life, minimal traffic disruption, a safer environment for workers and highway users, minimal short- and long-term user costs and life-cycle costs to the agency,

(*continued*)

Box 4-2 (*continued*) **Get In, Get Out, Stay Out! Workshop**

and minimal community and environmental impacts. In addition, participants were asked to identify research and technology development needs. All teams produced innovative and realistic approaches to renewing the Long Beach Freeway. Workshop participants identified research and technology needs in the following areas: highway materials, pavement design, traffic management, traffic operations and work zone traffic control, economics and finance, nondestructive evaluation, construction equipment, and approaches to dealing with overpass structures.

Ideas from this workshop are being employed in several projects in California:

- A trial of rapid renewal techniques on Interstate 10—replacing a lane with high-performance concrete in 55 hours over one weekend—used public awareness techniques and an ITS-based traffic control system similar to approaches suggested at the workshop.
- The design of a project to rehabilitate a nearby section of the Long Beach Freeway includes a heavy-duty asphalt overlay, environmental and aesthetic improvements, weekend closures, and other features suggested at the workshop.
- The section of I-710 addressed in the workshop has now entered the design stage, and many of the suggested innovative approaches to design, construction, work zone traffic management, and aesthetic enhancement are being incorporated into the plans being developed.

A more subtle but significant change inspired by the workshop has also taken place. The California Department of Transportation now considers the needs of an entire freeway corridor, rather than project-by-project needs, for renewal of urban freeways in southern California.

Sources: TRB (2000) and Neil Hawks, personal communication.

aesthetics of the built environment, and reflect high standards of environmental responsibility. Highway renewal affords an opportunity to provide structures specifically designed to carry higher volumes and heavier loads, extend service life, and meet increased customer expectations in these other areas.

Highway agencies have achieved these objectives on isolated, high-profile projects, with tremendous expenditure of effort and resources. This approach is consistent with the traditional project-oriented nature of new highway construction. However, individual renewal projects are part of a much larger system, and one that must function 24 hours a day. As more and more of this system requires the same treatment as these special projects, the highway industry will need to approach infrastructure renewal in a radically new way. It will be necessary to use a wide variety of technologies and strategies, assess the appropriateness and trade-offs of each for a given situation, and analyze the impacts of renewal work on both the facility in question and the system as a whole. And facing larger workloads without commensurate increases in staff, agencies and their consultants and contractors will need to be able to do all of this in a reliable, systematic, financially and human resource–efficient manner so that the new way of doing business can be applied effectively in a greater number of situations.

The struggle in which highway agencies are engaged is manifested in the way they are currently investing their financial resources. On the basis of 1999 obligations (FHWA 2001), "system preservation" (primarily resurfacing) is being performed annually on 20,586 miles (12.85 percent) of the 160,000-mile National Highway System. This amounts to a 7- to 8-year resurfacing cycle. On the other hand, in the same year only 3,200 miles was scheduled for reconstruction, yielding a replacement cycle of exactly 50 years. These statistics imply a demand for 50-year service lives. The difficulty is the huge backlog of older highways within the system that were only designed for 20-year service and the present inability to design and construct with confidence highways with much longer lives. At the same time, the cost of keeping the system intact is escalating. System preservation represented 37 percent of the total federal-aid budget in 1993, affecting 9,574 miles, compared with 52 percent affecting 20,586 miles in 1998. The bulk (more than 15,000 miles) of this latter amount is devoted to resurfacing, restoration, and rehabilitation. This work has the salutary impact of restoring a smooth riding surface and providing much-deferred maintenance, but it is really only buying time. In sum, agencies are faced with rapidly escalating maintenance costs but are making relatively small reinvestments in physical plant to meet the increasing demands described earlier.

Renewal of Urban Street Networks

The challenge of highway renewal as described here exists for all classes of roads. However, urban streets have unique needs that merit particular focus in a future strategic highway research program. In many ways, renewal of urban streets is a more complex issue than Interstate and freeway renewal, with a more immediate and more regular impact on the public. To begin with, urban street renewal affects not only motorists and truckers, but also pedestrians, bicyclists, and transit vehicles. Disruption of urban roads for construction activities can have detrimental effects on adjacent businesses, especially small, local establishments. Users of city streets experience frequent disruption from utility cuts, which in turn accelerate the degradation of pavements that must be patched and repaired prematurely. Identification and relocation of utilities can add significantly to delay and disruption in urban roadway renewal projects. Innovative treatment of utilities is needed to address these concerns.

Renewal activities themselves encounter unique situations on urban streets. Frequently, there are severe space limitations due to the proximity of buildings and private property. Noise is a concern for nearby residents and businesses. Special materials, construction techniques, and approaches to traffic operations may be required to deal with these issues. Cultural, historical, and aesthetic considerations may be more exacting in cities, where historic sites and cultural activities may also be a source of economic sustenance. Special design considerations are required in these cases, and strict requirements may dictate the construction schedule. On the positive side, renewal of urban streets can provide opportunities to improve safety and traffic flow and to promote designs that are more aesthetically pleasing, more pedestrian- and bicycle-friendly, and more accessible to persons with disabilities.

Meeting the Highway Renewal Challenge Through a Future Strategic Highway Research Program

In the preceding section a description was given of how highway renewal meets the first of the criteria set forth in Chapter 1 for selecting the strategic focus areas for F-SHRP: it is an issue that bears on national transportation goals and is of continuing concern to highway agencies. The other two F-SHRP criteria—appropriateness for a SHRP-style program and the effectiveness or expected impact of the research—and how the proposed program of highway renewal research meets these criteria are addressed in this section.

Appropriateness for a SHRP-Style Research Program

The proposed program of research to achieve highway renewal that is rapid, long-lived, and minimally disruptive is appropriate for a SHRP-style program. The achievement of this objective requires significant resources and continuity over several years. Delivery of needed research products on a schedule that can meet growing needs requires a coordinated, systematic approach. Multiple types of research—including work in materials, construction methods, equipment, financing and management approaches, operations, safety, and design—must be performed and integrated into useful tools. Numerous players—including federal, state, and local road agencies; the construction and supply industries; the financial community; and others—must be actively engaged throughout the program. Institutional constraints affecting existing research and technology programs (such as the need to compete annually for scarce research and technology funds with many other, sometimes shifting, priorities) make this integrated, systems approach very difficult to carry out in the time frame dictated by the urgency of the issue. The continuity and clearly defined scope of a SHRP-style approach can overcome this barrier, freeing researchers to focus entirely on achieving the desired outcomes. In addition, past experience with individual projects performed using a rapid, minimally disruptive approach indicates significant potential for success of this research under F-SHRP. Examples are provided in Boxes 4-3 and 4-4.

The specific subject matter of the proposed research is not notably different from much related work being done within existing research programs. The scope and scale of this work, however, are insufficient to move the industry toward widespread and effective application of a rapid, long-lived, minimally disruptive approach to renewal. Furthermore, if the research is pursued independently, suboptimal results are likely. An integrated program can exploit synergistic relationships among materials, equipment, construction methods, nondestructive evaluation, work zone traffic analysis, and other aspects of this research area.

Effectiveness or Expected Impact of the Research

Several benefits can be expected from the consistent application of an approach to highway renewal that is rapid, causes minimal disruption, and produces long-lived facilities. Improved roadway conditions would translate into savings for users since rough, pothole-covered roads cause vehicle wear and tear and increased fuel usage. Commercial and community savings could be expected from a reduction in temporary loss of or restricted access to commercial and residential areas affected by renewal projects. Rapid, less-disruptive renewal techniques also mean less delay from work zones. The reduced delay would be achieved not only during renewal activities, as a

Box 4-3

Interstate 15 Reconstruction Project, Utah

Salt Lake City, Utah, is the site of the 2002 Winter Olympics. I-15, a freeway that runs along the Salt Lake Valley and will play a critical role in transporting millions of international visitors, was in need of significant rehabilitation because of its deteriorating condition. The renewal work involves approximately 17 miles of highway, with up to 12 driving lanes, and 144 bridges. The work needed to be done in time for the Olympics and with minimal disruption to current users. The Utah Department of Transportation employed a suite of innovative techniques—including partnering, design–build contracting, incentive payments for early completion, innovative construction methodologies and materials (wick drains, lightweight fill, innovative structural designs, high-performance concrete)—to create a high-quality facility on a tight schedule with minimal user disruption. In this case, users indicated in a public survey that they would prefer "a lot of pain for a short period of time" instead of having the project last longer. Consequently, total facility closures were used at scheduled intervals to accomplish work rapidly and thoroughly before the facilities were opened to traffic. The use of these approaches allowed the I-15 Reconstruction Project, a $1.325 billion undertaking that would normally have required 10 years of construction, to be completed in 4.5 years with $500 million of savings in construction costs and $500 million in economic benefits as a result of the shorter construction schedule.

Source: AASHTO Success Stories website: www.transportation.org/aashto/success.nsf/homepage/overview and www.i-15.com.

consequence of better management of work zones, but also over the life of facilities through the use of long-lived materials and methods. Delay can be quite costly to users. One study revealed that highway delay in just 68 urban areas was estimated to cost users about $78 billion in 1999.[3] Approximately 54 percent of this delay was due to nonrecurring incidents, such as construc-

[3] See Schrank and Lomax (2001). That study defines travel delay as the amount of extra time spent traveling due to congestion. The cost of delay includes the value of lost time in passenger vehicles and increased operating costs of commercial vehicles in congestion. Details on how the delay costs were derived are documented in Appendix B of that report.

Box 4-4

Whittier Access Tunnel, Alaska

Whittier, Alaska, is an important cargo port and recreational and tourist destination, responsible for about 20 percent of Alaska's revenue. Until recently, however, Whittier had no highway access because of the barriers formed by lakes, glaciers, and mountains. The only surface transportation link was a rail line with a 2.5-mile tunnel through the mountains; cars had to be carried into Whittier by train. Direct highway access would benefit the area economically, but an overland route or a new tunnel would be prohibitively expensive and raise significant environmental and aesthetic concerns. The Alaska Department of Transportation and Facilities therefore decided to convert the rail tunnel into a dual-use rail–highway tunnel. The work had to be done rapidly, without disrupting rail traffic. The use of nontraditional work schedules (most construction was performed during the winter) and innovative methods and materials—such as constructing highway pavement from precast concrete panels in which track was embedded and using a rail-mounted gantry crane that allowed excavation, grading, and panel placement to occur simultaneously—permitted the work to be completed ahead of schedule, in 40 days. There were only nine track outages, which were scheduled to be compatible with barge traffic at Whittier. The project increased the automobile capacity of the tunnel by a factor of 25. Other innovative technologies—computerized traffic management, video monitoring, emergency response, and ventilation systems—were installed during construction to support the operation of the facility. The project also included two bridges, a 500-foot highway tunnel, 2.6 miles of roads, and various support facilities.

Sources: American Society of Civil Engineers (2001) and presentation by Alaska Department of Transportation and Facilities staff at AASHTO Spring Meeting, Wichita, Kansas, May 20, 2001.

tion work, disabled vehicles, and crashes. If implementation of the results of this program, together with the results of the travel time reliability research described in Chapter 6, reduced such incident-related delay in these urban areas by just 5 percent, the result would be annual savings of about $2.1 billion for these areas.

There are prospects for achieving significant improvements through the proposed research program. Focused research in some of the specific areas described later, integrated with products of established highway research and technology programs, can revolutionize the way highway renewal work is done. Using an integrated, systems-oriented approach such as that proposed here will help overcome implementation barriers by addressing them up front, with the input of all relevant stakeholders. Since much related work has been performed for many years, the highway research community should be well equipped to carry out the proposed program. Those involved will, however, need to become quickly acclimated to the integrated, implementation-oriented approach being taken and may need to develop some additional expertise in the areas of work zone operations and urban street networks. State agencies are immersed in the issues surrounding highway renewal, and the need for progress in this area is so pressing that it is reasonable to expect their active participation in the proposed program. It is also reasonable to expect that agencies will rapidly adopt the findings of the research. Local agencies, also faced with urgent reconstruction and rehabilitation needs, may be less able to participate because of greater resource constraints. However, their involvement from the beginning of the program is so crucial that its achievement will need to be a priority of the research team.

Proposed F-SHRP Research

Major Research Objectives

The proposed research program has two major objectives:

- To achieve renewal, that is performed rapidly, causes minimum disruption, and produces long-lived facilities.
- To achieve such renewal, not just on isolated, high-profile projects, but consistently throughout the highway system.

In this section a review is given of what is entailed in and currently known about achieving these objectives, as well as areas in which additional knowledge and development are required.

Achieving Rapid Renewal

Rapid renewal, for purposes of the proposed research, refers to the duration of renewal activities on the facility itself: the time during which renewal activities are taking place on the roadway should be dramatically reduced. However, many stages of the effort, including planning and community involvement, environmental analysis, facility design, and work zone traffic operations and safety analysis, take place before the field work begins. Decisions and plans made during these earlier stages can have significant impacts on the rapidity of construction and therefore are also important areas in which to focus research and technology. Moreover, shortening the preliminary engineering phase will accelerate the resolution of existing deficiencies or disruptive elements. Development of improved remote sensing and rapid, nondestructive testing techniques for planning and design would be particularly useful.

To meet the need for rapid renewal work, existing research programs have developed paving materials that set up quickly, allowing traffic to resume soon after paving. Some research has also been done on innovative contracting procedures that include incentives and disincentives aimed at encouraging contractors to find faster ways of performing renewal work. Additional research and development is needed in the following areas: performance-related specifications for new technologies; efficient construction equipment and methods; nondestructive, real-time sensing to determine readiness for traffic; use of modular or prefabricated construction to speed renewal and minimize disruption; and use of advanced computing technologies, such as web-based management, that could speed up renewal projects by providing for better coordination across disciplines and project stages.

Another area in which there is a particular need for additional research is rapid, long-lived renewal of bridges. Bridge renewal can have a significant impact on time, budget, and highway design. Advanced materials and construction methods, including prefabrication and automation, can help reduce the impact of bridge renewal on highway renewal projects and reduce the frequency of bridge deck replacement activities.

Achieving Long-Lived Renewal

Producing a reconstructed or rehabilitated infrastructure that is long-lived means reducing the frequency and severity of future interventions on the same segment of infrastructure. Facility life requirements depend on facility class, usage, and customer expectations. An agency needs to identify how frequently it can intervene or allow maintenance activities to take place from community, operational, and financial points of view. Decisions about facility life will in turn influence decisions about materials and design, as well as operational and possibly aesthetic characteristics. Facilities that are going to be used for a long time without opportunities for modification may be expected to meet higher standards and to be more flexible. Decisions made concerning such facilities must generally take into account a wide variety of possible future scenarios regarding demand, environmental impact, and contribution to the local community and economy.

Existing research programs have addressed the long-lived objective through the development of materials and designs for longer-lived pavements and bridge elements (particularly bridge decks). Critical to meeting the long-lived objective are performance measures and performance models for long-lived materials and designs. For pavements, the Long-Term Pavement Performance (LTPP) program is collecting data to validate and enhance such models; however, models are generally lacking for other materials and elements of highway facilities. Designs are needed for site-specific applications (based on traffic composition and behavior, environmental conditions, and evolving land use). Early indicators of long-term quality and nondestructive means of measuring these indicators during construction are also needed.

Achieving Minimally Disruptive Renewal

The objective of minimum disruption encompasses a number of concerns. Disruption can refer to operational characteristics of a facility, as well as to economic, environmental, social, and aesthetic impacts. The actual renewal work should create as little disruption as possible while it is being carried out. It should have the minimum possible impact on surrounding facilities. And it should provide for minimal future disruption from additional maintenance and renewal interventions, according to the determination of facility life discussed above.

Among the three objectives of rapid, long-lived, and minimally disruptive renewal, the last is perhaps the most neglected in existing research—especially in combination with the other two. The ingenuity of the contractor is often relied upon for achieving minimal disruption on individual projects (for instance, responding to the incentive–disincentive clauses mentioned earlier). Little research has been done on the effectiveness of these means or on the impact of project-focused methods on the entire highway system. For example, contractor ingenuity cannot be relied upon for the development of ways to perform selected improvements on other roads so they can be used as alternate routes or bypasses while renewal work is being done. In addition, disruption is usually defined in terms of lane closures and delay, with little attention to environmental, community, economic, and operational disruption—all areas in which research is needed.

Research is needed as well in the areas of robotics and automated equipment that can reduce the amount of work space required, especially for lane closures; preconstruction work zone analysis to assess impacts of renewal activities on other roads and other transportation modes in the corridor; work zone safety considerations and countermeasures to minimize hazardous situations for the public and highway workers; innovative work schedules (long shifts, night work, weekend work, off-season construction) and their impact on both workers and the quality of the work; improved management methods for affected areas and work area traffic management and construction staging; improved work zone traffic information systems and advanced traveler information systems that would allow users to make informed decisions about alternatives and decrease travel through work areas to the extent possible; methods of utilizing capacity improvements on adjacent roads or in other modes during highway renewal; innovative approaches to dealing with hydraulics, storm water management, and urban utilities to minimize disruption from repeated entries into the roadway; public involvement and communication methods, such as design workshops and use of visualization technologies; alternative approaches to meeting mobility needs during renewal activities, such as providing more transit or promoting carpooling and telecommuting; and planning and design of work zones to accommodate pedestrians, bicycles, persons with disabilities, transit, and goods movement safely and efficiently.

Integrating Renewal Objectives and Methods

Clearly, the objectives of rapid, long-lived, and minimally disruptive renewal cannot be entirely independent of one another on major renewal projects. Sometimes they reinforce each other, and sometimes they conflict. For example, a long-lived facility will decrease future disruption in the vicinity of the facility. Likewise, rapidly performed construction must still produce a high-quality, long-lived facility. In addition, minimizing the immediate operational disruption of a renewal project could cause the project to extend over a very long period of time, while extremely rapid renewal could cause significant disruption for a short period (for instance, if a facility is fully closed). One of the key challenges of the proposed research, then, is to achieve an integrated approach to these three objectives. Integration in this respect means pursuing all three objectives in a simultaneous and balanced manner, evaluating the trade-offs and possible impacts of advances in one objective on the others.

There are many potential means of achieving this integration, using materials, equipment, management and contracting methods, communications and sensing technologies, and traffic operations. Existing research programs are addressing each of these topics and more. A unique contribution of F-SHRP will be integration of the various means: bringing the tools and techniques together; evaluating them with respect to the three renewal objectives; performing selected research and development to address unmet needs; and developing integrated, implementable systems. Certain areas of research, such as constuctibility analysis, work zone operations, and project review, can be particularly helpful in the development of more integrated approaches.

Developing a Systemwide Approach to Renewal

Achieving rapid, long-lived, minimally disruptive renewal through a systemic approach introduces additional considerations. The need to look beyond individual projects to the overall highway system derives from the fact that so much renewal work will be required during the next two decades. Multiple work zones within a region or corridor will not be unusual. Impacts of renewal work will have to be evaluated over the entire transportation network. Highway agencies will not be able to apply extraordinary resources for performing rapid, long-lived, minimally disruptive renewal on a few, high-profile projects; such renewal will be expected on most projects. In both the development of implementable strategies and the performance of targeted research, the F-SHRP infrastructure renewal program will focus on tools and techniques that reflect consideration of the entire system or corridor in which the renewal work is to take place. The concept of a systemwide approach to renewal has begun to take root in some states. Yet very little research has focused on the impacts of particular renewal projects on the entire highway system or the overall transportation system and its many customers.

There are numerous specific areas in which systems-oriented research and technology are needed. Examples include planning to address other required work in an area (such as utility work, bridges, and safety appurtenances) when major renewal work is scheduled; traffic control technologies, including intelligent transportation systems (ITS) (both using such technologies during renewal and keeping them in place afterward to contribute to the operation of the system); innovative contracting and financing approaches and their impact on construction speed and quality, private-sector innovation, and risk allocation; life-cycle cost models that include delay and detour costs, vehicle operating costs, costs of future maintenance interventions, and impacts on businesses dependent on the facility; methods of reflecting these costs in specifications and performance measures; impacts of innovative contracting and construction practices (including performing the work during nights and weekends) on the level of innovation, the quality of the work, personnel, and safety; analysis of the impacts of renewal work on the performance of highway corridors and networks; development of models to predict these impacts and to determine the effectiveness of various traffic management strategies prior to project execution; and assessment of the effects of these analyses and strategies on the timing, size, and duration of projects when the projects are viewed as part of a corridor-level program.

Proposed Research Tasks

F-SHRP will produce a systematic method for analyzing renewal needs and evaluating alternative strategies and technologies, thus allowing highway agencies to design approaches tailored to their particular circumstances. To achieve this objective, F-SHRP will focus on the following tasks:

- *Synthesize existing solutions.* Much research and technology work has already been done in a number of areas relevant to highway renewal. F-SHRP will produce syntheses of this work, assess the resulting techniques and technologies, and develop guidelines for applying them. Examples of possible synthesis topics include traffic control technologies for work zones, contracting methods, and nondestructive evaluation methods. These syntheses will provide opportunities for early application of improved methods before the full research program is completed.
- *Conduct original research and development for unmet needs.*[4] F-SHRP will include research in selected areas, outlined in the previous section. The results of this research will be incorporated in F-SHRP's systematic method for approaching infrastructure renewal projects. Box 4-5 lists some potential research topics under this task.
- *Integrate syntheses and results of research to develop a systematic method with appropriate decision support tools.* The final product of the F-SHRP efforts is

[4] Previous reports have identified a number of research gaps in the area of highway renewal (National Research and Technology Partnership Forum 2000; TRB 1997; TRB 1998).

Box 4-5

Potential Research Topics Addressing Unmet Needs

The following specific research topics would address important unmet needs:

- Construction methods, such as modular or prefabricated construction and innovative work schedules
- Construction equipment, including robotics and automated equipment
- Innovative materials for greater durability and early opening of facilities to traffic
- Nondestructive, real-time sensing and evaluation technologies
- Innovative management, contracting, and finance methods
- Work zone and corridor traffic analysis and traffic management alternatives
- Work zone safety techniques
- Work zone traffic information and traveler notification systems
- Life-cycle cost analysis, including agency and user costs
- Performance measures for performance-related specifications
- Advanced computing technologies to provide better coordination across disciplines and project stages
- Particular focus on rapid replacement of bridges and bridge decks

intended to integrate the findings of the syntheses of existing work and of F-SHRP's original research to produce a repeatable, systematic process for analyzing, planning, designing, and carrying out rapid, long-lived, and minimally disruptive highway renewal projects. The process will include appropriate decision support tools and guidelines for analyzing the needs and characteristics of projects, evaluating various techniques and technologies, assessing trade-offs and impacts of these techniques and technologies on the parameters listed below, improving public communication and involvement, planning highway renewal work, and designing work zones.

The analysis and evaluation method to be developed under F-SHRP will include assessment of a number of important parameters and how they are affected by the choice of strategies and technologies applied to a project or corridor. Among these parameters are the following:

- Agency and user costs, including life-cycle costs;
- Project and corridor or network traffic impacts;
- User requirements for information and travel time reliability;
- Human resource needs and impacts, including special training needs;
- Work zone safety for workers and users of the facility;
- Impacts on other modes of transportation and possible use of other modes to mitigate the effects of renewal work; and
- Effects of renewal work on access and on the economy of an area.

Relationship to Other Work

Other Research and Technology Efforts

Several existing highway research and technology programs are addressing important aspects of the infrastructure renewal issue. The success of the infrastructure renewal activities proposed for F-SHRP will depend on the continuation of these highway research programs, since an important part of the proposed F-SHRP is integration of the results of these other programs into a comprehensive and systematic approach to highway renewal. Some of these programs are listed below with examples of their current or planned activities:

- FHWA performs research and technology activities in several areas related to infrastructure renewal: high-performance materials, accelerated pavement testing, highway structures, nondestructive evaluation techniques, and work zone analysis.
- Work under the LTPP program, originally part of the first SHRP and now administered by FHWA, includes determining the long-term durability of pavement materials and providing data that can be used to validate long-term performance models and develop performance standards.
- NCHRP includes research in many areas related to infrastructure renewal, such as materials and design for pavements and structures, and innovative contracting.
- State DOTs conduct a wide variety of highway research and technology activities in such areas as materials, bridge inspection, accelerated pavement testing, maintenance and preservation strategies to reduce rehabilitation and reconstruction, and work zone safety and operations. For the most part, these activities are directed at the specific needs of the state performing the research, although some findings and techniques can be applied more widely.

- Industry organizations, such as the National Asphalt Paving Association and the Innovative Pavement Research Foundation, sponsor or perform research in pavement materials, construction, maintenance, and rehabilitation. Construction equipment manufacturers develop improved equipment.
- Universities contribute to virtually all areas of highway research and technology since they frequently conduct the research and development funded by the above groups. University programs tend to focus on specific areas such as materials, ITS applications, construction management, and public policy implications.

The interim work stage between publication of this report and initiation of F-SHRP (described in Chapter 8) will include a thorough review of the above efforts to ensure that F-SHRP does not duplicate those efforts, but integrates their results into its final products. Throughout the conduct of F-SHRP, close communication, and cooperation where appropriate, will take place with these other highway research and technology efforts.

Other Strategic Focus Areas in F-SHRP

While this research program is oriented in particular toward meeting the strategic goal of accelerating the renewal of America's highways, it can also contribute to addressing F-SHRP's other strategic focus areas if renewal activities are used to implement the outcomes of those other research efforts. For example, reconstructed highways could incorporate the results of safety research (by reflecting knowledge about driver behavior in work areas, geometric design, roadside hardware, pavement marking, and signage), travel time reliability research (by using designs that better accommodate incident management or reduce other impacts on travel time), and research aimed at improving the environmental and community compatibility of highways. In particular cases, renewal activity could provide an opportunity to improve facility design in such areas as aesthetics, safety, and environmental or community impacts. Rapid, long-lived, minimally disruptive construction technologies could also contribute to new capacity objectives discussed in Chapter 7.

Administrative and Implementation Considerations

The very nature of the proposed program—taking an integrated, systems-oriented approach—requires active coordination and collaboration between F-SHRP and existing highway research and technology programs from the outset. One or more formal partnership agreements may be appropriate to outline the respective roles, activities, and expected products of the programs so that implementable, customer-oriented products can be delivered on a reasonable schedule. Potential members of such partnerships could include FHWA, NCHRP, industry research and development programs, individual states or groups of states, and universities or university consortia. The objectives of the partnerships would be to leverage financial, material, and intellectual resources at various institutions and to ensure that certain research and development activities would be carried out according to mutually agreed-upon schedules, budgets, and intended outcomes.

The success of the highway renewal portion of F-SHRP will be measured by how quickly and extensively accelerated renewal strategies are implemented effectively by state and local highway agencies. As mentioned earlier, particular effort should be made to facilitate local government participation. Implementation, however, must include more than just public-sector agencies; the highway contracting and supply industries must also be involved. The participation of all stakeholders must be secured from the initiation of the project. The formal partnerships mentioned above will assist greatly in achieving this goal, but stakeholders that are not formal partners in specific research and technology activities must also be engaged. An appropriate program of outreach, information sharing, and technology transfer will therefore be important. Partnerships with technology transfer entities (such as FHWA Resource Centers and Local Technical Assistance Program Centers) could be developed to help meet this need and leverage available resources.

One of the advantages of the proposed approach is that it will not only promote the use of new technologies developed under F-SHRP but also will foster the use of existing technologies by demonstrating their effectiveness as part of an integrated package tailored to specific needs.

Highway renewal will ultimately be a joint endeavor of the public and private sectors, and private-sector innovation will be critical to achieving F-SHRP's research goals. The private sector has some incentive to undertake research and technology related to two elements of the overall highway renewal problem (equipment development and construction management), but most of the individual research areas have been largely the domain of the public sector because of public ownership of the highway system and a lack of economic incentive for private-sector innovation. Traditional procurement practices offer little if any reward for private innovation. In addition, the volume of this type of work has been so small to date that it has not justified capital investment on the part of the private sector. F-SHRP research could include some focus on improving incentives for private-sector innovation. More important, perhaps, development of a systematic process that would allow a greater number of projects to be handled consistently with a rapid, long-lived, minimally disruptive approach could help promote a larger and more stable market for such work and thereby provide the market incentive required for private-sector innovation.

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ABBREVIATIONS

ASCE	American Society of Civil Engineers
BTS	Bureau of Transportation Statistics
FHWA	Federal Highway Administration
TRB	Transportation Research Board

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ABBREVIATIONS

FHWA	Federal Highway Administration
GAO	General Accounting Office
IPRF	Innovative Pavement Research Foundation
NAPA	National Asphalt Pavement Association
TRB	Transportation Research Board

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CHAPTER 5

Safety: Making a Significant Improvement in Highway Safety

Overall research program goal: To prevent or reduce the severity of highway crashes through more accurate knowledge of crash factors and of the cost-effectiveness of selected countermeasures in addressing these factors.

Challenge of Highway Safety

Each year approximately 42,000 people are killed on the nation's highways, and 3 million are injured. The cost of these crashes approached $182 billion in 1999 (NSC 2000). Highway fatalities account for approximately 95 percent of transportation-related deaths (BTS 1999, Table 3-1). Indeed, the annual highway death toll is equivalent to a jet airliner crashing and killing everyone on board *every day of the year.* Highway crashes represent the single largest category of accidental deaths and the most frequent cause of death among children and young adults (Insurance Institute for Highway Safety 2001). (Box 5-1 shows some additional statistical comparisons.)

Significant improvements have been made in highway safety during the last several decades. From 1988 to 1999, for example, the number of highway fatalities dropped from 47,087 to 41,611, an 11.6 percent decline, and the fatality rate in deaths per 100 million vehicle-miles traveled (VMT) dropped from 2.3 to 1.5, a 34.8 percent decline. During the same period, the injury rate dropped from 169 to 120 per 100 million VMT, a 29.0 percent decline. There have also been reductions in alcohol-related deaths and pedestrian and bicyclist fatalities and increases in the use of safety belts. These advances are due to improvements in vehicles (safety belts, airbags, crashworthiness), infrastructure design (roundabouts, shoulder rumble strips), roadside hardware (guardrail end treatments, breakaway signposts and light

Box 5-1

How Highway Crashes Compare with Other Causes of Death and Injury

- Every 34 minutes someone is murdered; *every 13 minutes someone dies in a highway crash.*
- Every 35 seconds there is an aggravated assault; *every 15 seconds there is a highway injury.*
- America lost 620,000 citizens during all wars since 1775; *more than 3 million were lost on the nation's highways during the last century.*
- In 1998 fewer than 700 people died in airplane crashes; *more than 41,000 died in highway crashes.*
- In 1985, deaths from heart disease and neoplasms (tumors) were responsible, respectively, for 11.8 and 15.6 life-years lost per death; *motor vehicle crashes in the same year were responsible for 37.3 life-years lost per death.*

Sources: Cirillo (2001); Rice et al. (1989, Tables 16 and 18).

posts), traffic engineering (raised pavement markings, new reflective sign sheeting or special applications), and enforcement and public awareness efforts (safety belt and alcohol laws and programs). These improvements in turn are the result of federal and state legislation and applied safety research carried out by federal and state agencies, universities, and industry. However, decreases in fatality and injury rates have leveled off since the early 1990s, as shown in Figure 5-1. In addition, as noted earlier, low fatality and injury rates still mean large numbers of deaths and serious injuries because of the significant increase in VMT (see Figure 5-2). Between 1988 and 1999, VMT rose 35 percent from 2.0 trillion to 2.7 trillion.[1] This means improvements in safety, as reflected in declining fatality and injury rates, are not keeping up with increases in VMT. If these trends continue, more aggressive highway safety efforts will be needed just to keep the absolute numbers of fatalities and injuries from rising and certainly to reduce these numbers significantly.

[1] All statistics in this paragraph are from NHTSA (2000, Table 2).

Figure 5-1 Highway fatality and injury rates (NHTSA 2000, Table 2).

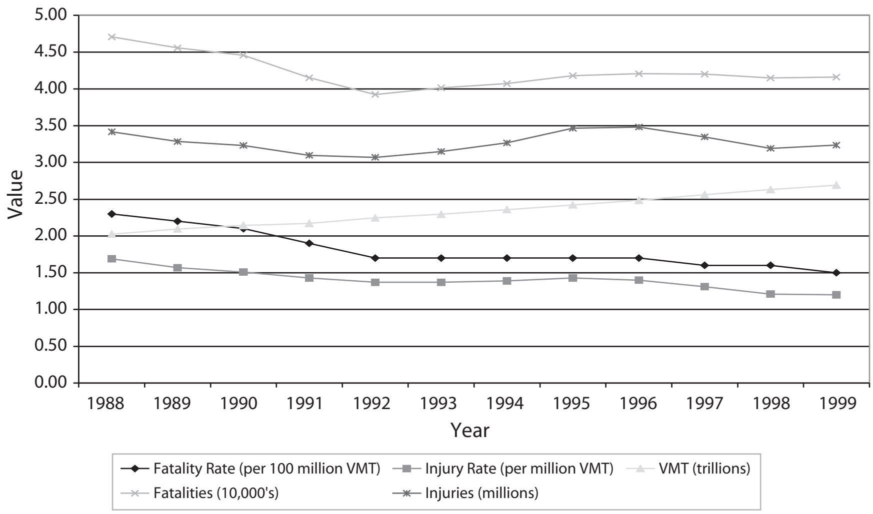

Figure 5-2 Highway fatalities, injuries, and fatality and injury rates, 1988–1999 (NHTSA 2000, Table 2).

Several other factors add to the challenge of achieving safer highways:

- Changes in vehicle design and in the popularity of particular vehicles (such as sport utility vehicles) make it difficult for highway agencies to keep roads and roadside hardware compatible with the vehicle fleet.
- Demographic changes raise a number of issues with regard to driver performance and crash survivability. First, there continues to be an increase in the number of older drivers, who are more susceptible to injury in a crash and less likely to survive their injuries. The oldest drivers may exhibit a decline in vision, quickness of reaction, and cognitive skills associated with the performance of complex tasks. In addition, an increase can be expected in the number of teenage drivers, who have little experience or mature judgment.
- New vehicle technologies, such as antilock brakes, onboard navigation systems, and adaptive cruise control, have certain safety benefits but are accompanied by changes in driving behavior that may reduce (or in some cases negate) those benefits.
- Even without the new technologies, highway designers are finding, driving behavior has changed in important safety-related ways. For instance, comparison of the new version of the Highway Capacity Manual (TRB 2000) (used to design highways) and the earlier version (TRB 1994) reveals that drivers are willing to accept shorter distances between vehicles for a given speed.

As is evident from the above considerations, the highway safety problem is both serious and extremely complex. The committee received many suggestions for safety-related research during the outreach process. After consultation with safety experts, the committee identified two knowledge gaps whose remediation through appropriate research would help the highway safety community use many existing countermeasures more effectively and potentially develop improved countermeasures as well.

First is the need for more precise understanding of how various factors contribute to crashes. Many factors contributing to the occurrence or severity of crashes have been identified. These factors include roadway geometry, speed, alcohol use, driver fatigue, poor visibility, unforgiving roadside objects, and many others. However, most of the research that has addressed these factors has been constrained by limitations on the availability or accuracy of the data or on the ability to draw conclusions about the relative contributions of individual factors. In particular, even the best studies have lacked adequate exposure data for the noncrash population and accurate precrash data. A variety of new technologies offer unprecedented opportunities to collect data on crash factors and exposure that have never before been available.

The second major knowledge gap relates to the cost-effectiveness of the countermeasures already in use or under consideration. The highway community is spending many millions of dollars on a wide variety of countermeasures—flashing lights, driver education, enforcement strategies, new sign colors and sizes, different signal timing—without having adequate knowledge of their cost-effectiveness, whether singly or in combination, in preventing crashes or reducing crash severity.

These two major knowledge gaps are closely related. Without more precise knowledge of the contributions of various crash factors, it is difficult to determine how much effort should be focused on any one of them. Even if the most significant crash factors are identified, it is not clear which countermeasures address those factors most cost-effectively. In addition, some factors may be particularly resistant to countermeasures. This is the case with many human factors because it is more difficult to change human behavior than to change vehicle or roadway design. Moreover, even when a countermeasure is technically effective, it may be incompatible with social, political, or legal requirements or may be prohibitively expensive. All of these issues must be taken into account if optimal investments in highway safety are to be made. And the absence of accurate data on each aspect of the problem is a major barrier to achieving a substantial leap forward in highway safety.

The research proposed in this chapter is intended to overcome this barrier and provide the data and analysis needed to make the highway system as safe as possible. This research will require the collection and analysis of a larger quantity and wider variety of data than has previously been available for crash analysis studies, including both noncrash and precrash data. Moreover, the research will focus specifically on the effectiveness of selected crash countermeasures. To carry out such an ambitious study, the committee proposes that researchers use available advanced technologies to the extent possible. Additional description of the proposed research and potentially useful technologies is provided later in this chapter.

Meeting the Highway Safety Challenge Through a Future Strategic Highway Research Program

How highway safety meets the first of the criteria set forth in Chapter 1 for selecting the strategic focus areas for F-SHRP was described in the preceding section: it is an issue that bears on national transportation goals and is of continuing concern to highway agencies. The other two F-SHRP criteria—appropriateness for a SHRP-style program and the effectiveness or expected impact of the research—and how the proposed study of crash factors and cost-effectiveness of countermeasures meets these criteria are addressed in this section.

Appropriateness for a SHRP-Style Research Program

The study envisioned by the committee will require resources well beyond the capability of existing highway safety research programs. For any of these programs to attempt such a study would mean abandoning other critical contributions to highway safety. A study of crash factors will also require several years of continuous, predictable funding, not subject to the vicissitudes of the annual budget decisions that affect all existing programs. In addition, an integrated approach is required in the research design to encompass the various factors—driver, vehicle, and roadway—that must be studied. The conduct of the study will require coordination and cooperation among several players, including a number of federal agencies [FHWA, the National Highway Traffic Safety Administration (NHTSA), the Federal Motor Carrier Safety Administration (FMCSA)], state and local agencies, vehicle manufacturers, the insurance industry, the legal community, and others. A focused research program, independent of many of the institutional constraints appropriate to existing research programs, will be in a position to bring these players together more effectively and forge new alliances while building on the institutional strengths and historical alliances that characterize existing programs.

A study of the scope, scale, and rigorous research design envisioned by the committee is not likely to be carried out by an entity other than F-SHRP because of funding and institutional constraints. At the same time, both the ultimate goal—a significant improvement in highway safety—and the specific path chosen toward that goal—a comprehensive study of crash factors and the cost-effectiveness of countermeasures—are appropriate focuses of public-sector concern and resources. This is true for several reasons: the vast majority of highways are publicly owned; safety on the highways is a significant public health issue;[2] and longer-term, higher-risk research such as this is a traditional responsibility of the public sector.

[2] The committee would like to emphasize that the notion of highway safety as a public health problem and a particular concern of the public sector does not diminish the personal responsibility of individual drivers, cyclists, and pedestrians to contribute through their own behavior to the safest possible roadway system.

Effectiveness or Expected Impact of the Research

In selecting focus areas for F-SHRP research, the committee sought to identify research opportunities with the potential to yield results that would surpass qualitatively or quantitatively what existing highway research programs are likely to provide on their own. While the outcomes of a study of crash factors and effectiveness of countermeasures are less certain than those of other, lower-risk types of research, this study by its very nature is oriented toward fundamental knowledge and therefore fundamental advancement. In addition to providing a basis for wiser investments in existing countermeasures, results of this study can potentially be applied to produce new countermeasures in a wide variety of safety programs, from intelligent transportation systems (ITS) strategies, to highway and vehicle design, to enforcement and driver training approaches. Application of more fundamental knowledge of crash factors and effectiveness of countermeasures could lead to sizable reductions in deaths and injuries, making it possible to outstrip the anticipated growth in VMT. Every 1 percent improvement in highway safety resulting from application of the results of this study would mean more than 400 lives saved, 30,000 injuries averted, and $1.8 billion in economic costs avoided annually.

The study is expected to take approximately 7 years. Some interim results could be available earlier, but it is expected that analysis of the full study results along with recommendations on cost-effective implementation of countermeasures could begin to be available within 10 years of the start of the study (assuming that the pilot study discussed below could be conducted in advance of the next highway reauthorization so that the full study could begin at the start of the next authorization period).

Barriers to the conduct of the research program are largely legal and institutional (as discussed in more detail below), but initial indications are that they can be overcome. Barriers to implementation are likely to be financial and institutional. However, these barriers, too, should be surmountable given the importance of the problem; the results obtained on the cost-effectiveness of specific countermeasures; and the existence of potential implementation mechanisms, such as the *AASHTO Strategic Highway Safety Plan*[3] and the highway safety manual currently being initiated by NCHRP.

The highway safety research community has never conducted a study of this type. However, experience gained through NHTSA's crash analysis pro-

[3] Available at safetyplan.tamu.edu/index.htm.

gram, the truck crash causation study currently under way at FMCSA, the pilot study proposed below, and other related efforts should adequately prepare the research community for the undertaking. The ability to implement the study results will vary among the responsible groups—federal, state, and local agencies and industry. Moreover, where the burden of implementation lies will depend on what is learned from the study. For example, highway design issues will fall within the purview of government agencies, while vehicle design issues will have to be addressed by the automobile industry. One of the challenges involved in the conduct of the study will be to keep the various stakeholders apprised of its progress and to find appropriate ways of involving them, building on the strengths and interests of each.

Proposed F-SHRP Research

Major Research Objectives

The proposed research has two major objectives:

- To identify more accurately the contributions of various factors to highway crashes, fatalities, and injuries; and
- To determine the cost-effectiveness of selected countermeasures in preventing or reducing the severity of highway crashes.

What is entailed in achieving these objectives is examined in this section. In addition, since the development of certain data and communications technologies offers unprecedented opportunities to meet these objectives, these opportunities are explored as well.

More Accurate Knowledge of Crash Factors

The issue of what constitutes a crash factor is complicated. While such factors are sometimes referred to as causal factors, limitations in the research design of traditional crash analysis studies (as discussed in this section) make it difficult if not impossible to infer causality. Indeed, the committee has chosen to avoid using the term "causation" in recognition of the complexity of the problem and the different perspectives on what constitutes the cause of a crash. To illustrate the point, Box 5-2 describes a simple crash scenario, as well as the multiple judgments about causality and potential solutions that might result from analysis of the incident by various experts. The proposed study will not resolve these

Box 5-2

Perspectives on Crash Causation and Solutions: An Example

An inexperienced driver drives through a short transition section where a freeway ends and a local highway begins, and approaches the first signalized intersection at too high a speed. The vehicle in front, driven by an older driver, stops when the light is near the end of the caution signal. The younger driver assumes that the older driver will go through and rear-ends the older driver. The headrest in the older driver's vehicle is poorly positioned. The older driver suffers whiplash. The younger driver suffers a knee injury. The following are the causes and solutions for this incident that might be suggested by various investigators:

Psychologist:

- Cause of crash: inattention; inappropriate high speed.
- Solution: driver training.

Human factors expert:

- Cause of crash: incorrect assumption about movement of vehicle in front; difficulty of making quick decision in "dilemma zone"; driver still adapted to higher freeway speed and takes time to adjust.
- Solution: change in roadway and signal design, driver training.

Vehicle designer:

- Cause of injury: design of headrest in older driver's vehicle (new ones prevent such injury); poor design of younger driver's vehicle with respect to knee clearance and deformation process.
- Solution: redesign of vehicle.

Traffic engineer:

- Cause of crash: vehicles caught in dilemma zone.
- Solution: need for long-distance detection on traffic signals so that detectors wait for gap in traffic before turning signal to caution, and drivers at high speeds are not confronted with a go/no-go decision; need for signs warning of freeway end.

(*continued*)

Box 5-2 (*continued*) **Perspectives on Crash Causation and Solutions**

Road designer:

- Cause of crash: too short a transition zone.
- Solution: need for longer transition zone to bring speeds down from freeway levels; need for changes in road cross section to inform driver that road type has changed.

Police officer:

- Cause of crash: speed higher than posted.
- Solution: speed enforcement.

Source: Alison Smiley, Human Factors North, Inc., personal communication, Aug. 24, 2001.

differences in perspective or reduce the complexity of highway safety to a simple algorithm. Nonetheless, a comprehensive study of crash factors performed by a multidisciplinary team (representing human factors, traffic engineering, vehicle design, roadway design, enforcement, and other disciplines), using the most accurate data and most scientifically rigorous research design currently available, can greatly improve decision making with regard to highway safety. Most highway safety decisions are based on a small amount of data and analysis and a large amount of professional judgment and experience, tempered by political and financial constraints. A multidisciplinary team of experts can provide the fullest possible understanding of the interplay among various crash factors and the relative effectiveness of different countermeasures. Enhancing the quality of crash data and the robustness of safety analysis will lead to better decisions that will save lives and reduce injuries and property damage (the exact nature and extent of this improvement will depend on the results of the proposed research).

The main challenge of the proposed study and the key to its ultimate contribution is the scientific rigor of the research design. All other crash analysis studies[4]—from the seminal Indiana work of the 1970s, to the regular NHTSA investigations on which the industry depends, to the current FMCSA truck crash causation study—have had limited research designs as a result of con-

[4] See Appendix C for brief descriptions of these studies.

straints on funding, time, or technological capability, thus constraining the ability to draw causal inferences from the data produced. Researchers too often have resorted to gathering the data that are available instead of those needed to address the salient questions. To remedy this situation and provide the strongest possible intellectual basis for designing and implementing effective safety strategies, the proposed study of crash factors must have the following characteristics:

- A statistically significant, representative sample of all vehicles;
- Analysis of fatal, injury, and property damage–only crashes;
- A control of noncrash circumstances to measure exposure in the driving population; and
- New and more precise data about precrash circumstances and actions.

These characteristics are discussed in turn below.

Statistically Significant, Representative Sample of All Vehicles To achieve such a sample, (*a*) a large enough number of vehicles must be studied that the number of crashes expected to occur among these vehicles will itself be sufficient to meet the requirements of statistical significance; and (*b*) the vehicles must be chosen randomly so they are representative of all vehicles, thereby avoiding bias toward or against any significant crash factor (such as driver characteristics, geography, or type of vehicle). Although this characteristic implies a vehicle-based sampling design, the researchers should also be sure that the design will yield crashes on a representative distribution of roadway types and classifications (for example, rural and urban roads, Interstates and arterials). This characteristic of the research program is fundamental to the next two characteristics.

Analysis of Fatal, Injury, and Property Damage–Only Crashes Existing crash studies are based on a pool of crashes that have been reported to police. Therefore, crashes involving minor injuries or property damage only, which may never be reported, are systematically omitted from those studies. Detailed investigations of randomly selected crashes nationwide are performed under the NHTSA Crashworthiness Data System for crashes involving a towed passenger car, van, or truck that is less than or equal to 10,000 pounds gross vehicle weight. This level of investigation is not performed for other types of crashes. The proposed study will overcome this limitation and thus yield entirely new information about crash types not previously well researched.

Control of Noncrash Circumstances to Measure Exposure in the Driving Population One of the most critical elements in determining the significance of a given factor in crashes is to control for other factors. A perfect experimental control is not possible in a highway crash study because of the lack of information about exposure to risk in a large enough sample. However, statistical means can be used to control for various factors hypothesized to contribute to crashes if the study includes a control population of drivers and vehicles not involved in crashes. Since the unit of analysis in most crash analysis studies is the crash event, often triggered by a police report, these studies do not include analysis of drivers and vehicles that have not been involved in crashes.

An example may help illustrate the importance of this point with regard to designing and implementing effective safety measures. One may know from analyzing a number of crashes that 25 percent of the drivers were suffering from fatigue. It may appear obvious, then, that fatigue was a significant factor in the crashes. But if one were to discover that 25 percent of the driving population at large suffers from fatigue—including those who never experience a crash—it would clearly be necessary to look for other factors as significant contributors to the crash. Better knowledge of the role of various crash factors would then lead to much more effective design and implementation of safety policies and programs, helping highway safety professionals choose countermeasures that address the truly critical crash factors rather than factors that accompany crashes but may not be the most significant contributors to crash occurrence or severity.

New and More Precise Data About Precrash Circumstances and Actions Most existing information about crashes consists of the observable data after a crash, such as the type of crash, the nature and extent of damage to the vehicle, and the injuries sustained. It is sometimes possible to learn about precrash events by interviewing witnesses or by drawing inferences from postcrash evidence (such as skid marks), but for the most part the chain of events and circumstances leading up to a crash is not known with much detail or accuracy. As a result, the presence or absence of various factors can be difficult to determine, and investigators often resort to identification of the first harmful event of which they are aware (such as a collision with another vehicle), which may not in fact be the first or most harmful event. NHTSA has begun to use event data recorders (EDRs), or onboard recording devices, to gather some precrash data pertaining to vehicle performance and driver behavior. This approach offers much promise. The use of such devices is an important component of the proposed program and is discussed further below, along with other technologies now available to facilitate the conduct of the study.

Exploiting Opportunities Offered by Technology

The conduct of this study will require a suite of data gathering and analysis methods, including on-site investigations, surveys, interviews, and use of police accident reports. The exact details of the research protocol will need to be developed during the interim work discussed later. However, several technologies currently available provide an opportunity to perform this study in a way that could only be imagined just a few years ago. These technologies include EDRs, video recording systems, cell phones, the Global Positioning System (GPS), and sensors. Those developing the research design should fully consider the possibilities offered by these technologies.

Event Data Recorders EDRs make it possible for researchers to gather objective data about certain precrash and crash conditions. Such devices have been available in one form or another in some motor vehicles since the 1970s when airbags were introduced. Early recorders were used to monitor the readiness of airbags, provide warning to the driver if a bag appeared likely to malfunction, and record the bags' actual performance. Since that time, EDRs have increased in sophistication and have been included in more vehicle makes and models. They can now be designed to record such data as vehicle speed, acceleration, braking, and safety belt use, as well as airbag deployment. If made available to researchers, the data thus obtained would provide unprecedented insight into the circumstances and events leading up to a crash. The improvement in crash-related data potentially available from the use of EDRs is illustrated in Figure 5-3. The figure shows two examples of the Haddon matrix, which encompasses the human, vehicle, and environmental data available about the precrash, crash, and postcrash periods.[5] The first matrix shows the data available without EDRs and thus has several empty cells for precrash and crash data. The second matrix shows those cells filled, plus additional data in other cells resulting from the EDR capability.

NHTSA has begun to take advantage of the data available from vehicles equipped with EDRs. The agency has also formed a working group with gov-

[5] The Haddon matrix, originated by William Haddon, Jr., M.D., provides a method for studying the complex interaction of human, technological, and environmental risk factors surrounding an injury event.

	Human	Vehicle	Environment
Precrash		Skid marks	
Crash		Calculated velocity	
Postcrash	Injury	Collision damage	Environment after collision

(a) Haddon matrix without event data recording capability.

	Human	Vehicle	Environment
Precrash	Belt use Steering Braking	Speed Antilock brake system Other controls	Conditions during crash
Crash	Airbag data Pretensioners	Crash pulse Measured velocity Yaw Airbag activation time	Location
Postcrash	Injury Automatic collision notification	Collision damage Automatic collision notification	Environment after collision Automatic collision notification

(b) Haddon matrix with enhanced event data recording capability.[a]

[a] The capabilities shown do not necessarily reflect what is currently recorded by in-vehicle EDRs, but what the devices could potentially record if designed to do so.

Figure 5-3 Improvement in availability of crash-related data with use of event data recorders [slightly modified from Chidester et al. (1999, Tables 4 and 5)].

ernment and industry members to encourage the use of EDRs, develop performance requirements and data definitions, and resolve legal and privacy issues.[6] The National Transportation Safety Board encourages the use of on-board recording devices in all modes of transportation.[7] Devices for downloading data from some EDRs are commercially available and relatively inexpensive.

The major issues associated with EDRs pertain to legal, privacy, and data consistency concerns. Clearly, the owners of vehicles included in the proposed research will need to be informed about the EDRs on their vehicles and consent to their use for the study purposes. At the same time, the vehicle owners

[6] As this report was approaching publication, the final report of the NHTSA working group became available (NHTSA 2001). The report contains information about the status of EDR use, types of data that can be collected, data collection and management issues, privacy and legal issues, and other topics that will be highly useful in the further development of the research proposed in this report.

[7] See www.ntsb.gov/recs/recording_device.htm.

must be protected from third-party access to the data. Thus security measures will be required in the handling of the data, including masking the identity or source of specific data. In addition, the researchers and the data will have to be protected from subpoena in legal proceedings. Such protection is not unusual in research involving human subjects or data that individuals would be unlikely to reveal to researchers if they thought those data could be used against them. This legal protection also serves as a safeguard for the integrity of the research because individuals are less likely to provide inaccurate data to avoid a potential personal threat. In the case of the proposed study of crash factors, this means drivers will be less likely to modify their driving behavior to avoid getting into trouble, so researchers will be able to obtain a more accurate picture of their behavior.[8] A possible mechanism for this purpose is to apply for a Certificate of Confidentiality that the Department of Health and Human Services is authorized to issue. This certificate acknowledges that certain types of research have special privacy requirements and that people need to be protected from use of the resulting data against them. The National Transportation Safety Board is similarly protected from releasing data it downloads from aircraft and motor vehicle recorders.

Video Recording Systems Video recording systems also offer unique advantages for this type of research. The Kentucky Transportation Cabinet has installed such a system at a high-incident intersection in Louisville (*Urban Transportation Monitor* 2001). The system uses continuous-loop cameras and microphones to monitor the intersection. When the microphone picks up the sounds of a collision, it saves several seconds of video and allows the cameras to capture several more seconds, providing visual data for before, during, and after the crash. If intersection crashes were chosen for particular analysis in this study, such a device could be installed at the sampled intersections. In addition to providing for crash footage, an appropriate research design could be developed for randomly sampling vehicles approaching and progressing through the intersections to gather visual data on driving behavior and intersection operational performance under noncrash circumstances.

In-vehicle cameras have been used to capture data about events both inside and immediately outside of a vehicle. FHWA is using in-vehicle cameras to

[8] For example, Lehmann and Reynolds (1999) cite several European examples in which the presence of EDRs appeared to cause drivers to alter their behavior. The examples all involved professional (commercial or government) fleets, where employers would have been able to identify the drivers of specific vehicles.

track driver eye and hand movements and other driving behaviors under experimental conditions. Some private and police vehicle fleets have cameras mounted on the rearview mirror to record events occurring in front of the vehicle should a crash occur.

As with the use of EDRs, privacy and legal issues must be addressed in the use of video recording systems. For example, cameras external to vehicles (such as intersection-mounted cameras) should not be aimed at private property and should not capture individuals in the vehicle. In-vehicle cameras would require owners' permission. In practice, it may be possible to use such cameras only on vehicle fleets whose owners may have their own incentives for camera use. Video data (and audio data, if included) would also need to be protected from legal proceedings.

Cell Phones, GPS, and Sensors Cellular telephone technology could be used to alert researchers when a crash takes place (or at predetermined intervals to collect noncrash data) and to transmit recorded data efficiently and inexpensively. GPS could be installed on vehicles (as is already the case on some vehicles) to locate a crash for further, on-site investigation of highway geometry and roadside hardware. In the event of a crash, sensor technology could be used to gather data on weather, pavement condition (presence of ice or moisture), and traffic volumes and speeds. These data could be transmitted remotely as well. Technology for automated collection of site and crash geometry data could be used by researchers to improve the speed and accuracy of data collection.

In addition to sensors that can gather weather, roadway, and traffic data, recent advances have resulted in a number of technologies oriented toward driver performance that are being field tested by NHTSA, FMCSA, and the AAA Foundation for Traffic Safety. These technologies include passive alcohol sensing technology; eyelid monitoring (PERCLOS); and other devices that provide information about the driver's state of alertness, sobriety, attention status, and use of cell phones or telematics devices. Such technologies could provide objective data about whether and to what degree these driver conditions and activities contribute to crashes and would be especially useful for gathering exposure data. By the time the proposed study is launched, these technologies will have seen several more generations of development. Similarly, lane tracking and night vision systems are already on the market and could be used to add environmental data to the vehicle data collected by EDRs.

Even if all of these technologies cannot be used throughout the study, it may be possible to test some of them in portions of the research as experimental data-gathering methods. These newer methods could be compared with more traditional data gathering techniques, such as interviews and use of police reports, which will also be employed in the research. As newer technologies emerge, they could be more fully employed in future studies.

Determination of Cost-Effectiveness of Countermeasures

In the course of the outreach conducted for this study, the committee encountered the argument that the money required for a comprehensive study of crash factors might be spent more effectively on implementing countermeasures already in existence or under development. This is a reasonable point of view, and certainly implementation of existing countermeasures must continue. However, as effective as certain countermeasures are, there are many whose effectiveness is not well established, and there is still little basis for determining which countermeasures are the most cost-effective. Improved knowledge of crash factors, together with knowledge about the cost-effectiveness of countermeasures, will help agencies prioritize the various countermeasures now available, make more rational investments in their implementation, and direct the development of new countermeasures. In addition, some countermeasures are controversial; one reason the political will to implement them is lacking is that there is no clear basis for weighing the safety benefits gained against social or economic costs. The proposed study can provide a basis for informed public discourse and policy development in this regard.

The specific countermeasures to be studied will be determined during the interim work stage. The kinds of countermeasures the committee has in mind are effectiveness of guardrails, impacts of roadway and shoulder width, aspects of intersection safety (signal type and phasing, geometrics), and enforcement strategies. In choosing countermeasures, researchers should examine the incidence of fatalities and injuries from various crash types and identify countermeasures intended to address these crash types. By using data from the study of crash factors, researchers should be able to identify countermeasures that are designed to address the most critical factors and then perform analyses of their relative cost-effectiveness. Researchers may also want to examine commonly used countermeasures to determine whether investments in those approaches are in fact likely to yield safety benefits comparable with their expense.

Example

An example may be helpful to show how more accurate knowledge of crash factors, including better precrash and noncrash data, can lead to more effective use of crash countermeasures. Run-off-the-road crashes account for 33 percent of highway fatalities (FHWA, personal communication). Potential factors in these crashes include roadway geometry (a curved road, for example); excessive speed for that geometry; absence or inadequate visibility of lane markings or signs indicating the road's curvature; the presence or absence of a guardrail; the presence or absence of objects (such as signposts, trees, and walls) that may be struck by an errant vehicle; vehicle malfunction, such as brake failure; driver behavior, such as safety belt use and braking; and driver distraction, fatigue, or substance abuse.

To know the importance of road geometry, it is necessary to have accurate data about crash location. Often these data are only approximate (to the nearest mile marker, for instance) or are not available at all (because they were inadvertently omitted from the police report or purposely excluded from the data set to protect privacy). As a result, it is difficult to pinpoint high-accident locations and establish reliable relationships between crash types or severity and particular roadway geometries. The use of GPS can help identify crash locations with much greater accuracy. More accurate crash location data can also allow researchers to see exactly what pavement marking, signage, guardrail, and other traffic control and safety appurtenances and roadside objects are at the scene.

Speed is usually estimated from physical evidence associated with the crash, such as skid marks (if the vehicle does not have antilock brakes) and damage to vehicles and other objects. In some cases, speed can be determined by interviewing witnesses or someone involved in the crash. These methods (especially interviews) are only approximate, however, and can be extremely inaccurate. EDRs can provide accurate speeds, as well as changes in speed (delta V) during the crash. In addition, if EDR and GPS technologies are used to gather information about typical speeds on similar geometries where crashes do not occur, researchers will have a much better idea of how significant a factor speed is in crashes and what ranges of speeds may be safer.

As noted, EDRs can provide highly accurate data on vehicle functions, as well as some aspects of driver performance or behavior. A driver may report that he or she applied the brakes or was wearing a safety belt at the time of a crash. But an EDR will record if and when the brakes were in fact applied and which, if any, of the safety belts in the vehicle were in use.

Measures of driver characteristics are more difficult to obtain. Police may administer tests related to alcohol use, but they do not always do so. Information about possible sources of driver distraction may be observed (a cell phone, several children in the vehicle), but it is difficult to know whether a given distraction was actually taking place just before the crash. Interviews are again the main source of this kind of information, as well as that concerning fatigue or possible mental distractions (such as whether the driver was worried about a problem at home or at work). Yet the technologies described earlier can help provide more accurate data on driver activities through use of video and audio recording, if appropriate permission is obtained and privacy issues are adequately addressed. Similar information (for example, on cell phone use, external distractions, eye movement, drowsiness) from noncrash circumstances would help determine the extent to which these factors differ between crash and noncrash situations.

Such improved data could inform more effective use of countermeasures in several ways. Changes in velocity during a crash, for instance, have implications for the design of vehicle safety features and roadside hardware because they determine the amount of energy that must be absorbed by the vehicle or hardware to reduce injury to the vehicle's occupants. More accurate data on speed not only could be used to design better roadside hardware, but also could affect geometric design, signage, traffic control devices, and enforcement strategies. More accurate data on crash locations would allow researchers to compare crash severity at locations with various geometric designs and under use of different countermeasures, such as the design and placement of guardrails or crash attenuators.

There are many other considerations related to run-off-the-road crashes, and similar examples could be developed for intersection crashes, vehicle rollovers, and other types of crashes. Given the complexity of these crashes, the researchers will have to strategically select which factors and countermeasures should be the focus of the research design and analysis. This selection can be made on the basis of existing data from NHTSA and FHWA on the incidence of various crash types and countermeasures.

Summary

This proposed research program is intended to identify a strategic direction (critical knowledge requirements for substantially improved highway safety) and potential opportunities in this area afforded by research and the use of advanced technologies. The committee is aware that this is a very broad and ambitious proposal. While all four proposed research programs will require additional definition during the interim period, the safety program depends most critically on this interim work. The committee recognizes that the research cannot address the entire universe of possible crash types, crash factors, and crash countermeasures. However, the human suffering and economic burden resulting from highway crashes warrants something significantly more than continued small-scale, incremental improvement. Given recent advances in computer data storage, processing, and communications technologies, what once would have been an overwhelming if not impossible task is now only challenging. The advanced technologies currently available make it feasible to gather more accurate and some previously unobtainable data to develop a robust and scientific understanding of highway crashes upon which decisions about cost-effective, life-saving safety investments can be based. While expert interpretation of the objective data will still be required, the increased objective data provided by the proposed study will reduce much of the need for conjecture and subjective opinion in the analysis of crashes.

Proposed Research Tasks

A feasibility study should be conducted and a detailed research plan developed before the full-scale study is initiated. The feasibility study corresponds to the interim work (described in Chapter 8) that is required for all four F-SHRP programs and should include the following tasks:

- *Define clearly the goals of the study, the questions to be addressed, and the data needed to answer these questions.* Research questions will focus on issues such as the contribution of various factors to particular crash types and the relative cost-effectiveness of selected countermeasures in addressing these factors. The feasibility study should help identify crash types, factors, and countermeasures for which the full-scale study can be expected to yield beneficial results. The relative strengths and weaknesses of different options for the focus of the full-scale study should be identified. The study might also address such issues as the following: Are drivers compensating for the benefits of new safety measures by pushing the limits more? How can emerging advanced communications technologies (telematics) be used strategically? How can drivers be informed about the potential benefits and risks of these technologies?
- *Assess the capability of EDRs, GPS, video technology, and other methods to capture the required data.* Define critical shortcomings, and propose alternative means of acquiring data in these areas.

- *Perform an analysis to assess the feasibility of carrying out the study of crash factors as described.* This analysis should address such issues as the following:
  – Whether the EDRs and GPS devices already in vehicles can be used for the study, or the researchers will need to equip vehicles with specially designed devices.
  – How other in-vehicle devices, such as cameras and sensors, might be used. For example, can they be installed in a representative sample of vehicles, or should a separate sample of fleet vehicles be equipped with these technologies? What are the trade-offs in terms of the cost and value of the data?
  – Whether the legal and privacy issues concerning EDRs, cameras, and other technologies significantly compromise their use in the proposed study.
  – If any of these technologies are not feasible, whether other methods can be used to obtain equivalent data.
  – How data will be handled: who will collect them, where they will reside, how privacy will be protected, and how and which data (if any) will be available to other researchers.
  – Whether use of the Department of Health and Human Services Certificate of Confidentiality is appropriate and feasible for this study.
  – How coordination with other, related programs can be achieved to avoid duplication and leverage financial resources and expertise.
- *Design a research protocol that will result in obtaining the appropriate data and performing the required analyses, taking into account the results of the feasibility study.*
- *Investigate possible incentives that could be offered to vehicle owners for participation in the study,* such as provision of navigation technology (if this does not introduce a bias to the research) or automatic notification of 911 in the event of a serious crash.
- *Develop a cost estimate and schedule for the full-scale research program.*

If possible, a pilot study to test the research protocol should also be performed before embarking on a large-scale research program. If this is not possible, such a pilot study would be the first task under the formal research program. Other broad tasks within the study, pending development of a detailed plan, are as follows:

- *Conduct of the study*—This task will be accomplished using whatever suite of research methods is determined to be appropriate in the detailed research plan. These methods may include surveys, interviews, on-site crash investigation, use of police accident reports, and collection of data by means of advanced technologies. The study should focus on a set of crash types, crash factors, and countermeasures, taking into account the strengths and weaknesses of the options identified in the feasibility study. The research team should include the following disciplines, and others as appropriate: human factors, traffic engineering, vehicle design, roadway design, enforcement, driver education, and public awareness.

- *Analysis of data*—The detailed research plan will include the specific questions to be addressed by the research (which will drive decisions about which data to collect). Appropriate analyses will be performed on the data to address these questions and develop conclusions about the relative contributions of various crash factors in certain crash types and the cost-effectiveness of selected countermeasures.
- *Recommendations concerning countermeasures*—On the basis of the knowledge gained from the study, the selected crash countermeasures (which may include roadway designs, vehicle designs, education, public awareness programs, and enforcement strategies) should be assessed and recommendations made about those most cost-effective to implement.

Relationship to Other Work

Other Research and Technology Efforts

Other highway safety efforts can provide opportunities for dialogue with and involvement of stakeholders, complementary research results, articulation of safety goals, and venues for implementation. These other efforts include the following:

- NHTSA's Fatality Analysis Reporting System uses state DOT, police, and other data to study fatal crashes. The agency's National Automotive Sampling System examines all types of crashes using the General Estimates System, which looks at a nationally representative sample of crashes using information from police reports; and the Crashworthiness Data System, which performs detailed analyses of 5,000 crashes per year, supplementing police reports with on-site investigation and other data (including some use of EDRs).
- NHTSA is conducting a study in Georgia using EDRs on 1,100 vehicles to test the use of this technology in crash studies. The results of that effort should be considered in the feasibility study for this proposed research.
- As noted, FMCSA is conducting a congressionally mandated $15 million to $20 million truck crash causation study. The study will include in-depth

investigations of a representative sample of large-truck crashes involving fatalities or serious injuries. Trained investigators from NHTSA and FMCSA are involved in the study.

- FHWA performs limited crash analyses using the data from eight states in the agency's Highway Safety Information System. FHWA has also developed the Interactive Highway Safety Design Model (IHSDM), which can be used to better integrate safety analysis into the planning and design phases of highway development. IHSDM design modules use estimates of the effectiveness of various countermeasures (such as wider lanes or larger curve radii) in reducing accidents. At present, this model focuses predominantly on two-lane rural highways, but it will be expanded to higher-volume and more complex road configurations in coordination with NCHRP's development of a highway safety manual (discussed below). FHWA has also funded the development of the ALERT vehicle, a law enforcement vehicle equipped with advanced communications technology to aid police officers in collecting more accurate data at crash scenes.
- The Comprehensive Highway Safety Improvement Model is a 6-year, $2.5 million project to develop an expert system for use by each state, with its particular databases, to screen the road network, identify high- or higher-than-expected accident locations, diagnose the accident causes from the patterns seen in collision diagrams and site visits, select countermeasures related to the particular accident types, and compare the cost–benefits of these countermeasures to select those most appropriate.
- Under the Intelligent Vehicle Initiative (IVI), the U.S. Department of Transportation's Joint Program Office for Intelligent Transportation Systems has created a partnership with industry aimed at developing in-vehicle technologies that can help in avoiding common types of crashes, such as rear-end collisions, single-vehicle run-off-the-road crashes, and intersection collisions. A promising area is the development of cooperative vehicle–infrastructure ITS to enhance safety. FHWA has formulated initial plans in this area, but little work has been done to date because of a lack of funding. A crash causation study of limited scope may be proposed as part of the IVI activities, as well as studies of naturalistic driving (to learn more about driver behavior).
- NCHRP has initiated a study on the use of EDR technology for the collection and analysis of highway crash data.
- The development of prototype countermeasures under the proposed program should be closely coordinated with related ongoing safety research being conducted by NCHRP, state DOTs, universities, and industry.

• The *AASHTO Strategic Highway Safety Plan*[9] was developed in 1997 by AASHTO in cooperation with FHWA, NHTSA, and TRB and with input from a broad range of highway safety stakeholders and interest groups. The plan targets the goal of saving 5,000 to 7,000 lives annually and substantially reducing health care costs related to highway crashes over a period of 5 to 7 years. Emphasis is placed on making a concerted effort to implement proven highway safety strategies and on conducting some model development and demonstration of emerging strategies in 22 key emphasis areas. The plan does not identify long-term knowledge gaps or research needs; however, the implementation of proven strategies builds on historical safety research, and the model development and demonstration effort requires the support of existing safety research programs at FHWA, NCHRP, and state DOTs. NCHRP Project 17-18, with additional pooled funding from state DOTs, involves a series of tasks aimed at implementing the AASHTO plan. One of these tasks (Task 5) will involve developing an integrated management system for highway safety.

• The development of a highway safety manual through NCHRP is a new effort to evaluate, standardize, and disseminate best practices in highway safety.

• AASHTO is developing safety software that will, among other things, facilitate more accurate crash reporting for police.

Other Strategic Focus Areas in F-SHRP

Lessons learned from this study about the role of highway design and roadside features will be applicable to highway renewal projects, as well as to the construction of new highways that may be required to meet increased demand. Improved safety will also contribute to highway system reliability by reducing the number of crashes that take place within the system.

Administrative and Implementation Considerations

Several considerations should be kept in mind during the development and performance of the proposed study. For example, research should be done in close cooperation with FHWA, NHTSA, and FMCSA. Lessons from the ongoing truck crash causation study being sponsored by FMCSA and from the EDR studies being undertaken by NHTSA and NCHRP should be incor-

[9] Available at safetyplan.tamu.edu/index.htm.

porated into the design and conduct of this research program. The use of EDR technology will require the active involvement of vehicle manufacturers, whose cooperation must be sought as early as possible in the study. In addition, the insurance industry may be interested in participating.

Additional considerations pertain more directly to implementation of the research results. For instance, the recently initiated NCHRP highway safety manual could be an ideal implementation vehicle. Assessments of the cost-effectiveness of selected countermeasures would be extremely useful information for users of the manual. Researchers engaged in improving existing countermeasures or in developing new ones could benefit from data about crash factors. In general, the research program staff should maintain regular contact with safety professionals within state and local agencies to keep them abreast of the program as it develops and to obtain their input in the development of prototype countermeasures.

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ABBREVIATIONS

BTS	Bureau of Transportation Statistics
NHTSA	National Highway Traffic Safety Administration
NSC	National Safety Council

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ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
DOT	U.S. Department of Transportation
GAO	General Accounting Office
TRB	Transportation Research Board

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6 CHAPTER *Reliability: Providing a Highway System with Reliable Travel Times*

Overall research program goal: To provide highway users with reliable travel times by preventing and reducing the impact of nonrecurring incidents.

Challenge of Providing Reliable Highway Travel Times

As indicated in Chapter 4, vehicle-miles traveled (VMT) on the nation's roadways increased 76 percent between 1980 and 1999, a period during which the total lane-miles of roads increased by only 3 percent. Along with rising VMT, there are some indications that congestion is getting worse. In its study of 68 urban areas, the Texas Transportation Institute (TTI) found that on average, the percentage of daily traffic in congested periods increased from 32 percent (about 5 hours per day) in 1982 to 45 percent (about 7 hours per day) in 1999 (Schrank and Lomax 2001). FHWA reports that average daily delay (based on the difference between estimated actual travel speed and free-flow travel speed) increased 8.5 percent between 1993 and 1997, from 8.268 to 8.973 hours per 1,000 VMT (FHWA and FTA 2000).[1] Average daily vehicles per lane on urban Interstates rose 43 percent between 1985 and 1999, from 10.331 million to 14.757 million (FHWA 1999; FHWA 2001a). In addition, highway trips are longer and involve more interstate travel; there are fewer alternative routes for many of these trips; and more bottleneck situations have developed in many regions, causing significant user delay. In 1999, 4.5 billion hours and 6.8 billion gallons of fuel were wasted in just 68 urban areas as a result of highway delay. The cost of this congestion was estimated at $78 billion (Schrank and Lomax 2001). Moreover, VMT increases are expected to continue with very little additional capacity for the foreseeable future. As a

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[1] There has been some decline in this measure since 1995, when average daily delay was calculated to be 9.348 hours per 1,000 VMT.

consequence, the importance of managing existing capacity for optimal performance is rapidly increasing.

Optimal performance for many users (travelers and freight haulers) is a totally free-flowing system. However, it is unlikely that congestion can be entirely eliminated, or even significantly reduced. In fact, recent FHWA surveys show that drivers have accepted a certain amount of recurrent travel delay and have made lifestyle adjustments to accommodate the reality of congestion (FHWA 2001b). Moreover, shippers and carriers of goods account for expected congestion in their scheduling and logistics algorithms. The real problem for users is unexpected delay, the time they do not plan to spend on the highway—in short, the unreliability of the system (Loudon and Layden 2000; Golob and Regan 2001). The closer to capacity a system operates, the more severely it will react to disruptions, and therefore the greater will be the impact of its unreliability on users. For freight carriers, unreliability is a two-edged sword: as a result of the emergence of just-in-time delivery, carriers are penalized for being too early as well as too late. Reliability of the highway system is important for transit vehicles as well, so they can adhere to the schedules their riders expect. And when emergency evacuation is required, reliability is required to move people to safety predictably and consistently on very short notice.

There are many sources of unreliability in highway travel time. Perhaps most obvious are nonrecurring incidents such as crashes, broken-down vehicles, road debris, and spills. In addition, the need to renew significant portions of the highway system means an increasing number of work zones, with corresponding impacts on reliability. Special events such as parades, sporting events, and large conventions can significantly increase travel times as well if drivers are not aware of them in advance and are not given the opportunity to adjust their travel time or route. Precipitation, sun glare, and the occasional lost tourist can also have dramatic effects on the flow of traffic. Efforts to improve system reliability may address all these issues and more.

Improving travel time reliability is primarily a matter of system operations, but the discipline of highway operations is still an emerging field.[2] While

[2] The development of the field of transportation operations is a top priority for many in the transportation community. Since 1999, a National Dialogue on Transportation Operations, sponsored by the ITS Joint Program Office at FHWA with the involvement of AASHTO, the American Public Transportation Association, and the Institute of Transportation Engineers, has engaged transportation professionals in wide-ranging discussions about the future of the field. Information on this initiative is available at www.ite.org.

operational improvements are continually being made, the urgency of practical, day-to-day problems forces most agencies to respond reactively to operational demands as they arise. Many new technologies are available to aid managers and users of the highway system, including simulation and prediction models, better signal systems, traffic control technologies, driver information systems, and other technologies developed through research on intelligent transportation systems (ITS), but these tools need further development and integration into effective strategies aimed at more clearly defined performance expectations.

In addition, roadway operations in their broadest sense involve a wide variety of people and institutions. Beyond users of the highway itself—private individuals, commercial users, transit (buses), pedestrians, and cyclists—others are affected by highway operations, such as adjacent businesses and communities and local and regional economies. Various types of incidents and special events involve a host of other interested parties. For example, police, fire, and rescue personnel may be involved in responding to crashes; hazardous materials (hazmat) specialists have responsibility for responding to hazardous spills; and managers of sports stadiums and convention centers and organizers of major civic events are important stakeholders in the highway operations surrounding their events. Successfully integrating the involvement of all these customers and stakeholders—with their widely varied objectives, incentives, and cultures—is one of the greatest challenges facing those who would manage highway operations for improved system reliability. Box 6-1 describes an example of how the state of Rhode Island addressed special events in the city of Providence, while Box 6-2 illustrates a statewide approach to incident management and response in the state of Maryland.

In this context, the committee proposes for F-SHRP a program of research focused on improving travel time reliability by addressing the impacts of particular types of nonrecurring incidents and special events. A portion of this problem is already covered under the highway renewal program (see Chapter 4), which addresses user delay from work zones. Under the present program, integrated approaches to other types of incidents will be developed. Examples include vehicle breakdowns and spills, which cause physical impedance to traffic both when they occur and while they are being addressed on site by various authorities; special events, which are becoming increasingly common, especially in already congested metropolitan areas where stadiums and convention centers are being built to boost the local economy; and other conditions that can affect travel time reliability, such as weather, wind, and sun glare.

Box 6-1

Incident Management Plan, Providence, Rhode Island

Providence, Rhode Island, was not accustomed to the multihour peak traffic periods common to many metropolitan areas, so the state highway agency—and not a few highway users—were surprised when traffic came to a standstill one day in February 1999 as a result of a flower show in the city's convention center. Upon further investigation, it became clear that the reason for the unexpected tie-up was that the many authorities and stakeholders associated with the event—the Rhode Island DOT (RIDOT), the police department, the convention center authority, the transit agency, private parking operators, and a private developer that had a lane closed for construction of a nearby building—had not communicated with each other, but had performed actions or given clearance for actions that compounded the effects of the flower show on traffic conditions. No plan was in place for dealing with such events, and several even larger special events were scheduled for the ensuing months.

Given the potential impact on city streets and Interstate 95, which passes through Providence, RIDOT set about developing a traffic management plan. This effort involved coordination of more than 30 stakeholders, integration of several innovative technologies and techniques (including variable message signs, highway advisory radio, use of radio and television to inform travelers, traffic signal systems, surveillance cameras, surveillance personnel stationed in vehicles, and a traffic operations center), and more traditional techniques (such as signs, pavement markings, and cones). The information needed to carry out the plan was documented in a "playbook" that was given to each stakeholder so everyone would have the same information. The plan went into effect for the next special event, which went off very smoothly; even the newspapers commented on how good the traffic flow and parking were.

Source: Shaw et al. (2000).

Box 6-2

Statewide Incident Management Plan, Maryland

As part of its statewide operations program, CHART, the Maryland State Highway Administration (SHA) has developed a nationally recognized incident management program. In cooperation with the Maryland State Police and the Maryland Transportation Authority, SHA ensures an immediate response to traffic incidents to protect the safety of travelers and emergency personnel and to allow normal traffic flow to resume as quickly as possible. The incident management program involves a number of tools: emergency traffic patrols provide emergency motorist assistance and relocate disabled vehicles out of travel lanes; emergency response units establish traffic control at crash locations; and freeway incident traffic management trailers quickly set up preplanned detour routes when incidents require full roadway closure. Maryland uses a “clear the road” policy that calls for rapidly removing vehicles from travel lanes instead of waiting for a private tow service or time-consuming off-loading of disabled trucks that are blocking traffic. An Information Exchange Network Clearinghouse, provided by the I-95 Corridor Coalition, shares incident and traveler information with member agencies along the corridor. Other tools to facilitate incident management include portable arrow boards, portable variable message signs, and portable traveler advisory radio transmitters for traffic management; front-end loaders, tow rigs, and push bumpers to move vehicles; and training exercises to maintain a high competency level for teams working under hazardous conditions.

Source: Most of this paragraph is taken directly from the Maryland State Highway Administration website at www.sha.state.md.us.

Improving travel time reliability involves more than addressing nonrecurring incidents and special events; however, it is crucial to the effectiveness of the research program that there be an application-specific focus. The emphasis of the proposed research on incidents and special events is not meant to imply that other aspects of the problem are unimportant, but to concentrate intellectual, financial, and implementation resources on specific problems with measurable outcomes. As an indication of the magnitude of the impact of nonrecurring incidents, the above-referenced TTI study (Schrank and

Lomax 2001) suggests that in 1999, such incidents were responsible for approximately 54 percent of highway delay—2.4 billion person-hours at a cost of $42 billion—in the 68 urban areas studied. An effective incident management and response program can be an excellent investment: Chicago's program has an estimated benefit/cost ratio of 17 (Cambridge Systematics, Inc. 1990). Nonrecurring incidents also increase the likelihood of secondary crashes, thereby reducing highway safety.

Significant improvements in travel time reliability can thus be achieved through a focus on nonrecurring incidents and special events. To this end, the proposed F-SHRP research will address customer performance requirements, institutional issues, data and information needs, and selected technologies associated with this aspect of the travel time reliability problem. Lessons learned from a focus on this aspect of the problem will certainly apply to other challenges faced by highway system managers.

Providing Solutions for the Reliability Challenge Through a Future Strategic Highway Research Program

How improved travel time reliability for highway users meets the first criterion set forth in Chapter 1 for selecting the strategic focus areas for F-SHRP was described in the preceding section: it is an issue that bears on national transportation goals and is of continuing concern to highway agencies. The other two F-SHRP criteria—appropriateness for a SHRP-style program and the effectiveness or expected impact of the research—and how the proposed program of research meets these criteria are addressed in this section.

Appropriateness for a SHRP-Style Research Program

A SHRP-style research program is appropriate for addressing the impact of nonrecurring incidents and special events on travel time reliability for several reasons. First, to achieve a significant improvement in system reliability will require a predictable concentration of resources on a clear goal over a period of several years. It will also require an integrated, systems approach involving numerous stakeholders, issues, and potential tools. Important work addressing the problem of nonrecurring incidents is being conducted in existing research programs, and a number of jurisdictions have developed incident management programs. However, a concentrated effort aimed specifically at improving travel time reliability—with emphasis on defining customer performance requirements and responding to those requirements through the advancement and interplay of technology, data, and institutions—conducted in coordination with existing activities, can accelerate progress toward specific operational goals. Indeed, the institutional aspect of this issue is so critical and so neglected in terms of solid research foundation that work on this aspect alone may make the most significant contribution to a significant improvement in highway system operations. A focused independent program such as F-SHRP, because of its relative freedom from the institutional constraints of existing programs, is best equipped to sponsor research in this sensitive area and to integrate the aspects of customer needs, data, and technology into a single, outcome-oriented program. Finally, while the benefits of improved highway travel time reliability will accrue to many individuals and groups, some of the necessary investments in research and development are unlikely to be made by the private sector (since individual firms would not be able to capture the returns on these investments); this is therefore an appropriate area for public-sector involvement.

Effectiveness or Expected Impact of the Research

Given recent technological advances, integration of the salient technologies—together with research in customer requirements, data needs, and institutional issues—can be expected to yield substantial improvements in highway operations that will significantly increase system reliability. The potential impact of such improvements is large. One measure of the potential impact is the user savings from reduced highway delay. As noted earlier, TTI's study of 68 urban areas revealed that highway delay cost users in these areas approximately $78 billion in 1999, about 54 percent of which could be attributed to nonrecurring incidents such as construction work, disabled vehicles, and crashes. If implementation of the results of the research described in this chapter and Chapter 4 reduced such incident-related delay in these urban areas by just 5 percent, the result would be annual savings of about $2.1 billion.

It is reasonable to expect the proposed research to yield results in 5 to 7 years. Barriers to implementation will be largely institutional and financial, which is why these areas will be the particular emphasis of research and stakeholder involvement. The implementing community is a diverse group, and focused effort will be required to assist them in the implementation effort. Finally, some of the proposed research—especially in the institutional area—will require expertise and research methodologies not commonly brought to bear in highway research; new sources of research capacity (primarily in the social sciences) will therefore need to be sought and introduced into the highway operations arena.

Proposed F-SHRP Research

Major Research Objectives

The proposed research program has two major objectives:

- To characterize the chosen incident types in terms of likelihood of occurrence, impacts on users, and customer expectations for management and response; and
- To develop integrated strategies or approaches that effectively apply the many tools and technologies available for managing and responding to the chosen incident types.

What meeting these objectives entails and how the objectives are addressed by the proposed focused research program are described in more detail in this section.

Characterizing Incident Types

A number of different types of nonrecurring incidents and special events affect highway operations and consequently travel time reliability. Several of these are briefly described here as examples. One of the first tasks of the research program will be to choose which of these incident types can be addressed most effectively.

Crashes Crashes generally require a quick response, especially for the care of injured parties. The use of sensing and communications technology can help authorities identify incidents and respond both more quickly and with the most appropriate equipment and medical help. Very serious crashes may require the presence of fire trucks, ambulances, and helicopters, all of which take up significant space on the roadway. The police must gather certain data at the crash scene, which can be facilitated by advanced data-gathering technologies. All of these activities cause disruption to the flow of traffic and increase the likelihood of secondary crashes. The involvement of multiple institutions (police, fire, medical, state highway forces) introduces complex issues of coordination and authority, which can also add to the time the roadway is blocked. In addition, motorists not involved in a crash often contribute to disruptions in traffic flow in both directions by slowing down to view the scene.

The unplanned nature of crashes (as well as other types of incidents) poses challenges for the task of communicating with users about impacts on traffic flow and travel time and about alternate routes. A number of technologies are available to address this challenge, but effective communication about incidents is still in its infancy. Technologies are also under development that would allow highway system managers to adjust signal timing (where applicable) to reduce the impact of incidents on traffic flow.

Disabled Vehicles Vehicles can break down for a number of reasons, including mechanical failure, a flat tire, or lack of fuel. The response to such events is much less urgent than in the case of crashes with injuries. However, the presence of a stationary vehicle in the roadway is disruptive to traffic flow and can potentially cause a crash. Minor crashes are similar situations, but usually with the added factor of two or more drivers standing in the road exchanging insurance information or waiting for police to arrive. The main objective in all these cases is to clear the vehicle (or vehicles) from the roadway as quickly as possible in order to reduce the safety hazard and the traffic disruption. Many states have experimented with ways of achieving this objective. Examples are the use of "courtesy patrols"—DOT vehicles that travel over major commuting routes to help motorists with broken-down vehicles by changing a tire, providing fuel, or towing a vehicle out of the travel lane—and the posting of signs asking motorists to pull off the road in the case of a fender bender instead of leaving their vehicles in the travel lanes.

Hazardous Materials Spills Any material spill on a highway will disrupt traffic flow and pose a potential safety problem, but in the case of hazardous materials, additional human and environmental safety considerations frequently cause a roadway to be completely closed even if the actual physical impediment is small. Procedures for cleaning up such spills can be quite time-consuming as well. As in the case of crashes, the use of technology to quickly learn of a spill event, respond, identify the nature of the hazardous material, and contain or remove it can significantly reduce the impact on traffic flow and safety.

Road Construction and Maintenance Construction work zones constitute another type of incident, although usually one that is planned well in advance—a fact that provides the opportunity to communicate with users about potential traffic impacts and to address alternative routes, times, and modes of travel. Work zones also introduce specific types of safety concerns, both for workers who are in close proximity to moving vehicles and for drivers who may have difficulty negotiating new traffic patterns established during construction activities. As noted, the impacts of work zones on highway users will be dealt with in some detail under the proposed highway renewal research (see Chapter 4).

In contrast to highway renewal work, maintenance activities are frequently smaller-scale activities that may take less time or may progress along the highway, creating a moving bottleneck. Moreover, such activities often are not planned well in advance, since they can include filling a pothole, removing an animal struck by a vehicle, or repairing a sign or signal. At the same time, these activities may not involve coordination with other institutions and so may be amenable to a broader range of strategies for which DOT staffs can be well prepared.

Special Events The special events referred to here generally consist of planned activities of sufficient size or duration that they may have significant impacts on traffic flow and access. Such events can include parades (which often involve closing long stretches of road, with consequent impacts on cross streets as well), conventions, sports events, and civic events. Some special events (including those that are annual or seasonal) may occur on a regular schedule and at a fixed location (for example, a stadium or convention center). In these situations, it may make sense to install specialized traffic control technologies in the vicinity of the events and develop a management plan for repeated use. Other events are irregular or unique and may involve special considerations. Their sponsors may not be accustomed to thinking about traffic impacts and may have no experience with planning the transportation logistics related to their events (including bus access, parking, roadway capacity, and the time it takes for a large volume of vehicles to negotiate even a simple traffic pattern). Much of the activity may take place on private property but may have significant spillover effects on public roadways. Engaging the many types of sponsors of such events in transportation management and operations poses significant institutional challenges.

Characterizing the Selected Types It will be necessary to develop a full characterization or understanding of each type of incident or special event chosen for the research. This characterization should include, for example, the following points:

- Frequency of incident occurrence and likelihood of occurrence under particular circumstances (such as inclement weather) or in particular locations (such as near shopping malls or on long stretches of rural highway).
- Impact of incident type on different classes of users (commuters, vacationers, truckers, transit users, shippers).
- Customer requirements that may drive incident management and response, such as how far in advance commuters must be informed of a special event or what type of detour information is useful to a commercial vehicle operator when a crash occurs. (For example, truckers need information well in advance of their destination so they can decide what to do; commuters are not usually that far from their destination, so the timing of their information needs may be different.)
- Performance requirements for different authorities responding to an incident (police, DOT personnel, hazmat experts, fire and ambulance personnel) and for various sponsors of and participants in special events.

To the extent that some of these characterization efforts have already been addressed by other programs, the F-SHRP research will synthesize and build on those efforts. For example, in a study sponsored by the Trucking Research Institute in 1990, it was estimated that disabled vehicles accounted for 80 percent of recorded incidents and approximately 20 percent of incident-related vehicle-hours of delay, while crashes accounted for 10 percent of recorded incidents but nearly 60 percent of incident-related delay.[3] Updated information of this sort could help determine the specific focus of the research program.

Developing Integrated Approaches

For effective management of and response to incidents and special events, it is necessary to have strategies or approaches that integrate institutional issues, data and communication issues, and associated tools and technologies. These three topics represent distinct research areas, as described below. Yet following a systems approach, which is an important part of F-SHRP's

[3] See Cambridge Systematics, Inc. (1990). Statistics in this study are based on reported incidents recorded by police and highway agencies; they do not include minor events or work zones.

philosophy (see Chapter 1), requires that these three areas be addressed in an integrated manner. For example, data and communication issues are clearly affected by both institutional culture and technology. Technologies must fit with institutions, and institutions often must change in response to technologies to better carry out their mission. The F-SHRP research will address these topics in an integrated way and produce results—analyses, information, technologies, best practices—that can likewise be implemented in an integrated manner, with appropriate guidelines for application to specific operational environments.

Institutional Issues Incident management and special events can involve a wide range of stakeholders with diverse goals, incentives, and cultures. One of the biggest challenges to consistently achieving effective incident management is coordinating and integrating the responses of the groups involved, each with responsibility to serve the public, but with sometimes divergent priorities and performance objectives. Highway personnel are sensitive to their public responsibility of keeping the roads operating smoothly, knowing that disruptions in traffic flow have very real safety and economic implications. Fire and rescue personnel are concerned with the safety and medical care of those immediately involved in an incident, as well as with the safety of their own people who are exposing themselves to traffic, fire, and other dangers. Hazmat specialists are concerned with environmental safety as well as immediate human safety. Police, in addition to victim, public, and personal safety, are responsible for specific law enforcement actions and record keeping (such as citations and accident reports). All of these people expose themselves to personal danger in the name of public service. Each group has its own norms, guidelines, sense of authority, and internal culture (based largely on the development of trust among team members). The involvement of multiple groups can threaten the sense of security and authority of each, leading to situations that may, ironically, cause such groups to unconsciously de-emphasize the public good each has set out to serve. Even within highway agencies, institutional challenges exist with respect to improving system operations. Performance measures, incentives, training, and resources can all constrain an agency's ability to meet customer expectations more consistently.

Addressing such issues is not as straightforward as research and development in technological areas. However, it is possible and critically important to engage in systematic and objective research in this area to find or develop ways to overcome the institutional obstacles involved. The committee believes a portion of F-SHRP resources should be focused on this topic. Research methods may include a variety of approaches appropriate to social science studies, such as surveys, interviews, case studies, and quasi-experimental designs. It may even be possible to perform demonstrations of best practices in this area. The challenge is twofold: (*a*) bringing the diverse groups involved together to design and carry out the research program and (*b*) conducting a research program that differs significantly from traditional highway research in engineering and planning disciplines. The F-SHRP program is ideally suited to address these challenges by bridging institutional, cultural, and disciplinary boundaries.

Data and Communication Issues In the context of travel time reliability, information is important to both users and managers of the system. Managers must have accurate, timely, and consistent data on system operation. To this end, they need data collection tools that are easy and inexpensive to install, require little maintenance, and record data reliably and accurately. Once the data have been acquired, they must quickly be analyzed and transformed into useful information about system operation, in this case travel time reliability. This information must then be made meaningful for various classes of highway users and communicated to them in a timely manner. Accurate and timely information about system operation can at least forewarn users about unusual travel delays when they occur, and in combination with information about alternative routes and modes, system operation information allows users to make choices that best meet their own requirements and priorities. Even better, the right information about system operation, combined with predictive simulation models and various traffic control tools, can allow planners and operators of the highway system to respond to events to mitigate their impact on reliability, or even anticipate events to reduce the severity of potential impacts.

Every step of this process is fraught with both challenges and opportunities. Technologies exist, at various levels of sophistication, for implementing each step. The institutional, technological, and economic issues discussed elsewhere are among the challenges, but questions about the human factors aspect of data and communication also require focused research. It is necessary to know what reliability means to different users, how physical measures of events occurring on the system relate to these customer performance requirements, what kind of information users need to make appropriate decisions about travel, and when and in what format they need this information. The success achieved in providing answers to these questions may well determine whether the new nationwide 511 number allocated by the Federal Communications Commission for traffic information will survive beyond its 5-year trial period. Research in this area may also address privacy issues arising from the collection and communication of certain types of data (concerning, for example, vehicle location).

Tools and Technologies A wide variety of tools, technologies, and techniques exist to aid highway agencies in operating their systems. These include detection or sensing technologies, traffic simulation models, prediction tools, travel information technologies, responsive and adaptive traffic control technologies, analysis and design methodologies, management techniques that improve highway flow and contribute to crash reduction, the deployment of ITS infrastructure that enables real-time management of highways, and the availability of information that allows customers to use the transportation system more efficiently.

While much more research and development needs to be done in all these areas and others, there are at least two implementation challenges with regard to existing technologies. First, it is not always clear how these technologies can best be used, and in what combinations, to achieve particular performance requirements in specific operational settings. Second, the implementation of many new technologies is extremely resource-intensive. The initial cost of equipment and installation is the first barrier, but regular maintenance then requires money and trained personnel, both of which are scarce in most jurisdictions. The F-SHRP research will help address the first challenge by assessing the effectiveness of existing technologies for improving travel time reliability in the management of incidents and special events. This assessment, in combination with lessons learned in the institutional research, will help address the second barrier by providing guidelines for the development of technologies that are more compatible with institutional realities, possibly by encompassing the technology development itself in some cases, and by helping institutions better implement tools designed to address customer needs for improved system reliability.

Proposed Research Tasks

One of the objectives of the interim work for this focus area (see Chapter 8) is to choose the set of incidents on which the research will focus. Examples of nonrecurring incidents have been described earlier in this chapter. The choice of specific incident types should be based on the greatest potential benefit to users. This determination may include estimation of the relative impact of each type of incident on overall travel time reliability (or its contribution to delay) and the potential for alleviating this impact through the application of research and technology.

The research proper will involve the development of effective approaches to increasing travel time reliability through management of and response to incidents and special events and will integrate institutional efforts, data, and technology. To this end, the research will focus on the following tasks:

- *Identify customer needs and expectations regarding travel time reliability.* Customer needs and expectations for different market segments (passenger versus freight movement, work commute versus recreational, special needs of particular groups) will be identified and quantified.
- *Develop corresponding performance measures and indicators for reliability.* Consensus-based performance measures and indicators will be developed for appropriate levels of system application and operational intensity to help agencies determine cost-effective approaches to meeting customer needs.
- *Perform research on institutional issues.* This task will include identifying diverse institutional goals, incentives, and requirements; describing institutional cultures; identifying best practices (e.g., of institutional coordination, communication, and resolution of authority); demonstrating and testing new methods; and developing guidelines for implementing best practices and for identifying and meeting education and training needs.
- *Perform research on information needs.* This research will involve identifying information needs for different customer segments under various travel conditions (such as commute, recreation, work zone, disaster, special event, and freight delivery) and under various geographic, weather, and travel density conditions, as well as for functional specifications of various roadway classes. It will also include developing indicators or indices that adequately communicate system performance to customers and operators in useful ways, studying human factors aspects of effectively communicating the information within the constraints of various media (telephone, broadcast, personal digital assistant, Internet, variable message signs), and determining how best to provide information about intermodal connections and alternatives.
- *Synthesize and assess existing and emerging technologies.* Syntheses of the status of salient technologies will be produced; their impact on reliability through application to incident and special event management will be assessed; and human and financial resource needs for implementation will be identified. Technologies addressed may include the following:

– Models for predicting travel time under different scenarios;
– Techniques for predicting location, frequency, duration, and type of incident as the basis for improving incident detection and response protocols, including prepositioning of service patrols, equipment, and personnel and targeting of traveler information;
– Use of on-site technologies (such as the Global Positioning System and video imaging from surveillance cameras) to substantially reduce the documentation requirements of serious crashes;
– Technologies for collection, storage, analysis, and communication of data;
– Simulation technologies for modeling impacts of incidents and special events;
– Micro traffic simulation models for more user-friendly applications;
– Low-cost/low-maintenance traffic-adaptive signal technology, especially for use in areas where special events occur regularly (such as near stadiums and convention centers); and
– Sensing and detection technologies, especially those that are low-cost/low-maintenance.

• *Perform research to improve or develop selected technologies.* Assessment of existing technologies may indicate that significant improvement can be gained from additional development of selected technologies or that specific technologies yet to be developed could improve the reliability of the highway system. Research and development may be conducted in these areas.

• *Develop guidelines.* The effectiveness of various treatments and approaches for achieving performance will be evaluated, and guidelines and warrants for using these approaches will be developed.

Relationship to Other Work

Other Research and Technology Efforts

Much related work in this area deals with incident management: describing the state of the art, promoting incident management techniques, and developing incident management programs in particular jurisdictions. Various state DOTs have developed incident management and response programs and protocols; this work has included successful efforts to address institutional issues. FHWA has sponsored work in traffic simulation models, traffic adaptive control systems, dynamic traffic assignment models, and the development of other technologies through the ITS program. The agency has conducted customer surveys and undertaken some initial work on defining reliability and other performance measures for highway users (for example, performance measures for freight movement across international borders) and has recently increased efforts to involve the public safety community in incident response. Under NCHRP, research has been done on performance measures, traffic control devices, and other aspects of traffic operations. The private sector also develops various traffic control and other technologies. The F-SHRP research program will be formulated and conducted in cooperation with these and other efforts.

Other Strategic Focus Areas in F-SHRP

This research is closely related to other F-SHRP focus areas. As noted, research on performing rapid, long-lived, minimally disruptive highway renewal will include a significant emphasis on work zone operations to determine how to decrease the impact of work zones on highway users. Improvements in safety resulting from a better understanding of crash factors and effective countermeasures will reduce the impact of crashes on the travel time reliability of the highway system. Better management of all kinds of incidents will, in turn, improve safety by reducing the risk of secondary crashes.

Administrative and Implementation Considerations

The importance of involving all relevant stakeholders in the conduct of this research and the implementation of its results was noted earlier. These stakeholders include state, federal, and local government agencies; fire, rescue, police, hazmat, and towing personnel; industries involved in developing the relevant technologies; and property owners and organizations involved in special events. In addition, the institutional research is likely to yield information that could significantly affect the education and training of transportation and other professionals. Universities and training professionals will also need to be engaged in this aspect of the program.

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ABBREVIATIONS

FHWA	Federal Highway Administration
FTA	Federal Transit Administration

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Additional Sources

ABBREVIATIONS

FHWA	Federal Highway Administration
ITE	Institute of Transportation Engineers

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CHAPTER 7

Capacity: Providing Highway Capacity in Support of the Nation's Economic, Environmental, and Social Goals

Overall research program goal: To develop approaches and tools for systematically integrating environmental, economic, and community requirements into the analysis, planning, and design of new highway capacity.

Challenge of Providing New Highway Capacity in an Environmentally, Economically, and Socially Responsive Manner

By 2020, the U.S. population is expected to have grown approximately 20 percent over the 1998 level (Bureau of the Census 1999). Automobile vehicle-miles traveled (VMT) will increase as individuals take advantage of the opportunities and enjoy the benefits afforded by a strong economy. Truck tonnage is expected to double in the same time frame (from 8.9 billion to 16.8 billion tons[1]) to meet the need for goods demanded by the growing population and economy. Increased international trade will mean more products flowing through the nation's borders and ports, which must be served by efficient highway connections. At the same time, trends such as e-commerce and just-in-time manufacturing will continue to result in more trucks on the road carrying electronically ordered goods and serving as mobile warehouses for industry.

Improvements in operations (including those resulting from the research programs proposed in Chapters 4 and 6) and safety (supported by the research

[1] Results of FHWA study, available at www.ops.fhwa.dot.gov/freight/wefa.ppt (Slide 18).

proposed in Chapter 5) will increase the effective capacity of the current system. But these measures will not come close to meeting the capacity needs resulting from the expected increase in VMT. There is already and will continue to be a need for additions to the highway system. For example, although lane-miles of roads increased by only 3 percent between 1980 and 1999, this figure still represented an average of almost 20,000 new lane-miles per year during that period. This new highway capacity does not encompass only completely new roads on new land, but often includes expanded capacity on existing roads. However, capacity expansion sometimes involves impacts on new land, such as when a bypass is built or a road must be relocated because of environmental, aesthetic, community, or historic concerns.

At the same time that customers require new highway capacity, they also demand a healthy environment and livable communities. Frequently, these needs are regarded as conflicting because of understandable concerns about the adverse impacts of highway construction. In its early days, the highway program focused on efficiency, mobility, uniformity, and safety. Critics of this earlier approach cite a number of adverse impacts: once-thriving communities severed by highways that disrupt their cohesiveness and often spell their demise; wildlife habitats disturbed, with unforeseen negative impacts on local species and ecosystems; highway runoff polluting adjacent waters with oil, fuel, metals, and salt; vehicle emissions causing significant regional air pollution and contributing to global warming; highways that detract from rather than enhance historic, cultural, community, and aesthetic values; increased crashes on high-speed through-streets in communities previously accustomed to a lower volume of slower traffic; and the disproportionate bearing of impacts of this sort by communities of lower socioeconomic status. In recent years, the highway program has focused more on providing context-sensitive design, mitigating environmental impacts, and enhancing community values and involvement. Indeed, it is now generally recognized that the highway development process must address all of the concerns mentioned above—efficiency, safety, aesthetics, environment, and community values—in an integrated and balanced manner.

Highways yield tremendous benefits to society. They are part of the essential infrastructure for a strong economy, providing access to jobs and making an array of goods and services available to all sectors of society in an efficient manner. They offer access to cultural and natural resources and allow family and friends to maintain frequent face-to-face contact despite the great distances that may separate them. All of these examples represent material contributions to the ideal of the United States as a land of opportunity. New highway capacity is needed to maintain and promote economic productivity, and highway transportation has a real role to play as an enabling agent in the attainment of many quality-of-life and social equity goals that remain to be fulfilled. However, building highway capacity is a long-term investment that requires significant lead time. Excessive delay in addressing the need for new capacity would result in serious long-term negative impacts of an economic and social nature. A sizable increase in the cost of transportation due to high levels of congestion would affect markets, jobs, and availability of goods. Transportation costs and bottlenecks could constrain the growth of existing industries and the development of new ones, just as increases in population are creating demand for both the products delivered via highways and the jobs created directly and indirectly by the highway transportation industry. Restricted mobility can constrain the economic, social, and cultural opportunities of all sectors of the population, but it most severely affects the less advantaged members of society.

As these examples show, the nation's highway system represents but one of many systems—including natural, social, political, and technological systems—that interact with each other to form the complex fabric of social and economic life. The planning and design of highways must therefore be performed with adequate attention to how these systems interact and influence one another. Highways can respond to as well as promote economic development. They can adversely affect or enhance the natural, social, and aesthetic environments. They can limit or create opportunity and reduce or enable social interaction. Much remains to be learned about these interactions. Research and experience have yielded some understanding of the impacts of highways on air and water quality, noise levels, habitats, and neighborhoods. But there are far more unanswered questions than solutions in all these areas and others, such as environmental justice, land use patterns, long-term economic impacts, and safety trade-offs involved in context-sensitive design.

Many of the existing methods, tools, and organizational approaches used in constructing highways are modified versions of those used to create the Interstate highway system. They have not been adequately modernized to account for dramatic changes in travel patterns, travel behavior, land use development patterns, technology, social behavior, environmental protection policies, scientific knowledge, and highway user needs. Moreover, differing regulations, tools, and methods are often employed both among and within states. As a result, the various analyses performed are not integrated with each other. In addition, most solutions addressing social and environmental concerns are developed as mitigating measures after the design work has been completed.

Meeting the demand for additional highway capacity will require innovative methods, tools, and organizational approaches to transportation planning, design, and environmental analyses and documentation. Analyses will need to be performed in an integrated manner and occur earlier in and throughout the highway development process. Box 7-1 describes how the state of Kentucky used such an approach to address capacity needs in a rural area.

In addition to demanding that highways be planned and designed with consideration of a broader range of performance requirements, the public and industry want the new capacity to be provided much more rapidly. They do not wish to wait 10, 20, or 30 years for capacity that was probably needed yesterday. Performing highway planning and design more rapidly while conducting more detailed analyses of a broader range of issues and impacts presents a daunting challenge to highway agencies.

The committee recognizes that there are more than technical aspects to this problem; political, ideological, and emotional elements figure strongly as well.

Box 7-1

Widening of Paris Pike, Kentucky

Paris Pike, a road running through the bluegrass horse country of Kentucky, had become a dangerous route because of the increased traffic on the small, two-lane facility. When the Kentucky Transportation Cabinet sought to widen the road, it met with opposition from local residents who were afraid the road expansion would alter the "country road" character of the facility. By working together with the residents, the Kentucky Transportation Cabinet was able to design a safe facility that retained and enhanced the aesthetics appropriate to its location. Public involvement included participation in traffic counts to verify actual traffic volumes, development of proposals for design elements, and voting on specific changes. Use of special materials and methods, such as wood for guardrails, dry-laid stone walls, and designs that retained significant landscape features, enhanced the overall aesthetics of the facility.

Source: AASHTO Success Stories website: www.transportation.org/aashto/success.nsf/homepage/overview.

Unfortunately, these nontechnical elements have frequently led to a standoff whereby neither the economic and mobility needs of a community nor its environmental, social, and aesthetic requirements are being met. Better tools will not eliminate these nontechnical problems, but without such tools the goal of addressing the full range of requirements for highway transportation is extremely difficult to fulfill. While efforts must continue in such areas as streamlining regulatory procedures and identifying the public will through the political process, research can provide the tools needed to realize the desired outcomes identified through these processes in the most effective manner possible. The current need for a better way to provide highway capacity, together with the possibilities offered by new technologies, represents an opportunity to meet customer needs more objectively than through a purely political process.

The committee proposes that F-SHRP exploit this opportunity by developing a systems approach to highway development that integrates environmental, social, and economic issues into the highway development process. Ideally, these issues should be addressed throughout the highway life cycle, from initial conception through operation of the facility. This research topic is focused on the preconstruction stages of the highway development process; however, coordination with the proposed research on highway renewal (see Chapter 4) and nonrecurrent incident management (see Chapter 6) will ensure that these considerations carry over into the construction and operation stages.

This research will incorporate what is already known about environmental, economic, and community impacts, as well as the pursuit of new knowledge in selected areas (which could include institutional issues, land use patterns, and secondary and cumulative impacts of highways). The knowledge thus gathered will be integrated and applied by means of a set of tools that can be used collaboratively by highway practitioners (in public-sector agencies and private firms) and stakeholders (including private citizens and interest groups) to analyze the issues and impacts associated with providing new highway capacity, and to implement the results of these analyses in planning and designing highways that are more responsive to economic, environmental, and community needs.

Meeting the Challenge of Providing New Highway Capacity Through a Future Strategic Highway Research Program

How providing highway capacity in a way that is more responsive to environmental, economic, and community requirements meets the first of the criteria set forth in Chapter 1 for selecting the strategic focus areas for F-SHRP was described in the preceding section: it is an issue that bears on national transportation goals and is of continuing concern to highway agencies. The other two F-SHRP criteria—appropriateness for a SHRP-style program and the effectiveness or expected impact of the research—and how the proposed research meets these criteria are addressed in this section.

Appropriateness for a SHRP-Style Research Program

The appropriateness criteria for F-SHRP apply well to this topic. A research program of critical mass and continuity is certainly required to integrate so many diverse issues—environmental concerns, economic analysis, community involvement, and aesthetics—and develop a suite of tools that applies the results of analysis of these issues to the highway development process. Coordinating such a wide array of disciplines and stakeholders will require substantial time and resources. While research is currently being performed in many related areas (air quality modeling, control of highway runoff, noise, and habitat, for example), little effort is being made to integrate these areas with each other and into the highway development process. As a result, practitioners have a collection of tools that do not fully address the challenges they face. While many stakeholders are involved in this area, public-sector responsibility is critical since the public sector owns the highways and since many of the issues addressed under this topic—especially environmental and community impacts—pertain to social goods that cannot be advanced effectively by individuals alone.

Effectiveness or Expected Impact of the Research

While the challenges in this area are significant, there are opportunities for significant benefits from the application of both advanced technologies and institutional improvements. The principal impact of this research will be the provision of new capacity where it is needed, along with all the economic and quality-of-life benefits derived from that capacity, in a way that responds to the full range of customer requirements: highways that are aesthetically pleasing, enhance historical and community values, and contribute to a healthier economy and environment.

These types of benefits are difficult to quantify. However, using one set of estimates for selected environmental impacts—specifically the costs of road dust, highway runoff, and road noise—a 5 percent cost reduction due to more environmentally sensitive design would translate to savings of approximately $180 million per year.[2] There are other potentially quantifiable benefits from better highway planning and design and many nonquantifiable benefits related to enhanced aesthetics, public involvement, and community values.

A focused effort over the proposed time period should produce implementable results. Implementation barriers are likely to be institutional, economic, and political, such as the need to build consensus among organizations with different philosophies and goals, address the cost of acquiring new technologies, develop or modify regulations, and train personnel. Involvement of stakeholders from the outset of the research and development will help address these barriers. The committee believes the research community has the capacity to perform the proposed work, although some disciplines that are not traditional components of highway research, such as social science and data management, will have to be involved as well.

Proposed F-SHRP Research

Major Research Objectives

The proposed research program has three major objectives:

- To develop an integrated, systems-oriented approach[3] to meeting this multifaceted challenge;
- To use the many potential tools and technologies for applying this approach in a systematic way throughout the highway development process; and
- To address the institutional issues surrounding highway development.

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[2] This estimate is from Delucchi (2000), who provides high and low estimates for a number of external environmental costs associated with motor vehicle use. Low estimates for costs associated with road dust, runoff, and noise were used to calculate the potential benefits of the proposed research in terms of savings in these areas, which could reasonably be addressed by this research. Road dust is just one, relatively small, component of air pollution from highways. Its cost is measured in health impacts (air pollution–related diseases) that are likely to occur as a result of exposure to road dust. Highway runoff causes pollutants such as oil, metals, and salt to enter bodies of water and harm aquatic life, drinking water, and local economies dependent on water-based recreational activities. Noise can disturb sleep, rest, work, learning, and other activities. The cost of highway noise is related to losses in housing value due to noise. If Delucchi's high estimates are used, a 5 percent reduction in costs associated with road dust, runoff, and noise is equivalent to $8.45 billion per year.

[3] It is not necessarily intended that this research will produce one analytical framework or approach. It may be appropriate to develop different approaches for different situations—for example, urban, exurban, and rural areas.

What is entailed in achieving these objectives and how the objectives are addressed by the proposed F-SHRP research are examined in this section.

Developing an Integrated, Systems Approach

The development of integrated, systems approaches to strategic highway challenges is an important characteristic of F-SHRP. Integration of environmental, economic, and community goals into the planning and design of highways is the central focus of this research program. Addressing institutional issues will help identify those goals and facilitate the implementation of plans to achieve them. Tools and technologies will enable analysis, planning, and design. But the real intellectual challenge, and the most significant practical contribution of this research, will be the integration of fields of knowledge and analytical techniques that have tended to exist independently.

Integration of analysis across such areas as air quality, water quality, habitats, noise, community impacts, aesthetics, safety, and economics requires a common rationale and framework that can link the various performance measures used in each of these areas. Such a framework will be important for analysis of the secondary and cumulative impacts of providing new highway capacity. In examining these impacts, it will be necessary to address issues of land use and sprawl and of areawide, as opposed to site-specific, environmental impacts. Moreover, as noted earlier, all these analyses should be integrated earlier into the planning and design processes to promote an emphasis on preventing rather than mitigating environmental impacts—in fact, on seeking to improve the environment through the transportation system. There is relatively little knowledge about how to accomplish these goals, which is why this research is so urgently needed.

To perform such integrated analysis, it will be necessary to bring representatives of many disciplines together: engineers, environmental scientists, landscape and other architects, safety experts, economists, and others. For example, designing roads that are more compatible with local ecology, culture, and history may have particular implications in such areas as materials, geometric design, and wildlife crossings. Integrated analysis also implies the need to consider trade-offs among different goals. For example, context-sensitive designs may raise safety issues, and in some cases, regional economic benefits must be weighed against local community impacts. The research should include development of an analytical framework that encompasses these disciplines and issues to the extent possible and that can be used to analyze various types of benefits and costs and the trade-offs among them. Box 7-2 describes how

Box 7-2

Context-Sensitive Design on Route 235, Maryland

Expansion of a governmental facility and new private-sector development required that the capacity of MD-235 be increased from four lanes to six. The project area included urban, commercial, and park environments, and both pedestrian use and business visibility had to be considered. The goals of the project were to create a green boulevard and a pedestrian-friendly environment, maintain sensitivity to the surrounding business environment, mitigate the impact of overhead utilities, reduce the impact of paving, enhance the visual image of the area, and give proper attention to environmental mitigation and reforestation issues. The Maryland State Highway Administration worked with citizens, public officials, and other stakeholders in a collaborative process involving a wide range of disciplines: civil, structural, and traffic engineering; landscape architecture; and environmental sciences. Once completed, the project will meet all the goals identified at the outset and serve the needs of the various users and stakeholders. The integrated process used to plan and design the project enhanced not only the results obtained, but also the way in which the various disciplines approached their respective responsibilities.

Source: AASHTO (2001).

the state of Maryland integrated analysis of various issues into a new capacity project.

Using Tools and Technologies

Studies and analytical frameworks are ineffective if they are not embodied in tools that practitioners can readily apply. The strategic focus of this research—providing highway capacity in support of the nation's economic, environmental, and social goals—implies a need for data; simulation and prediction models; and analytical, planning, and design tools. The following are examples of the tools and technologies needed:

- Integrated electronic data collection, management, and analysis methods and technologies that can make use of the Global Positioning System (GPS), satellite imagery, digital photography, video logging, geographic information systems (GIS), and electronic document management systems.

• Integrated highway planning, design, and environmental processes and technologies that encompass national, regional, statewide, and local transportation planning processes and impact analyses. The technologies include workstations and software that offers predictive models for travel demand, land use, demographics, air and water quality, and secondary and cumulative impacts. An example for design activities is computerized processes for context-sensitive design that integrate data collection, data management, alignment development, 3D/4D visualization, project management, document preparation, and public participation. An example for environmental functions is analysis techniques that are integrated into the planning and design processes, as well as the technology needed to facilitate such integration. Priority areas of environmental impact to be addressed include air, noise, and water; ecological, community, social, economic, and land use impacts; environmental justice; hazardous waste; and aesthetics.

• Expert systems for highway planning, design, and environmental analysis, along with technical assistance and training needed to use these systems. Examples are tutorial software to guide users through the analyses, and review and documentation processes for planning, design, and environmental work.

• Better tools for highway planning, design, and environmental program and project management, such as software that computerizes the program and project management work.

• Automated quality control and assurance methods and tools, such as software that integrates quality control and assurance into planning, design, and environmental analysis.

• Communications technologies to facilitate project coordination and public and stakeholder participation.

Advanced technologies such as expert systems, GPS, GIS, and advanced simulation software can make the tools developed under F-SHRP faster, more effective, and more user-friendly. The tools developed will be adaptable to different user needs, so that various locales will not be forced to conduct a "one-size-fits-all" analysis. In addition, the research should address potential implementation barriers and incentives, such as the cost of new methods and tools, needs for training and expertise, and participation of the private sector (and possibly public-sector agencies other than transportation agencies) in the technology development and implementation processes. The tools will also be designed for collaborative use, building on lessons learned from the research on institutional issues (discussed below). Various public-sector agencies, private-sector firms, interest groups, and members of the public should be able to use the tools to work together on defining objectives for highway development, contributing to design concepts, and evaluating alternatives and trade-offs. Box 7-3 describes how the state of Florida used technology and institutional change to improve its highway development process.

Given the complexity of the issues involved, the tools produced through this proposed research cannot be expected to provide absolute or definitive solutions. Many of the tools will be educational and demonstrative in character, presenting best practices, widening the spectrum of potential options, and demonstrating possible outcomes and implications.

Addressing Institutional Issues

Institutional issues, broadly understood, affect this research area in a number of ways. First, the organizational structures of most state DOTs were established during the Interstate highway–building era. Although they have served the transportation field well, they have not evolved at the same pace as the issues they must be used to address. New organizational approaches are

Box 7-3

Efficient Transportation Decision Making, Florida

As in many states, Florida's highway development process was lengthy, involved certain stakeholders too late in the process, and overly segmented the various stages of development. To improve the process and the resulting highways, the Florida Department of Transportation worked with its partners to develop an improved transportation decision-making process. All relevant agencies are now brought into the process at an earlier stage to identify issues and needs, create a team that will coordinate activities throughout the project, and allow permitting activities to move forward concurrently. Continuing opportunities for public involvement are provided, including access to project information through an interactive database that uses GIS technology to allow all stakeholders to share information and understand how others have arrived at their conclusions. The new process improves communication, streamlines the highway development process, and produces a facility that is acceptable to all stakeholders.

Sources: Florida Department of Transportation (2001); AASHTO (2001).

needed to enable state DOTs to respond quickly to changing demands. In addition, highway development must be coordinated with local jurisdictions and neighborhoods so that local, regional, statewide, and national transportation goals will be met. Even international concerns come into play, since the transportation system in many regions must support increased international goods movement at ports, airports, and borders.

Beyond transportation agencies, many other public and private organizations are involved in highway development. Federal and state environmental quality agencies, the U.S. Fish and Wildlife Service, the U.S. Army Corps of Engineers, and other public agencies have authority over environmental compliance aspects of highway development. Economic and community development agencies, county commissioners, public works departments, and mayor's offices are involved. Interest groups concerned with the environment, conservation, endangered species, history, archeology, social justice, safety, and business opportunity are all stakeholders in the highway development process.

An ongoing challenge for the institutions involved is effectively facilitating public participation through processes that are open, fair, educational, and productive. Box 7-4 describes how Connecticut used visualization technology to meet this challenge and improve the decision-making process.

Box 7-4

Visualization Technology on Route 20, Connecticut

At public meetings, the Connecticut Department of Transportation (ConnDOT) received mixed reactions to the widening of Route 20. Many citizens supported the idea; however, some members of the public opposed the widening because of concerns about how the new capacity would affect property owners, safe access to a nearby school, and the overall aesthetics of the area. ConnDOT used a computer-generated animated "drive-through" of the proposed changes, as well as modifications superimposed on still photos, to show the neighbors how reconstruction would affect the facility, including improved visibility for drivers, the relocated school driveway, and landscaping. This opportunity to visualize the changes helped alleviate public concerns, build broader support for the project, and provide a facility that met the needs of all citizens.

Source: AASHTO (2001).

The goals, philosophies, operating methods, and constituencies of all the above groups are quite diverse—in some cases even conflicting. One task for this research program will be to study examples of how these institutional challenges have been successfully addressed and to develop guidelines for best practices. As in the travel time reliability research described in Chapter 5, social science research methods can be applied in this effort. Important questions to be addressed include the following: What methods are most effective for arriving at consensus about highway project or program objectives among the diverse institutions involved? How can communication be maintained among these institutions throughout the development process, especially when changes to original plans may be necessary? How is public involvement best achieved? What kinds of expertise and training do DOTs need to handle the institutional aspects of the highway development process more effectively?

Proposed Research Tasks

As noted earlier, this F-SHRP research will involve formulating a systematic, integrated approach to highway development, together with accompanying tools and technologies, that can be used by highway practitioners and stakeholders to provide new highway capacity in a way that meets a broad set of performance requirements. To this end, the research will focus on the following tasks:

- *Synthesize and assess the status of analytical methods and tools.* Various analytical models and approaches already exist in such areas as water and air quality impacts, land use impacts, safety, aesthetics, and travel demand. Their strengths and weaknesses should be identified, as well as specific gaps in analytical capacity (for example, the need for analytical approaches to assessing the secondary and cumulative impacts of highways or to determining historical and archeological values).
- *Develop analytical approaches.* Using existing analytical methods as appropriate and formulating new ones as needed, one or more analytical frameworks for integrating engineering, environmental, economic, and community requirements will be developed.
- *Perform research on institutional issues.* This task will include identifying the goals, incentives, and requirements of the diverse institutions and stakeholders involved in highway development; describing institutional philosophies and cultures; identifying best practices (e.g., for institutional coordination, communication, public participation, and collaborative decision making); demonstrating and testing new methods; and developing guidelines for

implementing best practices and for identifying and meeting educational and training needs.

- *Develop tools and methods for planning and design.* Using the results of the institutional research and the above analytical frameworks, methods for systematically addressing new highway capacity needs in an integrated fashion throughout both the planning and design phases will be developed. Tools using appropriate technology will be developed as well to support these methods through data collection and analysis, simulation and prediction, visualization, and other activities that contribute to highway planning and design.
- *Develop guidelines.* Guidelines for effective use of the methods developed and the best practices identified will be produced. These guidelines will include human resource (expertise and training) requirements, as well as documentation of model operation.

Relationship to Other Work

Other Research and Technology Efforts

The research proposed in this chapter is highly dependent on ongoing efforts in other highway and environmental research programs. Environmental and planning research at FHWA and in NCHRP, as well as environmental work sponsored by the Environmental Protection Agency and performed in university programs, should be integrated, as appropriate, into the analytical methods and planning and design tools developed under F-SHRP. Related work is also being conducted under an NCHRP project that involves reviewing nearly 20 technologies in the following five categories to ascertain their usefulness for addressing environmental considerations in transportation planning and design: geospatial databases, remote sensing, transportation impact modeling, decision science, and visualization/simulation. Another NCHRP project is focused on developing a guidebook to assist transportation professionals in using current techniques for assessing the social and economic effects of transportation projects.

Other Strategic Focus Areas in F-SHRP

This research area complements the highway renewal research described in Chapter 4. While the research described in this chapter is oriented primarily toward providing new capacity, its outcomes can also apply to renewal efforts, which may present opportunities to improve the aesthetics and safety of a highway and mitigate undesirable environmental and social impacts. Rapid construction methods developed for highway renewal may also be useful in building new capacity. Finally, knowledge gained from the safety and travel time reliability research described in Chapters 5 and 6, respectively, can be integrated with the outcomes of this research topic.

Administrative and Implementation Considerations

As with the other research topics proposed for F-SHRP, the importance of involving all relevant stakeholders in the conduct and implementation of this research cannot be overemphasized. These stakeholders include state, federal, and local government agencies with responsibilities in such areas as transportation, environment, historic preservation, community development, economic development, and safety; private-sector firms that often perform the environmental analysis, planning, and design work for public projects; interest groups of various types; and private citizens and community groups. In addition, the institutional research is likely to yield information that could significantly affect the education and training of transportation and other professionals. Therefore, universities and training professionals will need to be engaged in this aspect of the program.

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ABBREVIATION
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ABBREVIATIONS
DOT U.S. Department of Transportation
EPA Environmental Protection Agency
FHWA Federal Highway Administration

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CHAPTER 8 *Administrative and Funding Structure*

The congressional request for a new strategic highway research program indicated that those conducting the study should determine the administrative structure and fiscal needs of the program. Given the diversity and scale of the proposed program, no single research institution, or even a small number of institutions, could undertake the research. Therefore, the F-SHRP committee began its analysis of administrative structures with the assumption that the proposed program would be a large, contract research program under a single administrative structure, as was its predecessor, SHRP. This approach will allow the program to take advantage of research expertise in dozens of institutions across the country while maintaining management focus on coordination in a central authority. In this chapter some key characteristics of successful applied research programs are reviewed; specific criteria based on those characteristics for F-SHRP's administrative structure are set forth; a comparison of potential administrative structures according to these criteria is presented; the administrative structure recommended by the committee is described; implementation considerations are addressed; the funding requirements and mechanism for the proposed research are delineated; and interim work that should be performed prior to passage of the next highway authorizing legislation is outlined.

Organizational Characteristics of Successful Applied Research Programs

Research is the acquisition of knowledge and the development of solutions through a rigorous, systematic, rational process.[1] Regardless of the research category (for example, basic versus applied, scientific versus fundamental

[1] There are many other ways of gaining knowledge and finding solutions, such as intuition, personal experience, trial and error, and professional judgment. However, the level of objectivity afforded by properly performed research can significantly increase the effectiveness of public decision making.

technology, long-term versus short-term), the criterion of applying a rigorous, systematic, rational process is common to all research and requires that research programs possess certain management and organizational characteristics. In transportation, one is generally concerned with applied research, whose aim is the implementation of research products to address current or future needs. This research aim suggests certain program characteristics. In the following sections some characteristics of successful applied research programs, which can be applied in various ways and to different degrees depending on the objectives of a particular program, are described.

Mechanisms to Mitigate Influences That Could Bias the Research

Objective: To avoid bias at the macro level (in the planning and management of the research program) and at the micro level (in the award of individual research projects) that could affect the validity or quality of the research.

An organization managing a research program should ideally be free of political interference, regional and social biases, and micromanagement to insulate those conducting the research from efforts by vested interests to predetermine the outcomes. In reality, influences and biases are not completely avoidable, so a research organization must be structured to protect the research from biases that could affect the quality of the research and to balance the influences of various groups. In fact, some influence is desirable: that which directs the research toward important questions and useful goals—legitimate stakeholder influence—is a positive thing, whereas that which biases the research in ways that jeopardize accuracy, quality, or responsible use of funds is detrimental. Mechanisms for achieving the necessary protection and balance at the macro level include establishing a program within an organization that has credibility among various stakeholders and open processes for stakeholder involvement and governance. Protection against biases at the micro level can be achieved through open solicitation of proposals to ensure that the highest-quality proposals are offered and through merit review to ensure that the best proposals are chosen. A balanced group of stakeholder experts should select the winning proposals.

Mechanisms to Ensure the Quality of the Research

Objective: To ensure quality at the project and program levels.

In addition to merit review of research proposals, stakeholder and peer review can be employed for ongoing research programs and individual research projects. Project panels may follow individual research projects throughout their duration. Within academia, peer review is often exercised at the journal publication stage. Some state and federal programs also use expert groups to perform periodic review or oversight of individual research projects.

Program-level peer review can be accomplished in many different ways, from one-time or periodic visiting committees of qualified experts and stakeholders to standing committees, such as those managed by TRB. The committees that review applied research programs should include both qualified technical or scientific experts and stakeholders; the former should review the quality of the research, while the latter should review its relevance.

Competence in the Type of Research and in Research Program Management

Objective: To ensure that appropriate capabilities are available to meet the unique technical and managerial requirements of the research program.

An institution must have the ability to support the particular type of research program to be conducted. Technical scope, scale, and the way a program is carried out (by in-house staff or through contracts or both) all have implications for the administrative structure and support functions required for an effective program. A research organization must be able to attract and retain skilled, highly educated, and motivated staff. Unique technical and managerial skills are required, including knowledge of specific technical topics in the chosen research areas and understanding of research management and the process of innovation in the industry. Competence should be an obvious requirement, but it is highlighted here because of the potential complexity of the applications involved and the range of competence—both theoretical and practical—that may be needed. There are several practical implications of this characteristic: recruitment, screening, and hiring of staff can be time-consuming and require the involvement of technical experts and managers knowledgeable about research; salaries must be adequate to attract the best talent in a field; and working conditions and resources must be suitable for creative, intellectual work to be performed.

Focus and Stability

Objective: To guarantee adequate dedication of resources to the research and to ensure that the research program can meet commitments to stakeholders and partners with regard to funding and milestones.

In any organization whose principal task is not research (such as FHWA, state DOTs, and manufacturers), the research effort requires some degree of independence from the main operational activities of the organization. This independence extends to the research and development organizational unit, staff, and budget. Even though applied research must be well connected to stakeholders, this does not mean blending their organizations. Otherwise, the budget and talented staff of a research unit would be easy prey to all the pressing matters of the operational elements of the organization.

Applied research programs are usually driven to produce a product within a relatively fixed time frame for a potential user. Achieving this goal requires stability and long-term commitment to the organization. Stable funding allows for continuity of staff, management, and operations that are not tied to political administrations or budget cycles. A reliable, known commitment of funds, not requiring interim financial decisions at the macro level, allows sufficient flexibility for program managers to make appropriate adjustments as the research progresses.

Customer/Stakeholder Involvement

Objective: To ensure the relevance of the research and the consequent effectiveness of the implementation of its results.

Applied research programs are intended to produce solutions, whether in the near or long term. This requires that the programs be oriented to the needs of users and stakeholders. Some programs, particularly those aimed at producing results in the near term, have their agendas set by those confronting the problems or issues. Although there are different mechanisms for soliciting topics, any applied research program should have some process for asking those who must deal with the problem to define the kinds of research that would be helpful, to indicate some priorities, and to monitor progress for potentially necessary changes in direction or focus.

In addition to determining the content of the research program, stakeholders may have a substantive role in overseeing individual research projects. For instance, a panel of experts, balanced in terms of constituencies, might perform this task. A high level of stakeholder involvement ensures focus and relevance and provides the ancillary benefit of educating the panel members on the subject being studied as the research is being conducted. This in turn helps overcome the typical lag between completion of the research and implementation of its results. By maintaining program focus and affirming relevance, stakeholder involvement helps ensure that the program is on the right track.

The involvement of stakeholders in longer-term research differs somewhat from that in shorter-term research. Most stakeholders are driven primarily by short-term needs and incentives, which are not necessarily good predictors of long-term trends and opportunities. One way of handling this divergence is to have a separate group of stakeholder-advisors for longer-term research. These advisors would be chosen for their ability to think beyond current problems to anticipate needs and opportunities in their industry 5, 10, or 20 years in advance.

There is a creative tension between this characteristic of stakeholder involvement and the necessary independence researchers need to avoid being influenced by biases from vested interests and being absorbed into nonresearch activities. In applied research there needs to be a balance between maintaining independence from undue influences and other duties while remaining tied to the problem context. Most attempts to eliminate this tension by oversimplifying the situation end in one extreme or another: producing research that is either not relevant to stakeholders or not creative and forward looking (and consequently not relevant in the long term). Maintaining the necessary balance is one of the unique challenges for research managers.

Criteria for F-SHRP Administrative Structure

By tailoring the characteristics described above to the needs of F-SHRP, the committee developed the following criteria for the F-SHRP administrative structure:

- *The F-SHRP organization should possess essential quality control mechanisms.* The organization should be free to choose the best proposals for each part of the research program using open solicitation and selection based on merit. Mechanisms for avoiding biases in the award and direction of research and for balancing interests and perspectives should be instituted. Appropriate review procedures should be employed throughout the conduct of the research, and the organization should have mechanisms for determining whether and when a particular avenue of research should be redirected or terminated and related contracts modified.
- *The F-SHRP organization should be competent to carry out a large contract research program.* The organization must possess experience in managing such

a program and have appropriate administrative and contract support functions. It should also have the ability to attract and retain talented staff and to obtain additional resources (for example, by entering into partnerships with other research programs and accepting loaned staff). The program should be centrally administered with distributed conduct of research to ensure that multiple subprograms and activities are coordinated and remain focused on the established goals and objectives, while taking advantage of the best talent in a wide variety of research institutions across the country and retaining appropriate control by technical experts over technical issues.

- *The F-SHRP organization should have focused core staff and secure funding over the program's time frame.* A core staff of appropriate size should be as constant as possible throughout the program, while additional staff may be loaned from other organizations or programs. The program should have a reasonably predictable budget, and the organization must be able to manage the budget on a multiyear, program basis, not subject to annual programming decisions or competition with other research priorities.
- *The F-SHRP organization should have the flexibility to institute stakeholder governance mechanisms.* The governance of the program, at both the executive, overall program level and the technical, component program level, should be carried out by stakeholders. A small governing body composed of leaders from major stakeholder communities should provide strategic direction and be ultimately responsible for the awarding of contracts. Panels for each of the four research programs, composed of users and high-level technical professionals in the disciplines covered by each, should provide technical direction and program review. These panels might also establish expert groups to advise them in particular technical areas. These governance mechanisms should exist in addition to the other types of customer and stakeholder involvement described earlier.

Comparison of Alternative Administrative Structures

In the Strategic Transportation Research Study (TRB 1984), several administrative structures are discussed as potential mechanisms for managing the first SHRP. Some of these options, including the one ultimately chosen, are presented here, along with an assessment of their strengths and weaknesses relative to the criteria discussed above. The various administrative options were considered in the context of a focused, discrete program; it is intended that the organizational structure will disband once the research has been completed.

SHRP Administrative Structure (National Research Council)

The National Research Council (NRC) was chosen as the institution best suited to carry out SHRP. A separate unit of NRC was established with a core staff, as well as loaned staff from other institutions, such as state DOTs and FHWA. The organization provided central coordination for a large contract program, was completely independent, and had the freedom to conduct open solicitation of proposals and to make decisions about midcourse corrections to the research agenda. It was able to attract good staff who were dedicated entirely to the program. The budget was not constrained by an annual programming procedure. SHRP was governed by an executive committee of major stakeholders, with advisory committees and expert task groups overseeing the development of four major research areas. At the completion of the research, the SHRP unit of NRC was disbanded.

One drawback of this approach was the start-up and close-down costs (both in financial terms and in intellectual capital) associated with setting up an entirely new, independent organization, along with all the support functions necessary to manage a large contract research program. In the last year of the program in particular, it was difficult to retain valuable, experienced staff. Although successfully handled by SHRP, this difficulty does represent a drawback of the SHRP model.

NRC continues to be a strong option. The institution (through TRB) is experienced in managing a large contract research program (NCHRP) and has the required administrative and contracting support functions. It has the ability to attract talented staff and other resources. NRC is experienced in convening diverse stakeholder groups and balancing various perspectives and interests. It offers the advantage of a reputation for bringing together a broad array of transportation stakeholders in an open and unbiased forum while utilizing access to experts in other fields. Stakeholder governance and external peer review are part of its normal operating procedures. In contrast to government agencies, NRC is much less constrained in certain management practices. For example, it can more quickly increase the size of its staff to support the program and similarly readjust staff size when the program draws to a close. It has greater flexibility and speed in negotiating and awarding contracts. It can fully implement merit-based selection processes. And it can establish stakeholder governance mechanisms using processes based on those employed in TRB's cooperative research programs and similar to the processes used for typical NRC committees. Among existing private-sector organizations, NRC, through TRB, is a well-known and trusted organization in the transportation community.

The drawback of start-up and close-down costs will exist for any option given the scale of the proposed program; in contrast to establishing a new private-sector organization, however, use of an existing organization such as NRC would involve lower start-up costs and less delay. If NRC were used, this drawback could be addressed by making use of experienced staff, support functions, and other resources both within NRC (perhaps by using an existing unit rather than creating a new one) and in other organizations, such as state DOTs, FHWA, and universities.

Other Potential Administrative Approaches

Because of the scope and scale of the proposed research, all of the following options assume that F-SHRP could not merely be part of an existing research program, but would need to be an independent program. The assessment provided here is based on how well the characteristics of each of the existing organizational structures align with the criteria set forth earlier.

FHWA's Research, Development, and Technology Program

FHWA has had a great deal of experience in managing a large contract research program and performing national-level coordination. The organization has the appropriate support functions for these tasks, can attract talented staff, and has some ability to engage other resources. The annual appropriations process, the impact of outside influences, reduced independence and central control of research, and constraints regarding stakeholder involvement in governance are some limitations of this option.

Other Federal Research Programs

Examples of salient federal research institutions include the Volpe National Transportation Systems Center, which is part of the U.S. Department of Transportation; the National Institute of Standards and Technology, which is part of the U.S. Department of Commerce; the National Science Foundation (NSF); and other national laboratories (for instance, those associated with the U.S. Department of Energy). These entities are experienced with large research programs, and, being exclusively research and technology organizations, have staffs and budgets that are independent of other responsibilities. On the other hand, with the exception of NSF, their research is performed predominantly in-house and therefore would make less use of talent and resources from other institutions than would be the case under the other options. These institutions also face annual appropriations processes and do not employ stakeholder governance mechanisms. They have the further disadvantage, in some cases, of not having established relationships with all the traditional transportation customers. In addition, national laboratories often have a vested interest in finding applications for technologies they have already developed, which may not be suited to the problems posed by stakeholders. NSF's mission and approach are not well suited to managing a large, coordinated program oriented toward implementable solutions in a relatively short time frame. Its mission is oriented more toward developing new scientific and engineering knowledge, tied only loosely to ultimate implementation. It is also accustomed to giving researchers a degree of autonomy over the content and direction of research that would be incompatible with the criterion of stakeholder governance.

National Cooperative Highway Research Program

NCHRP has experience in managing a large contract research program, has staff entirely dedicated to research administration, and is insulated from outside influences. It has well-established procedures for stakeholder involvement in governance, although they are limited to state DOTs. Most of its contract research is awarded through a competitive process. While NCHRP could possibly add other stakeholders to its governing body, F-SHRP would dwarf, and possibly overshadow, the traditional NCHRP. In addition, the program is developed on an annual basis, making the planning and conduct of multiyear programs difficult.

University Transportation Programs

University programs, whether at a single institution or utilizing a consortium of universities, are generally independent of outside influence, although internal and interuniversity politics can affect research agendas. The programs generally are characterized by a high degree of research competence but are typically less adept at management and coordination. Programs vary in their success at engaging stakeholders, since university researchers tend to prefer total independence from external direction. Peer review is a common and well-respected practice in the academic world, but it is generally applied after the research has been completed, when the findings are published. While universities are likely to be important in conducting the research under F-SHRP, the academic model is not generally well suited to the administrative requirements of such a program.

American Association of State Highway and Transportation Officials

AASHTO would be relatively free of outside influences and has established procedures for balancing the varied perspectives of its own members. However, the organization may be limited in its ability to involve other stakeholders besides state DOTs in the governance of the program. Although AASHTO has always been closely involved with transportation research, the current organization is not experienced in managing a large contract research program and does not have the support functions required for this work. It is reasonable to say that administration of a research program is not properly within AASHTO's mission.

Private-Sector Entity

Another possible option is to employ an existing private-sector entity (whether nonprofit or for-profit) or establish a new one specifically for the purpose of administering F-SHRP. NRC, already discussed above under the SHRP administrative structure, would fall under this category. Establishing a totally new organization would involve large start-up costs, potentially significant learning curve delay, and relatively high risk for such a short program as compared with using an existing organization. In considering this option, the committee decided it would be best to work with a known organization possessing a track record with the transportation industry.

Recommended Administrative Structure

The committee recommends that the chosen administrative structure adhere closely to the criteria described above. All four criteria should be met, but most important is for the structure to employ quality control mechanisms, such as competitive award of research contracts and merit review, and stakeholder governance mechanisms at the overall program level, as well as for each of the four component research programs. The choice of administrative structure for F-SHRP should be made during the interim work stage described below after appropriate analysis of the above options (and possibly others). The details of the mechanisms to be used to meet the four criteria should be developed during the interim stage as well. The organizational design should address the fundamental aspects of the F-SHRP philosophy outlined in Chapter 1. That is, it should support a customer orientation, a systems approach to research, the incorporation of nontraditional research, and coordination with existing highway (and other appropriate) research and technology programs. The committee points out that NRC meets these criteria and successfully administered the first SHRP.

Implementation Considerations During the Research Phase

While the program proposed in this report is focused on research, research is helpful only if its results are implemented. The committee anticipates that the majority of implementation activities will take place after the program has concluded. However, implementation must be considered from the earliest planning stages of the research. As discussed in Chapter 2, one of the lessons learned from the first SHRP was the need to address implementation more aggressively during the research program. In addition, early research results will be available for implementation well before the research program has been completed. In this section some implementation-related considerations that should be addressed at the appropriate times during the planning and conduct of the research are presented. These considerations are reviewed here because of their potential impacts on various aspects of the administration and funding of F-SHRP, such as coordination across the four research programs and with research programs outside of F-SHRP, decisions about the direction of the research programs as research results become available, and the allocation of funds to implementation-related activities within each research program. While the committee agrees that the requested funding for F-SHRP should be predominantly for research activities, the implementation-related activities described below also require adequate funding, which is included in the committee's overall estimate of required program resources.

- *Identification of expected research products and their users*—There should be some assessment of what the market will bear, in terms of cost and volume, with regard to products that may result from the proposed research. Implementation activities (demonstrations, test cases, training) should be outlined and human and financial resource requirements estimated. Institutional and other barriers should be identified. Users and stakeholders should be consulted about the feasibility of implementation given the required resources and about how the identified barriers can be overcome.
- *Engagement of potential users*—Potential users should be involved even while the research plans are being developed (see the later discussion of interim work requirements), and certainly during the research program, so that implementation barriers and incentives can be addressed as early as

possible and a cadre of users will be ready to implement the research products as soon as they are available. These early adopters may even begin to test products before they are generally available so that any problems can be resolved. Early implementers can also aid others in their implementation efforts.

- *Determination of where the long-term responsibility for implementation coordination and facilitation will lie*—Implementation will be done by the ultimate users of the research results: state DOTs, local transportation agencies, and other public and private organizations within the highway community. Some national-level coordination should take place, however. In the case of the first SHRP, FHWA was responsible for this coordination and received funds in the Intermodal Surface Transportation Efficiency Act of 1991 to facilitate implementation of SHRP products through training, conferences, demonstrations, and other activities. It is beyond the scope of this report to recommend the administrative structure or locus of responsibility for F-SHRP implementation activities. Nonetheless, in the interest of ensuring that the proposed research yields the greatest possible benefits, the committee urges that this decision be made as early in the program as possible so that implementation will be coordinated effectively from the outset. This activity will also require separate funding, which is not addressed in this report. The delegation of responsibility for coordinating and facilitating implementation should take into account the nature of the topics proposed for F-SHRP, the nontraditional research disciplines involved, and the wide variety of stakeholders and potential implementers in each focus area.
- *Dissemination of research findings*—This report has stressed the importance of stakeholder involvement in the research process. However, it is not usually possible for all stakeholders and potential users of the research to be actively involved. An effective research program needs to include appropriate methods for disseminating information about research results and products to all who may wish to implement them. Effective dissemination should facilitate implementation by communicating its benefits and connecting users to implementation tools, guidance, and resources.
- *Coordination of research efforts*—The interdependence of the various highway research programs has been emphasized throughout this report, largely from the perspective of the actual conduct of the research. Coordination of these efforts also has benefits from an implementation perspective, including fostering creativity and mutual learning, avoiding unnecessary duplication, and leveraging implementation activities and resources.

- *Testing and evaluation of research findings*—One of the most important and often neglected stages of the research and development process is the testing and evaluation of research results. Testing is done to prove and perfect the results or a prototype technology. It is usually performed under controlled or laboratory conditions and often consists of repetitive application or use under various hypothetical scenarios, including testing to failure, where appropriate. For certain highway products, such as materials and roadside hardware, testing is used to develop specifications that are required by the states before a new product can be incorporated into their procedures. Testing and evaluation also includes an advanced stage of testing that is particularly important for implementation and takes place in real-world, or close to real-world, circumstances. In the rush to market and implement research results, these critical stages may be shortened or neglected, thereby undermining successful implementation.
- *Evaluation and feedback*—Effective research should always incorporate an element of evaluation and feedback, creating an iterative process of continuous improvement both for specific research efforts and for the operation of the overall research program. Evaluation and feedback can be applied to the quality of the research itself (for example, through the peer review process mentioned earlier), the effectiveness of solutions developed through the research, and the success of dissemination and implementation efforts. Stakeholder involvement will ordinarily lead to at least informal feedback in these latter two areas. However, formal evaluation and feedback mechanisms are advisable to introduce some objective performance measures into the evaluation and eliminate bias from the feedback (hearing all praise or all complaints).

Funding Requirements and Mechanism

On the basis of the precedent set by SHRP, the committee recommends that F-SHRP be funded by a 0.25 percent takedown from apportionments from the Highway Trust Fund. Since the funding in question would otherwise go to states for highway programs, the support of the states for this funding mechanism is critical. The committee believes a 0.25 percent takedown will be acceptable to state DOTs if the proposed research is clearly oriented toward their needs and governed by committees that encompass their perspectives. Of course, the states would have to agree collectively to such a proposal and actively support it. Using the federal-aid highway funding levels of the Transportation Equity Act for the 21st Century and assuming a reauthorization period of 6 years, this recommended funding mechanism can be expected to produce approximately $450 million to $500 million.

Given the relative scope and complexity of the required activities, the distribution of estimated funding across the four research programs should correspond roughly to that shown in Table 8-1. During the interim planning work, detailed cost estimates should be developed and the total funding requirement, distribution, and percentage takedown of the proposed program modified as necessary. In the event that the established takedown does not provide the expected funding amount (because of a change in the length of the reauthorization period or the effects of revenue-aligned budgeting, for example), the scale and possibly the scope of the proposed research would need to be modified. The authority to effect such modification should be vested in the governing body established to provide overall direction to the program.

Interim Work Requirements

Should the highway community support F-SHRP as proposed herein, the time between publication of this report and passage of the next highway authorizing

Table 8-1 Estimated Distribution of F-SHRP Funding

Research Program Goal	Distribution of Funding (%)
To develop a consistent, systematic approach to performing highway renewal that is rapid, causes minimum disruption, and produces long-lived facilities	25
To prevent or reduce the severity of highway crashes through more accurate knowledge of crash factors and of the cost-effectiveness of selected countermeasures in addressing these factors	40
To provide highway users with reliable travel times by preventing and reducing the impact of nonrecurring incidents	20
To develop approaches and tools for systematically integrating environmental, economic, and community requirements into the analysis, planning, and design of new highway capacity	15

legislation presents an opportunity to develop detailed plans for carrying out the program. AASHTO and FHWA should consider funding and overseeing the development of these plans. The interim work should be guided by a governing body of stakeholders, which may be assisted by advisory groups of stakeholders and experts for each research program. The advisory groups should include experts in the nontraditional areas indicated for each research program. The following tasks could be funded and performed during the interim period to optimize the time and funding available for the research itself:

- Review in detail and synthesize the status of existing research and development programs in related areas. International as well as domestic efforts should be included in this review. In particular, the results of the international technology scanning tours sponsored by FHWA and AASHTO should be examined.
- Define in more detail the needs to be addressed by F-SHRP.
- Design research activities to address these needs.
- Identify stakeholders and potential partners for the full-scale research and development program and begin to engage them in the development of the program. International partners should be included where appropriate.
- Develop a budget and schedule for the full-scale research program.
- Recommend a detailed administrative structure, including how each of the criteria for the F-SHRP administrative structure described in this chapter will be addressed.
- Develop initial requests for proposals so that the solicitation process can begin as soon as funding is available. Particular effort should be made to ensure that the solicitation process yields researchers with expertise in the nontraditional research areas discussed in previous chapters. Potential solutions to the problems identified in this report should be drawn from the widest possible range of expertise, including that generally found in other industries.

In the event that this detailed planning work cannot be carried out during the interim period, it will need to be the first step taken once the research is funded.

Reference

ABBREVIATION
TRB Transportation Research Board

TRB. 1984. *Special Report 202: America's Highways: Accelerating the Search for Innovation.* National Research Council, Washington, D.C.

Additional Sources

ABBREVIATIONS

AASHO	American Association of State Highway Officials
CERF	Civil Engineering Research Foundation
HRB	Highway Research Board
TRB	Transportation Research Board

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CHAPTER 9 Recommendations

The highway system supports the nation's economy and quality of life and provides critical connections among the other modes of the transportation system. At the same time, highways pose challenges related to the mitigation of potentially adverse impacts on the environment and the communities through which they pass. Throughout the history of roads in the United States, research and application of new technologies have enabled the creation of a highway system that provides increasingly better service and contributed to the development of solutions for reducing adverse impacts. In 1987, a new model of highway research was initiated under the Strategic Highway Research Program. SHRP's success in contributing to improvements in the highway system and its operations has been attributed to its focus on a few strategic needs, addressed through research that complemented the efforts of established highway research programs.

New and perhaps more challenging strategic needs have arisen for the nation's highway system since the SHRP research was first performed. Today's strategic highway goals must be achieved under more varied constraints and in response to greater customer demands. In previous chapters of this report some of the most pressing strategic highway needs have been identified, and an ambitious but realistic program of research to address them has been described. A summary of the F-SHRP committee's recommendations is provided in this chapter. The essential characteristics of the proposed program are listed in Box 9-1. Additional details on each recommendation can be found in the noted chapters.

Research Program Recommendation

Recommendation 1: A Future Strategic Highway Research Program should be established.

Given the significant needs and problem areas identified through the outreach process conducted for this study, the opportunities to address these needs through research and technology, and the limited ability of existing programs to exploit these opportunities, the F-SHRP committee concludes that a large-scale, special-purpose, time-constrained research program, modeled after the first SHRP, is justified if the highway system is to meet its customers' demands over the next several decades. The research conducted under F-SHRP should be focused in the following four areas:

- Developing a consistent, systematic approach to performing highway renewal that is rapid, causes minimum disruption, and produces long-lived facilities (see Chapter 4);
- 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 (see Chapter 5);

Box 9-1

Characteristics of a Future Strategic Highway Research Program

The committee has identified various criteria and characteristics to help define different aspects of F-SHRP, the four strategic focus areas, specific research programs, and the overall program's administrative structure. Taken together, the following characteristics describe what F-SHRP should look like and provide a guide for further development of the program:

- Focused on a few topics of national significance for which a research program of critical mass and continuity is expected to achieve breakthrough impacts in highway practice
- Time-constrained
- Driven by stakeholders at the highest management and technical levels
- Complementary to and interdependent with other highway research and technology programs
- Customer service–oriented
- Systems-oriented
- Open to research in nontraditional highway-related areas
- Implementation-oriented from the research planning stages through adoption of research results

• Providing highway users with reliable travel times by preventing and reducing the impact of nonrecurring incidents (see Chapter 6); and

• Developing approaches and tools for systematically integrating environmental, economic, and community requirements into the analysis, planning, and design of new highway capacity (see Chapter 7).

Administrative and Funding Recommendations

> **Recommendation 2: The administrative structure of F-SHRP should meet the following criteria: (*a*) it should possess essential quality control mechanisms (including open solicitation and merit-based selection of research proposals, appropriate review procedures during the conduct of research, and mechanisms for redirecting research as needed on the basis of results); (*b*) it should have the characteristics required to carry out a large contract research program (including possessing appropriate management, administrative, and contract support capabilities and the ability to attract and retain talented staff and other resources); (*c*) it should have focused core staff and secure funding over the program's time frame (including a reasonably predictable budget that can be managed on a multiyear, program basis, not subject to annual programming decisions or competition with other research priorities); and (*d*) it should have the flexibility to institute stakeholder governance mechanisms at both the executive, overall program level and the technical, component program level.**

The choice of administrative structure should be made during the interim work stage (see Recommendation 5). The details of the mechanisms to be used to meet the above four criteria should be developed during the interim stage as well. The organizational design should address the fundamental aspects of the F-SHRP philosophy outlined in Chapter 1. That is, it should support a customer orientation, a systems approach to research, the incorporation of nontraditional research, and coordination with existing highway (and other appropriate) research and technology programs. The committee points out that the National Research Council meets these criteria and successfully administered the first SHRP.

Recommendation 3: The same funding mechanism used for SHRP is recommended for F-SHRP: a takedown of 0.25 percent of the federal-aid highway funds apportioned under the next surface transportation authorizing legislation.

Using the federal-aid highway funding levels of the Transportation Equity Act for the 21st Century and assuming a reauthorization period of 6 years, this recommended funding mechanism can be expected to produce approximately $450 million to $500 million. Given the relative scope and complexity of the required activities, the distribution of funding among the four research areas should be approximately 25 percent for the infrastructure renewal research; 40 percent for the safety research; 20 percent for the travel time reliability research; and 15 percent for the research on tools for providing new capacity in an environmentally, economically, and socially responsive manner. During the interim planning stage, detailed cost estimates should be developed and the total funding requirement, distribution, and percentage takedown modified as necessary.

Implementation Recommendation

Recommendation 4: F-SHRP should address the need for implementation of program results from the initial planning stages throughout the management and conduct of the program.

Recommendation 4*a*: A determination should be made as early as possible regarding where the long-term responsibility for coordination and facilitation of implementation will lie.

Recommendation 4*b*: A portion of the research funding should be devoted to implementation-related activities appropriate to the research stage; additional funding for full-scale implementation activities will be required once the research program has been completed.

(Other implementation-related considerations for the research stage are discussed in Chapter 8.)

Interim Work Recommendation

Recommendation 5: A strategic direction for F-SHRP is provided in this report; additional detailed planning is necessary before the research can be carried out. The American Association of State Highway and Transportation Officials and the Federal Highway Administration should consider funding and overseeing the development of detailed research work plans during the period immediately preceding initiation of the research program proper (which is assumed to take place at the beginning of the next surface transportation authorization period).

The interim work should include extensive outreach, a broad range of technical expertise appropriate to each research program, and review of relevant international efforts. (A description of this activity can be found in Chapter 8.)

APPENDIX A

Committee Meetings and Outreach Process

Committee Meetings

The committee held the following meetings to carry out its charge. A summary of the meeting agendas is included.

Meeting 1: June 22–23, 1999, Washington D.C. Discussion of task; briefings on study background; panel discussion on SHRP; outreach discussion; research brainstorming session.

Meeting 2: October 26–27, 1999, Washington, D.C. Panel discussions on strategic needs and research opportunities; panels represented users, engineering and construction industry, infrastructure (materials) supply industries, safety, universities, environment, and local and regional perspectives.

Meeting 3: March 8–9, 2000, Washington, D.C. Speakers on innovative contracting, environment, and user needs; discussion of selection criteria; discussion of outreach results to date.

Meeting 4: June 5–6, 2000, Woods Hole, Massachusetts. Presentations on context and policy issues, discussion of outreach results to date and potential research topic areas; discussion of principles for program administration.

Meeting 5: October 31–November 1, 2000, Washington, D.C. Discussion of focused technical outreach results to date and potential research topic areas; discussion of administrative and funding options; review of report outline.

Meeting 6: March 19–20, 2001, Washington, D.C. Discussion of additional technical outreach, administrative and funding options, and interim work; review of draft report.

Meeting 7: June 9–10, 2001, Irvine, California. Discussion of final technical outreach results; review of draft report; discussion of report dissemination.

Interviews with Individuals Involved in the First Strategic Highway Research Program

The following individuals were interviewed for background on the first SHRP. The affiliations given are those that obtained during the interviewees' involvement with SHRP; the dates shown are the dates of the interviews, which were conducted in person or by telephone.

- Damian J. Kulash, Executive Director of SHRP; January 29, 1999.
- Francis B. Francois, Executive Director, American Association of State Highway and Transportation Officials (AASHTO), member of Strategic Transportation Research Study (STRS) Steering Committee and SHRP Task Force, AASHTO ex officio member of SHRP Executive Committee; February 2, 1999.
- Robert J. Reilly, Director, National Cooperative Highway Research Program (NCHRP), Transportation Research Board (TRB), and NCHRP liaison to SHRP Task Force; February 3, 1999.
- Thomas B. Deen, Executive Director, TRB; February 4, 1999.
- Charles E. Dougan, Manager of Research, Connecticut Department of Transportation (DOT), member of SHRP Advisory Board on Snow and Ice Study; February 22, 1999.
- L. Gary Byrd, consultant on STRS report and Interim Director of SHRP; April 9, 1999.
- Thomas D. Larson, Secretary, Pennsylvania DOT, Chair of STRS Steering Committee, SHRP Task Force, and SHRP Executive Committee; April 11, 1999.

Outreach Activities at Committee Meetings

June 22–23, 1999, Meeting

The following individuals discussed the history of the first SHRP and provided suggestions for the present study (their affiliation with SHRP is noted above):

- Damian J. Kulash
- Francis B. Francois
- Thomas B. Deen

October 26–27, 1999, Meeting

The following individuals made formal presentations on strategic highway needs and research priorities (other groups were also invited but were unable to attend):

- Kaid Benfield, Senior Attorney, Natural Resources Defense Council
- Thomas W. Brahms, Executive Director, Institute of Transportation Engineers
- Amar Chaker, Senior Manager, Technical and International Activities Division, American Society of Civil Engineers
- Paul D. Cullen, Jr., Attorney at Law, The Cullen Law Firm, PLLC, representing the Owner Operators Independent Drivers Association
- Elizabeth A. Deakin, Director, University of California Transportation Research Center
- Brian Deery, Senior Director, Highway Division, Associated General Contractors
- Gene Griffin, Director, Upper Great Plains Transportation Institute, North Dakota State University
- Barbara Harsha, Executive Director, National Association of Governors' Highway Safety Representatives
- David Newcomb, Vice President, Research & Technology, National Asphalt Pavement Association
- David W. Pittman, Chief, Airfields and Pavements Division, Geotechnical Laboratory, U.S. Army Corps of Engineers
- Dan C. Raterman, County Engineer, McDonough & Henderson Counties, representing the National Association of County Engineers
- Richard Retting, Senior Transportation Engineer, Insurance Institute for Highway Safety
- Glenn Rhett, Environmental Laboratory, Engineer Research and Development Center, U.S. Army Corps of Engineers
- Valentin Riva, President and CEO, American Concrete Pavement Association
- Ted Scott, Chief, Highway Policy Division, American Trucking Associations
- Arun Shirole, Executive Director, National Steel Bridge Alliance
- Greg Smith, Managing Director, Contractors Division, American Road and Transportation Builders Association

• Willard W. Smith, Senior Economist, Office of Policy and Reinvention, U.S. Environmental Protection Agency
• Joseph M. Sussman, Japan Rail East Professor of Civil and Environmental Engineering, Massachusetts Institute of Technology
• G. Alexander Taft, Executive Director, Wilmington Area Planning Council, representing the Association of Metropolitan Planning Organizations

March 8–9, 2000, Meeting

The following individuals made formal presentations on strategic highway needs and research priorities:

• Mark Kulewicz, Director of Traffic Safety, Auto Club of New York
• Julie Lalo, Senior Director of Public Affairs, Western Pennsylvania Conservancy
• Nicholas Masucci, President, VMS, Inc.

June 5–6, 2000, Meeting

The following individuals made presentations on the broad context in which a future strategic highway research program must be considered and discussed potential areas for policy research:

• Alan Pisarski, consultant, Falls Church, Virginia
• Martin Wachs, Director, Institute of Transportation Study, University of California, Berkeley

Presentations Given by Committee Members and Staff

Presentations, discussions, and focus groups took place at the following meetings, led by F-SHRP committee members or TRB staff:

• AASHTO Board of Directors: October 3, 1999, Tulsa, Oklahoma; April 9, 2000, St. George, Utah; May 20, 2001, Wichita, Kansas
• AASHTO Standing Committee on Highways: October 1, 1999, Tulsa, Oklahoma; April 8, 2000, St. George, Utah; December 8, 2000, Indianapolis, Indiana; May 19, 2001, Wichita, Kansas
• AASHTO Standing Committee on Research: program session, October 5, 1999, Tulsa, Oklahoma; committee meetings, October 18, 1999, and March 28, 2000, Washington, D.C.

- AASHTO Research Advisory Committee: full committee and leadership focus group, July 31, 2000, St. Louis, Missouri; regional meetings, summer 1999
- AASHTO Standing Committee on Environment, December 9, 2000, Indianapolis, Indiana
- AASHTO Standing Committee on Planning, December 9, 2000, Indianapolis, Indiana
- AASHTO Standing Committee on Planning and Standing Committee on Environment joint meetings: March 22, 2000, Alabama; focus group, April 10, 2001, New Orleans, Louisiana
- AASHTO Standing Committee on Highway Traffic Safety, December 9, 2000, Indianapolis, Indiana
- AASHTO Subcommittee on Design, June 21, 2001, Ipsilanti, Mississippi
- American Trucking Associations, November 2000
- Association of Metropolitan Planning Organizations, November 11, 2000, Wilmington, Delaware
- Concrete Pavement Research Committee meeting, May 22, 2000, Tysons Corner, Virginia
- Conference on Small and Medium-Sized Cities, Little Rock, Arkansas
- Council of University Transportation Centers, January 7, 2001, Washington, D.C.
- Federal Highway Administration (FHWA): Annual Meeting, October 2, 1999, Tulsa, Oklahoma; RD&T Leadership meeting, May 11, 2000, McLean, Virginia
- Iowa Transportation Conference
- Long-Term Pavement Performance Program: U.S. Coordinators, January 7, 2001, Washington, D.C.; International Coordinators, January 7, 2001, Washington, D.C.
- Mississippi Valley Board of Directors, July 12, 2000, Chicago, Illinois
- Northeast Association of State Transportation Officials Board of Directors, April 30, 2000, Mashantucket, Connecticut
- Nevada Statewide Conference, Nevada
- No Name Group, March 30, 2000, Washington, D.C.
- Pennsylvania Quality Initiative meeting, March 30, 2000, Hershey, Pennsylvania
- Regional Research Advisory Committee meetings, four presentations during summer 1999
- Research and Technology Coordinating Committee, multiple meetings

- Rhode Island Transportation Forum
- Southern Association of State Highway and Transportation Officials: Board of Directors and Technical Session, August 28, 2000, New Orleans, Louisiana
- SHRP Implementation Task Force, April 6, 2000, St. George, Utah
- SHRP International Symposium, January 9, 2000, Washington, D.C.
- SHRP State Coordinators, January 9, 2000, Washington, D.C.
- TRB Annual Meeting sessions: January 11, 2000, and January 9, 2001, Washington, D.C.
- TRB Committees: A2D01 (Characteristics of Bituminous Materials) and A5015 (Spatial Data and Information Science), January 11, 2000; A5001 (Conduct of Research), January 12, 2000, Washington, D.C.
- University of Missouri, February 25, 2000, Columbia, Missouri
- Western Association of State Highway and Transportation Officials: Board of Directors, June 12, 2000; Technical Session, June 14, 2000, Rapid City, South Dakota

Organizations That Responded

Organizations also responded by letter, fax, e-mail, and telephone. Where it was possible to determine the source of the response, it is listed below. These responses include the panel presentations listed at the beginning of this appendix. Numbers in parentheses indicate that more than one response was received.

- State DOTs: Arizona (2), California, Colorado, Connecticut (3), Delaware, Florida (2), Georgia, Illinois, Indiana, Kentucky, Maine, Maryland, Minnesota (3), Missouri (2), Nevada (2), New Mexico, New York State, North Carolina, North Dakota, Oklahoma, Oregon, Pennsylvania, Rhode Island, Texas (2), Utah (2), Virginia, Washington State, Wisconsin, Wyoming
- Professional and industry organizations: America Society of Civil Engineers (2), American Concrete Institute, American Concrete Pavement Association, American Road and Transportation Builders Association, American Trucking Associations, Associated General Contractors, Association of American Railroads, Association of Metropolitan Planning Organizations, Institute of Transportation Engineers, Insurance Institute for Highway Safety, Materials Technology Center, National Asphalt Pavement Association, National Association of County Engineers, National Steel Bridge Alliance, National Stone Association, Owner Operators Independent Drivers Association, Salt Institute, National Industrial Transportation League

• Academic institutions: Bethune-Cookman College, Division of Business; Massachusetts Institute of Technology; Montana State University; New Jersey Institute of Technology; North Dakota State University; Northeastern University; Pennsylvania State University; Pennsylvania Transportation Institute; Texas Southern University; Texas Transportation Institute (2); University of Arkansas; University of California, Berkeley, Transportation Center; University of California, Berkeley, Department of Civil Engineering; University of Florida; University of Maine; University of North Carolina Highway Safety Research Center; University of Washington (Seattle); West Virginia University; Western Highway Institute

• Private-sector firms: Charles River Associates, Inc.; Daimler Chrysler (Traffic and Transportation Research Group); New Enterprise Stone & Lime Co., Inc.; Orth-Rodgers & Associates, Inc.; VMS, Inc.

• Federal agencies: Environmental Protection Agency, Energy and Transportation Sectors Division, Office of Policy; Federal Highway Administration, Eastern Resource Center; U.S. Army Corps of Engineers (2)

• TRB committees: A1B04 (Motor Vehicle Size and Weight), A1C08 (Telecommunications and Travel Behavior), A1E12 (Light Rail Transit), A2C01 (General Structures), A2D01 (Characteristics of Bituminous Materials), A2F07 (Fabrication and Inspection of Metal Structures) (3), A2L06 (Environmental Factors Except Frost), A3A10 (Highway Capacity and Quality of Service), A3B08 (User Information Systems), A3C03 (Maintenance and Operations Personnel), A5T57 (Transportation and Sustainability), a consortium of seven TRB Standing Committees, response signed by chairs of Committee A3A08 (Operational Effects of Geometrics) and the TRB Joint Subcommittee on Development of a Highway Safety Manual

• Other: Auto Club of New York; Commercial Vehicle Safety Alliance; High Speed Rail Ideas Committee, Task Force on Transportation Security; National Association of Governors' Highway Safety Representatives; National Safety Council; Natural Resources Defense Council; New Brunswick DOT; No Name Group; Operation Lifesaver; Pennsylvania Turnpike Commission; Western Pennsylvania Conservancy

Technical Advisory Groups for Stage 3 Outreach

Once the strategic goals of the program had been identified and the potential research topics narrowed down, small groups of experts were consulted to help develop a general outline of the research program. These individuals are listed below.

Crash Causation

- David Willis, AAA Foundation for Traffic Safety
- Forrest Council, University of North Carolina and TRB's Research and Technology Coordinating Committee
- Thomas Bryer, Pennsylvania DOT and Partnership Forum Safety Working Group Chair
- Richard Compton, National Highway Traffic Safety Administration
- Kenneth Stack, General Motors
- Keith Schultz, General Motors
- Terry Shelton, Federal Motor Carrier Safety Administration
- Richard Pain, TRB
- Jeffrey Paniati, FHWA

Infrastructure Renewal

- Jack Kay, Science Applications International Corporation (retired) and Research and Technology Coordinating Committee
- Stuart Anderson, Texas A&M University
- Robert Schuster, Sverdrup Civil (retired)
- Donn Hancher, University of Kentucky
- Herb Jakob, Astec Industries, Inc.
- Thomas Werner, New York State DOT
- Neil Hawks, TRB
- Phillip Ditzler, FHWA

Travel Time Reliability

- Phillip Tarnoff, University of Maryland
- Stephen Lockwood, Parsons Brinckerhoff
- Gary Larsen, FHWA
- Vincent Pearce, FHWA
- Christine Johnson, FHWA
- Jeffrey Paniati, FHWA
- Jeffrey Lindley, FHWA
- Mark Norman, TRB
- Richard Cunard, TRB

Providing New Capacity

- Sarah Campbell, TransManagement
- Hank Dittmar, Great American Station Foundation
- Genevieve Giuliano, University of Southern California
- Wayne Kober, Pennsylvania DOT, retired, and member of the Surface Transportation and Environment Cooperative Research Program Advisory Board
- Susan Mortel, Michigan DOT
- Kevin Keith, Missouri DOT
- Brian Smith, Caltrans
- Carol Cutshall, Wisconsin DOT
- John Carr, Kentucky DOT
- James Martin, Center for Transportation and Environment (CTE), North Carolina State University
- Gary McVoy, New York State DOT
- Janet L. Myers, CTE
- David Clawson, AASHTO
- Jon Williams, TRB
- Ysela Llort, Florida DOT
- Mary Lynn Tischer, Arizona DOT
- Marlin D. Collier, Mississippi DOT
- Shari Schaftlein, Wisconsin DOT
- William R. Hauser, New Hampshire DOT
- Ron McCready, NCHRP
- Christopher Hedges, NCHRP

Other FHWA and TRB Staff Who Participated in Outreach

Numerous staff from both FHWA and TRB participated in the outreach process, both by providing input in their areas of expertise and by identifying others to involve in the outreach process. The following individuals were particularly active in their participation:

- From FHWA—Robert Armstrong, Fred Bank, Susan Binder, Doug Brown, Charlie Churilla, James Cooper, Al Dimillio, Debra Elston, Robert Ferlis, Steven Forster, Michael Freitas, Raj Ghaman, Michael Halladay, John Harding, Tom Harmon, Connie Hill, Marci Kenney, Robert Kogler, Ray

Krammes, David Kuehn, Sue Lane, Kreig Larson, Dick Livingston, Aramis Lopez, Gary Maring, Regina McElroy, Susan Petty, Raymond Resendes, Shelley Row, Gloria Shepherd, James Shrouds, Fred Skaer, Mark Sarmiento, Michael Savonis, James Sorensen, Paul Teng, Samuel Tignor, Mike Trentecoste, Roy Trent, Toni Wilbur, Bill Wright

- From TRB—David B. Beal, Joedy W. Cambridge, D. W. (Bill) Dearasaugh, Jr., B. Ray Derr, Walter J. Diewald, Michael Grubbs, Amir N. Hanna, Edward T. Harrigan, Frederick D. Hejl, Timothy Hess, Kris A. Hoellen, Nancy P. Humphrey, G. P. Jayaprakash, Crawford F. Jencks, Frank N. Lisle, Thomas R. Menzies, Joseph R. Morris, Charles W. Niessner, Thomas M. Palmerlee, A. Robert Raab, Jean-Claude Turtschy, Julie Vandenbossche

APPENDIX B
Development of Research Focus Areas

The F-SHRP strategic focus areas and research topics as they developed throughout the study process are presented in this appendix. Table B-1 summarizes this information.

Initial Brainstorming List, July 15, 1999

The following list of focus areas was the result of the committee's brainstorming session at its June 1999 meeting. This list was sent out with the initial outreach letter to solicit reactions from stakeholders. A short description of each area and potential research topics are included.

1. Accelerating the Renewal of America's Highways

Much of the nation's highway system is in need of major repair or rehabilitation. The public wants this work done quickly, with as little disturbance as possible ("get in, get out, stay out"). To this end, agencies need to streamline the entire project delivery process, including planning, environmental review, design, construction, and procurement procedures. Agencies are also concerned about how to pay for this work. Despite these challenges, the need to renew aging highways also presents an opportunity to improve the safety, design, and performance of highway facilities; their interaction with the environment; and their role in the community.

Possible research topics: Construction methods, innovative materials, nondestructive evaluation technologies, innovative contracting and finance, work zone safety, creative design (see below), environmental mitigation design/techniques, life-cycle cost analysis, development of performance measures for performance-related specifications.

Table B-1 Development of F-SHRP Topics

Initial Brainstorming List, July 15, 1999	Potential Strategic Focus Areas, April 25, 2000	Potential Research Topics, May 22, 2000
Infrastructure renewal		
• Accelerating the renewal of America's highways	• Accelerating the renewal of America's highways	• Accelerating the renewal of America's highways – Achieve rapid, long-lived, minimally disruptive reconstruction of freeways and Interstates – Achieve rapid, long-lived, minimally disruptive reconstruction of bridges – Rebuild urban street networks to serve 21st-century cities – Improve infrastructure investment decisions by developing tools for asset management systems

NOTE: Column heads correspond to the section headings in the text of Appendix B under which the listed items are discussed.

Candidate Research Topics, July 5, 2000	Reintroduction of Fourth Strategic Focus Area, October 2000	Vision, Strategic Focus Areas, and Research Topics, March 2001
Infrastructure renewal		
• Accelerating the renewal of America's highways – Improve infrastructure investment decisions by developing tools for asset management systems – Achieve rapid, long-lived, minimally disruptive reconstruction of freeways and Interstates – Renew urban street networks to serve 21st-century cities – Improve infrastructure condition and operations through better preservation strategies	• Accelerating the renewal of America's highways (Topics remained the same.)	• Rapid, long-lived, minimally disruptive highway renewal

(*continued on next page*)

Table B-1 (*continued*) **Development of F-SHRP Topics**

Initial Brainstorming List, July 15, 1999	Potential Strategic Focus Areas, April 25, 2000	Potential Research Topics, May 22, 2000
Safety		
• Making a quantum leap in highway safety	• Making a quantum leap in highway safety	• Making a quantum leap in highway safety – Achieve a significant reduction in single-vehicle run-off-the-road crashes – Achieve a significant reduction in intersection crashes – Improve knowledge of crash causation through collection and analysis of more accurate and complete safety data – Improve the safety of highway designs through development of a compendium of information about the relationship between roadway design and safety – Improve postcrash emergency medical services – Achieve a significant reduction in truck-related fatalities

[a] As a result of report review, the Safety strategic focus area was revised to read "Making a Significant Improvement in Highway Safety," and the safety research program was revised to focus on crash factors and the cost-effectiveness of countermeasures.

Candidate Research Topics, July 5, 2000	Reintroduction of Fourth Strategic Focus Area, October 2000	Vision, Strategic Focus Areas, and Research Topics, March 2001
Safety		
• Making a quantum leap in highway safety – Improve knowledge of crash causation through collection and analysis of more accurate and complete safety data – Achieve a significant reduction in the number and severity of single-vehicle run-off-the-road crashes – Achieve a significant reduction in the number and severity of intersection crashes	• Making a quantum leap in highway safety (Topics remained the same.)	• Comprehensive crash causation study and selected countermeasures[a]

(*continued on next page*)

Table B-1 (*continued*) **Development of F-SHRP Topics**

Initial Brainstorming List, July 15, 1999	Potential Strategic Focus Areas, April 25, 2000	Potential Research Topics, May 22, 2000
Environmental quality		
• Integrated environmental review process • Controlling highway runoff	• Serving population and economic growth by providing new capacity in an environmentally sensitive way (At this stage, the concepts of environmental quality, impact analysis, and planning and design were merged into a single concept of how to provide highways that meet a wide range of customer requirements.)	• Serving population and economic growth by providing new capacity in an environmentally sensitive way – Envision 21st-century highway transportation – Envision 21st-century freight transportation – Improve transportation-related air quality through better data and models for decision making
Planning and design		
• Context-sensitive design • Integrated highway–truck design		
Analysis of impacts		
• Effect of communication technology on travel demand		

	Candidate Research Topics, July 5, 2000	Reintroduction of Fourth Strategic Focus Area, October 2000	Vision, Strategic Focus Areas, and Research Topics, March 2001
Environmental quality			
	• Delivering a sustainable highway system (this focus area was retitled at this point) – Improve scientific and policy information for sustainable highway systems – Develop a toolkit for practitioners to use in delivering sustainable highway systems	• Delivering a sustainable highway system (The two topics in this area were merged into one, combining the titles of both.)	• Environmentally, economically, and socially responsive highway development

(*continued on next page*)

Table B-1 (*continued*) **Development of F-SHRP Topics**

Initial Brainstorming List, July 15, 1999	Potential Strategic Focus Areas, April 25, 2000	Potential Research Topics, May 22, 2000
Operations		
	• Enhancing maintenance and operations in the information age	• Enhancing maintenance and operations in the information age – Improve the speed and efficacy of incident management and response – Significantly reduce delay through improved congestion management – Prepare transportation institutions to implement ITS operations strategies – Improve institutional preparedness for innovative maintenance approaches – Significantly improve pavement preservation
Institutions		
• 21st-century transportation agencies	(This concept was discontinued as a separate category, and institutional issues were integrated into each of the other strategic focus areas and research topics, as appropriate.)	

Candidate Research Topics, July 5, 2000	Reintroduction of Fourth Strategic Focus Area, October 2000	Vision, Strategic Focus Areas, and Research Topics, March 2001
Operations		
• Enhancing maintenance and operations in the information age (This strategic focus area was discontinued at this stage.)	• Increasing mobility by optimizing system performance (a new focus area was developed at this stage) – Providing real-time information to customers – Reducing congestion from nonrecurring incidents	• Reliable travel times

2. Making a Quantum Leap in Highway Safety

To respond to the public's demand for safe highways, significantly new approaches are needed. Comparatively straightforward solutions have already been implemented and have resulted in tremendous progress during the last few decades. Any significant reduction of the current toll of more than 40,000 lives lost per year in highway crashes will require addressing more complex factors, such as human behavior; the role of enforcement; and the interaction among vehicle, driver, and road. Such reduction will also require investigating and applying more advanced technologies, such as intelligent transportation systems (ITS) applications.

Possible research topics: Highway designs that communicate better with the driver and vehicle about safety, including the use of sensors and ITS-related technologies; safer designs that also meet environmental and aesthetic objectives; data collection and analysis regarding crash causation and improvements to safety from specific changes in roadway design; impact of the aging driver population; improved incident management.

3*a*. Integrated Environmental Review Process

Much attention is being devoted at the national and state levels to improving the environmental review process. Efforts to streamline the process must simultaneously address project delivery and environmental objectives. This can be done only by achieving better integration of environmental considerations and analysis into the overall planning process. Objectives must be clearly articulated and meaningful performance measures developed against which streamlining efforts can be evaluated.

Possible research topics: Development of technologies to support integrated environmental and planning analysis and decision making, such as geographic information systems (GIS), technologies based on the Global Positioning System (GPS), expert systems, and visualization technologies. Methods and performance measures for evaluating environmental review process streamlining and for assessing the implementation of resulting project designs.

3*b*. Controlling Highway Runoff

Environmental Protection Agency regulations regarding storm water runoff pose a challenge to transportation agencies, which must ensure that the runoff from highways and construction projects is not degrading water quality. Snow and ice control materials, maintenance operations, sediment from construction sites, and air emissions washed back in precipitation all contribute to pollution in highway runoff, but the processes by which this occurs and the impacts of various pollutant sources and mitigation measures are not well understood.

Possible research topics: Monitoring and modeling of the fate and transport of transportation-related runoff; assessment of the impact of storm water runoff of various types; development of best management practices and assessment of their performance, constraints, and costs.

4. Context-Sensitive Design

The public wants roads that get them where they want to go safely and efficiently and that are aesthetically pleasing, have minimal negative impact on the environment, and promote a healthy community. Much is known about designing roads for their basic functional performance: conveying vehicles safely and efficiently from one place to another. But there is little clear guidance on how to achieve this aim while also meeting safety, community, and aesthetic criteria. What are the critical design criteria in these other areas? How can apparently competing goals be balanced? What will the fundamental, unifying criterion be?

Possible research topics: Design methodologies that integrate performance, safety, aesthetic, and social criteria; innovative materials; and environmental concerns.

5. Integrated Highway–Truck Design

Potential increases in truck size and weight constantly contend with the limits imposed by pavement design (to reduce pavement damage by trucks) and roadway geometry (to maintain safe operation of trucks). Providing adequate pavement and roadway design is difficult since several generations of heavy-vehicle technology can be used over the life of a road. Achieving the combined goals of more economical commercial vehicle technology and high-quality and safe roadways requires a systems approach to the design of the vehicle and the highway.

Possible research topics: Pavement materials, construction, design methodologies; pavement–truck interaction models; truck suspensions; safety design for trucks; economic analyses; use of separate facilities or lanes for trucks; use of ITS technologies, particularly to address the possible safety impacts of new truck designs.

6. Effect of Communication Technology on Travel Demand

Communication technologies, such as personal computers and cellular phones, can have a significant impact on the amount, timing, and types of travel. For instance, with the growth of a web-based economy and the increase in people working at home, more commercial vehicles are using suburban streets to deliver goods ordered over the Internet and to bring professional mail, packages, and supplies directly to homes. Personal computers and cell phones do not appear to reduce travel as much as to increase the ability to communicate while one travels. Industry demands just-in-time delivery of products and materials, with the expectation that communication technology will eliminate the need to wait.

Possible research topics: Effects that the increase in commercial vehicle deliveries to private homes may have on commercial vehicle travel, local roads, and neighborhoods; development of travel models that address the impact of the increased use of portable communication technologies.

7. 21st-Century Transportation Agencies

Transportation agencies must be better prepared to deal with an environment that challenges traditional ways of doing business, characterized, for example, by a broadening set of performance demands imposed on the highway system. These demands include technical, environmental, economic, safety, social, and political requirements; the public's expectation of more communication; and the need for technologies and expertise not traditionally associated with highway engineers.

Possible research topics: Ways to address the need for a more varied and highly skilled workforce, including recruitment, training, and retention of personnel; extent to which universities are preparing engineers and other professionals for this field; effects of outsourcing, including how much can be outsourced without detriment to the agency's responsiveness and ability to manage, whether this depends on the type of activity, and how asset management can best be accomplished.

Potential Strategic Focus Areas, April 25, 2000

At the committee's March 2000 meeting, the results of the broad outreach effort were discussed, four strategic focus areas were developed, and crosscutting topics were identified; the concept of an overarching theme was also introduced.

Overarching Theme: Providing Outstanding Customer Service for the 21st Century

Challenges and opportunities in highway transportation are requiring new ways of thinking about moving people and goods. These challenges represent a broadening set of performance demands imposed on the highway system, including technical, environmental, economic, safety, social, and political requirements. Transportation professionals must learn to respond to the new economy (one that is global, rapidly changing, and customer-focused), the desire for greater environmental sustainability, a demand for ever-increasing quality of life, the public's expectations for greater involvement in transportation decision making, and the need for technologies and expertise not traditionally associated with highway engineers. Meeting all these expectations requires a systems approach, which includes sensitivity and responsiveness to the context (social, economic, environmental, technological) in which transportation takes place. The four strategic focus areas described below are aimed at supporting this overarching theme.

Strategic Focus Areas

1. Accelerating the Renewal of America's Highways

See earlier description.

Expected benefits: Improved facility and system performance; reduced user and life-cycle costs.

Additional possible research topics: Collection and analysis of data and development of predictive performance models to support asset management; development of renewal approaches that improve or restore urban quality of life; consideration of projected trends in vehicle design and their impact on highway design.

2. Making a Quantum Leap in Highway Safety

See earlier description.

Expected benefits: Reduced injuries and fatalities.

Additional possible research topics: Human factors studies, including research on special populations (older drivers, new drivers, impaired drivers, immigrant populations); better access and protection for bicycles and pedestrians; tools for data collection, such as event data recorders; a special study to investigate crash causation; development of standards and strategies for safety design; research on the effectiveness and best use of automated enforcement; communication between the vehicle and the infrastructure (automated vehicles/highways).

3. *Serving Population and Economic Growth by Providing New Capacity in an Environmentally Sensitive Way*

During the next few decades, the demand for personal travel and goods movement is expected to increase significantly. Factors contributing to this growth in demand include increasing population, growth of the economy, and other social and economic trends (such as e-commerce, just-in-time manufacturing, and customization of products) associated with the demand for flexible and rapid response to customer requirements. Yet any new capacity must be provided in the context of concerns regarding quality of life and environmental sustainability. The objective of this strategic focus area is to contribute significantly to a vision for a future highway/transportation system and to provide information and tools that the transportation community can use to help make that vision a reality.

Expected benefits: Better information and tools for decision making.

Potential research topics: Travel and freight demand forecasting models; understanding of the influence of economic restructuring on transportation supply and demand; methods for evaluating intermodal trade-offs and for integrating modes in a more seamless way for both passengers and freight; consideration of potential increases in truck size and weight and their effects on safety, infrastructure, and operations; development of logistical tools and techniques; evaluation of new approaches, such as privately managed roads and truck-only facilities; analysis of relationships and trade-offs among capacity enhancement, access management, and land conservation; better data, analysis, and design tools for predicting and avoiding or mitigating environmental impacts; methods for better communicating with the public about complex transportation issues and for gathering more representative public input.

4. *Enhancing Maintenance and Operations in the Information Age*

With the completion of the Interstate highway system, transportation agencies have increasingly turned their attention to maintenance and operation of the system. However, the importance of this focus area is not limited to the preservation and performance of existing highways; increasing demands on the system and the challenges faced in meeting these demands (see Focus Area 3) require that the existing system, any new system, and the transition between the two be managed with keen attention to operational performance. The objective of this focus area is to develop information and tools for improving the operational performance of the highway system.

Expected benefits: Better system performance for users; greater agency efficiency.

Potential research topics: "Smart" materials; sensors; characterization and measurement of system operational performance; tools for asset management (including performance data, performance measures, and cost-accounting methods); evaluation of demand and capacity management tools (such as high-occupancy vehicle lanes, pricing, and truck restrictions); logistics analysis and methods for both passenger and freight movement; ITS technologies for communicating real-time information to users and managers; skill requirements for operations and access management; enhanced operational models.

Cross-Cutting Topics

A number of topics recur throughout the four strategic focus areas. These topics may suggest promising areas in which to focus research.

First, several types of research or areas of technology development appear to provide opportunities for significant progress. These include the following:

- *Data and data systems:* Improvements in the quality and quantity of data and in data accessibility and management. This area could include collection of better crash data, transportation demand data, and asset management data (facility condition and performance, activity-based costs); improvements in the accessibility and coordination of current databases; and the development of new databases.
- *Methods and tools for design, analysis, and management:* Characterization and measurement of system performance (design impacts on safety, facility response to maintenance interventions, effectiveness of demand and capacity management techniques, effectiveness of environmental mitigation techniques); modeling and prediction of future conditions (travel demand, freight demand, demographics, global economic structure, sociotechnical and cultural changes).
- *Advanced technologies:* High-performance and "smart" materials; sensors; nondestructive evaluation technologies; ITS technologies (electronic and communications technologies for communication about system performance and condition, for communication between vehicle and road, and for automation applied to safety and mobility objectives); robotics; GIS; GPS; artificial intelligence techniques.

Second, regardless of the specific technical focus, any research undertaken will need to reflect the following considerations:

- *Systems approach:* Integration of diverse requirements, considerations, and criteria in planning, design, construction, operations, and maintenance; consideration of longer life cycles and broader issues and impacts. Examples are integrated truck–pavement–bridge design and an integrated approach to safety that includes driver, vehicle, and roadway.
- *Goods movement:* Recognition of goods movement as a major contributor to the economy and to quality of life; integration of goods movement as a significant factor in transportation planning, design, safety, and operations and in dealing with public concerns.
- *Institutional issues:* Rethinking roles, responsibilities, and institutional structures; identifying educational requirements for future transportation professionals; addressing workforce issues, such as recruitment, training, and retention; developing new ways of managing highway activities, including financing strategies that better leverage public funds and procurement methods that promote faster and higher-quality construction, rehabilitation, and maintenance; streamlining consensus processes with resource agencies.

Potential Research Topics, May 22, 2000

By May, a more focused technical outreach process had led to the identification of 17 potential research topics under the four strategic focus areas described above. These research topics were as follows:

- Accelerating the renewal of America's highways
  1. Achieve rapid, long-lived, minimally disruptive reconstruction of freeways and Interstates.
  2. Achieve rapid, long-lived, minimally disruptive reconstruction of bridges.
  3. Rebuild urban street networks to serve 21st-century cities.
  4. Improve infrastructure investment decisions by developing tools for asset management systems.
- Making a quantum leap in highway safety
  5. Achieve a significant reduction in single-vehicle run-off-the-road crashes.
  6. Achieve a significant reduction in intersection crashes.

7. Improve knowledge of crash causation through collection and analysis of more accurate and complete safety data.
8. Improve the safety of highway designs through development of a compendium of information about the relationship between roadway design and safety.
9. Improve postcrash emergency medical services.
10. Achieve a significant reduction in truck-related fatalities.

- Serving population and economic growth by providing new capacity in an environmentally sensitive way

11. Envision 21st-century highway transportation.
12. Envision 21st-century freight transportation.
13. Improve transportation-related air quality through better data and models for decision making.

- Enhancing maintenance and operations in the information age

14. Improve the speed and efficacy of incident management and response.
15. Significantly reduce delay through improved congestion management.
16. Prepare transportation institutions to implement ITS operations strategies.
17. Improve institutional preparedness for innovative maintenance approaches.
18. Significantly improve pavement preservation.

Candidate Research Topics, July 5, 2000

After additional outreach, the four strategic focus areas were reduced to three, the third focus area was retitled, and nine of the above research topics were chosen for further analysis.

Strategic Focus Area 1: Accelerating the Renewal of America's Highways

1. Improve Infrastructure Investment Decisions by Developing Tools for Asset Management Systems

Managers of transportation agencies are faced with countless needs and limited resources. They need the best information and tools possible to help decide which investments will yield the best return in their state or locality. The idea of asset management is being refined and more widely accepted, and some components or forerunners of asset management (such as pavement, bridge, sign, or maintenance management systems) are being used in all states. However, the data and tools needed for effective decision making about investments across highway assets are still not well developed. This research may address some of the following specific topics: data issues (data needs, sources, collection technologies, and integration); diagnostic tools (sensors and nondestructive evaluation technologies) to assess facility condition and performance; analysis tools for better life-cycle cost analysis, trade-off analysis, and sensitivity analysis; and institutional issues (use and possible misuse of information, required skills and training, impacts on institutional structure and ways of operating, ways of getting metropolitan planning organizations and other agencies involved).

2. Achieve Rapid, Long-Lived, Minimally Disruptive Reconstruction of Freeways and Interstates

Rehabilitation of aging highway infrastructure is a major concern to agencies across the country. Much of this infrastructure is heavily used and critical to the transportation system, so prolonged disruption of operations for rehabilitation imposes significant user costs. This research would focus on ways of performing highway rehabilitation quickly, with minimal disruption to operations and minimal need for future disruption due to maintenance and rehabilitation activities. Potential specific research topics include materials (especially regarding rapid setup and durability), design (pavement and structural), construction processes and methods (such as modular construction), equipment (possibly including automated or robotic equipment to improve quality and speed), sensing and nondestructive evaluation technologies, contracting and financing mechanisms, and traffic operations and management strategies and technologies (such as automated traveler information systems, VMS, pavement markings).

3. Renew Urban Street Networks to Serve 21st-Century Cities

This topic encompasses much of what characterizes the previous topic: aging, inadequate, but heavily used infrastructure in need of significant rehabilitation with minimum disruption to users. However, the focus on urban street networks rather than freeways and Interstates adds some issues particular to urban streets, such as pedestrian and bicycle safety and mobility; transit use (buses, access to subway and light rail); storm water management and treatment; and installation and repair of subsurface utilities. Specific research topics might include materials, design considerations (geometric, structural, bicycle/pedestrian, aesthetic or context-sensitive), construction methods, equipment, contracting and financing mechanisms, traffic operations and management, safety (especially bicycle/pedestrian), hydraulics, storm/wastewater management, maintenance management, and access and mobility issues (such as better intermodal access for passengers and delivery of goods in cities).

4. Improve Infrastructure Condition and Operations Through Better Preservation Strategies

Effective management of highway infrastructure requires that actions be taken in a timely manner to preserve the system, retard deterioration, and reduce the need for major rehabilitation in the future. Preservation strategies must be based on knowledge about current and predicted system condition and the effectiveness and proper timing of preservation actions. Research in this area might address specific topics such as integration of performance data and models from various management systems; funding issues (ensuring the availability of funding to perform appropriate preservation activities in a timely fashion); development of performance measures and specifications; development of mix design procedures; evaluation of alternative preservation techniques (such as various "thin" treatments); materials selection (required properties for aggregates in thinner layers, for bonding to existing material, and for rapid opening to traffic); construction practices and equipment that facilitate timely, high-quality maintenance treatments with minimal disruption to traffic and maximum safety for workers.

Strategic Focus Area 2: Making a Quantum Leap in Highway Safety

5. Improve Knowledge of Crash Causation Through Collection and Analysis of More Accurate and Complete Safety Data

Better understanding of the respective roles of the driver, the vehicle, and the roadway in highway crashes is critical to designing and operating a safer highway system. No comprehensive crash causation study has been conducted in the United States since a study performed in the 1970s by Indiana University. Driver characteristics and the driving environment have changed significantly since that time. In addition, new sources of data and better data collection technologies (event data recorders, GIS, GPS) are available now to improve the conduct of such a study. This research would produce better knowledge about crash causation, which could be used to develop countermeasures and programs. The research would also produce improved techniques for studying crash causation, which could be used by state and local jurisdictions to analyze local safety issues.

6. Achieve a Significant Reduction in the Number and Severity of Single-Vehicle Run-off-the-Road Crashes

Run-off-the-road crashes account for one-third of highway fatalities. Research in support of addressing this highway safety problem might include some combination of the following specific topics: data collection/crash causation study; ITS technologies (automated warning systems, lane-keeping technologies); human factors research; improved highway design; signage, lighting, and pavement markings; and enforcement strategies (including automated enforcement). Knowledge gained from this research could be used to develop safer designs; operational strategies; warning and prevention technologies; analysis tools for decision makers in planning, design, operations, and maintenance; and driver training.

7. Achieve a Significant Reduction in the Number and Severity of Intersection Crashes

Intersection crashes account for 22 percent of highway fatalities. Several categories of more-vulnerable road users—older drivers, very young drivers, pedestrians, and bicyclists—are involved in this type of crash. As with the run-off-the-road crash topic, research in support of addressing this highway safety problem might include some combination of the following specific topics: data collection/crash causation study; ITS technologies (collision avoidance and automated warning systems); human factors research; improved highway design and access management policies; signage, signals, lighting, and pavement markings; and enforcement strategies (including automated enforcement). Knowledge gained from this research could be used to develop safer designs; operational strategies; warning and prevention technologies; analysis tools for decision makers in planning, design, operations, and maintenance (such as simulation techniques for assessing the safety and operational implications of alternative intersection configurations); and driver training.

Strategic Focus Area 3: Delivering a Sustainable Highway System

8. Improve Scientific and Policy Information for Sustainable Highway Systems

Delivering a sustainable highway system requires knowledge about diverse aspects of the system and its relationship to the human and natural environments. Research in this area would be aimed at improving scientific and policy information in such specific areas as air quality, water quality, noise, environmental justice, habitats, context-sensitive design, community participation, economic impacts, land use, and financing strategies.

9. Develop a Toolkit for Practitioners to Use in Delivering Sustainable Highway Systems

Knowledge is not sufficient for achieving sustainable highways, but must be put in a form that is easily used by practitioners and stakeholders in the highway development process. Research in this area would be aimed at developing tools to assist in such tasks as planning and design of highways that are safe and compatible with their human and natural environments; assessment of economic, community, and environmental impacts; development of mitigation strategies and assessment of their economic impacts; visualization of designs prior to construction; and evaluation of outcomes of finished projects to provide improved knowledge for the future.

Reintroduction of Fourth Strategic Focus Area, October 2000

Stakeholder response to the above three strategic focus areas indicated a need to reintroduce the fourth area that had previously been removed. Two potential research topics were developed under this fourth area, and two other research topics were combined, yielding a total of ten topics at this stage. Appendix C contains a summary of the review of existing highway research programs that was performed for these ten topics.

Strategic Focus Area 1: Accelerating the Renewal of America's Highways

The following candidate research topics were included in this focus area at this stage:

1. Improve infrastructure development decisions by developing tools for asset management systems.
2. Achieve rapid, long-lived, minimally disruptive reconstruction of freeways and Interstates.
3. Renew urban street networks to serve 21st-century cities.
4. Improve infrastructure condition and operations through better preservation strategies.

Strategic Focus Area 2: Making a Quantum Leap in Highway Safety

The following candidate research topics were included in this focus area at this stage:

5. Improve knowledge of crash causation through collection and analysis of more accurate and complete safety data.

6. Achieve a significant reduction in the number and severity of single-vehicle run-off-the-road crashes.

7. Achieve a significant reduction in the number and severity of intersection crashes.

Strategic Focus Area 3: Delivering a Sustainable Highway System

8. Improve scientific and policy information for sustainable highway systems; develop a toolkit for practitioners to use in delivering sustainable highway systems.

Strategic Focus Area 4: Increasing Mobility by Optimizing System Performance (Added)

Roadway users want to be able to travel safely and to arrive at their destinations in a reasonable time frame. Congestion is already a major impediment to achieving these objectives in many metropolitan areas. At the same time, personal travel and goods movement are expected to increase significantly during the next 25 years. Providing new capacity is one answer, but congestion levels in 68 metropolitan areas are so high that 1,087 freeway lane-miles and 1,432 arterial lane-miles would need to be added annually just to maintain current congestion levels. There is an urgent need to make a major leap forward in the development and application of roadway operations to reduce congestion, provide safer roads, and support a growing economy that is increasingly dependent on just-in-time logistics and supply chain management.

Opportunities for significant improvements in this area are provided by progress made in several operations-related areas during the last decade. These areas include deployment of ITS infrastructure that enables real-time management of highways; development of management techniques that improve highway flow and contribute to crash reduction and avoidance of fatalities; and availability of information that allows customers to use the roadway infrastructure more efficiently. However, none of these tools, together with more traditional traffic and highway operations approaches, have yet been united in an integrated system or discipline that can be applied consistently in different circumstances to achieve significant mobility and safety results. Research in this area would be aimed at integrating these opportunities and focusing them on addressing one or more major operational issues.

Two candidate research topics were developed in this focus area:

9. Providing real-time information to customers: Given changes in lifestyle and the economy, roadway customers—private and commercial—place a high value on system reliability, security, and traveler information. Travel demand models have postulated and experience has shown that people will change their travel behavior in the presence of better travel information. Several existing technologies improve the accuracy and timely provision of information to users, including ITS-based travel pattern information, cell phones, and AVI position reporting data (TRANSMIT). Historical databases can form the basis for developing point-to-point travel time predictions. The use of real-time information may also drive changes in infrastructure investment and operations policy and practice. Research in this area could focus on the following specific topics:

- Performance requirements
  - Requirements and values of different customer segments under various conditions (such as commute, recreation, work zone, disaster, special event, freight delivery)
  - Performance measures, indicators, and indices that adequately communicate system performance to customers and operators in useful ways
  - Human factors considerations involved in effectively communicating the information within the constraints of various media [telephone, broadcast, personal data assistant (PDA), Internet, VMS]
  - Definition of minimum information requirements for various geographic, weather, and travel density conditions for the functional specifications of various roadway classes
  - Information about intermodal connections and alternatives to increase transit use, including door-to-door travel times, costs, and walking/waiting times
- Technologies for collection, storage, sampling, and analysis of data
  - Travel time prediction models
  - Alternative detection and surveillance technologies

10. Reducing congestion from nonrecurring incidents: Approximately 60 percent of delay has been attributed to nonrecurring incidents, such as crashes, work zones, and special events. Incidents also increase the likelihood of secondary crashes. ITS technologies have provided some capability to know what is happening on the roadway and to respond. Nevertheless, the actual real-time management of incidents is generally based on intuition

and trial and error; in addition, currently available tools for intervention are still relatively crude. Better management of incidents in advance (for planned events) and faster response (for unplanned events) could significantly reduce congestion and the frustration it generates, as well as improve safety. F-SHRP research in this area could focus on the following specific topics:

- Data and analysis technologies
  - Techniques for predicting location, frequency, duration, and type of incident as the basis for improving incident detection and response protocols, including, for example, prepositioning of service patrols, equipment, and personnel and targeting of traveler information. This research might include artificial intelligence (AI) approaches combined with ITS-based historical data and data mining techniques.
  - Use of on-site GPS/stereo/AI techniques and video imaging from surveillance cameras to substantially reduce documentation requirements for serious crashes.
- Traffic control technologies
  - Traffic control techniques, based on micro simulation and micro analysis, for real-time management of supersaturated bottlenecks; intensified traffic controls that might include automated and variable lane and speed control, coupled with automated enforcement
  - Micro simulation traffic models for more user-friendly applications (improvements to CORSIM, for example)
  - Low-cost/low-maintenance traffic-adaptive signal technology, especially for use in areas where special events occur regularly (near stadiums and convention centers, for instance), based on low-cost detection devices (such as video image processing) and wireless communications technology
  - Design, including technology, designs, and operating techniques for making roadways more flexible (for example, to modify flow patterns in response to special event traffic, recreational traffic, or other incidents)
  - Performance: development of performance measures and standards for appropriate levels of system application and operational intensity to help agencies determine cost-effective approaches to meeting customer needs

Vision, Strategic Focus Areas, and Research Topics, March 2001

At the committee's October 2000 and March 2001 meetings, a vision for the highway system was developed, and the research topics were reduced to four. These four, after further refinement, became the four research programs recommended in the report.

Vision

The committee developed the following vision for the highway system:

> *A highway system that actively contributes to improved quality of life for all Americans by providing safe, efficient mobility in an economically, socially, and environmentally responsible manner.*

Research Topics

Rapid, Long-Lived, Minimally Disruptive Highway Renewal

> *Overall goal: To develop a consistent, systematic approach to performing highway renewal that is rapid, causes minimum disruption, and produces long-lived facilities.*

Comprehensive Crash Causation Study and Selected Countermeasures

> *Overall goal: To build the foundation for a quantum leap in highway safety through the in-depth study of crash causation and the development of prototype countermeasures for selected crash types.*

Environmentally, Economically, and Socially Responsive Highway Development

> *Overall goal: To develop approaches and tools for systematically integrating environmental, economic, and community requirements into the analysis, planning, and design of new highway capacity.*

Reliable Travel Times

> *Overall goal: To provide highway users with reliable travel times by preventing and reducing the impact of nonrecurring incidents.*

C

APPENDIX

Review of Related Work and Analysis of Research Gaps

The committee's review of existing highway research programs with regard to the potential research topics identified in preparation for the June and October 2000 committee meetings is summarized in this appendix.

Strategic Focus Area 1: Accelerate the Renewal of America's Highways

After soliciting research needs from numerous stakeholders and highway research experts, the committee identified four promising research approaches within this strategic focus area. The first was to develop tools for asset management to help managers of transportation agencies, who face countless needs and limited resources, decide which investments will yield the best return in their state or locality. The second was to focus on methods and technologies for performing highway reconstruction and rehabilitation quickly, with minimal disruption to operations and minimal need for future reconstruction and rehabilitation. The third was to focus specifically on the renewal needs of city street networks. The fourth was to develop infrastructure preservation strategies for preserving the system, retarding deterioration, and reducing the need for major renewal in the future.

The committee reviewed existing highway infrastructure research and technology programs to assess the state of the art in each of these areas and identify research needs. The main programs reviewed were those of the Federal Highway Administration (FHWA), the National Cooperative Highway Research Program (NCHRP), the Transportation Research Board, and industry associations. In addition, a search of the Transportation Research Information Services (TRIS) database, including the TRIS Research in Progress database, revealed work being conducted in state departments of transportation (DOTs), universities, and other countries. Summaries of the results of these analyses are provided in the following subsections.

Asset Management[1]

FHWA is developing a number of analysis tools, such as life-cycle cost analysis and the Highway Economic Requirements System. FHWA, NCHRP, and state DOTs have developed many management systems for specific assets (for example, pavements, bridges, signs, and real estate). University research is focused on analytical frameworks and tools. Currently, many research papers and projects appear to focus on data collection, integration, and management, especially using newer technologies, such as the Global Positioning System, geographic information systems, and visualization techniques. The American Association of State Highway and Transportation Officials has a detailed *Asset Management Strategic Plan* covering the period 2000 to 2005, and work has already begun on the plan's initial tasks. In particular, an NCHRP report due in 2002 will address asset management using a top-down, holistic approach. The report will provide a synthesis of knowledge and tools, identify a recommended applications framework, and set forth research needs.

The F-SHRP committee identified research gaps in three areas related to asset management: (*a*) data and data management (methods and tools to make data gathering and database updating cheaper, easier, more reliable, and more accurate, and systems for integrating data from various sources); (*b*) analysis and decision making (performance measures, performance and prediction models, analytical methods that can be used across assets, tools for developing and presenting options at the highest management levels); and (*c*) institutional issues (how to organize to implement asset management, human resource needs, and methods to achieve stable funding of asset management support work).

Rapid Renewal of Interstates and Freeways

FHWA currently has several research projects under way on materials that are lighter and more durable and that facilitate faster construction. The agency also runs a nondestructive evaluation research program for bridges. Several smaller-scale programs under way or completed encompass the faster fabrication

[1] "Asset management in transportation can be defined as the sum of all the activities relative to the life of an asset resulting in a safe and efficient intermodal transportation system that contributes to the social and economic well-being of its benefactors. It can also be defined as a systematic process of operating, maintaining and upgrading transportation assets cost-effectively, by combining engineering practices and analysis with sound business practice and economic theory" (American Association of State Highway and Transportation Officials, *AASHTO Asset Management Strategic Plan,* November 1998).

and reconstruction of bridges and various state demonstration projects for the accelerated reconstruction of segments of roadway. FHWA is also continuing its development of a freeway simulation model for traffic operations and analysis tools for work zones. An agencywide team is developing an integrated approach to work zones (including infrastructure, safety, and operations considerations). NCHRP projects completed or under way include project-level reconstruction and contracting methods, mitigation of delays in the construction process, materials for early opening to traffic, and rapid rehabilitation of high-volume roads and replacement of bridge decks.

Gaps were identified in four areas related to rapid renewal: (*a*) performance measurement (for work zone performance, delay, user costs, methods to measure quality in the construction/maintenance phase, and monitoring of traffic composition and behavior); (*b*) methods and operations [rapid replacement/repair systems, construction for confined spaces, methods to address work zone operations during planning and design (including consideration of corridor and systemwide impacts), effective work zone traffic information systems and traffic management systems]; (*c*) materials and equipment (life-cycle cost optimization of materials for early opening to traffic, long-term performance of high-performance materials, mechanisms to foster development of innovative pavement construction equipment); and (*d*) designs that take advantage of renewal efforts to improve safety, environmental, aesthetic, and congestion mitigation aspects of the facility.

Renewal of Urban Street Networks

There is very little research focused specifically on the renewal of urban street networks, although some of the current and recent work described under the previous topic of Interstate and freeway renewal could also potentially apply to this area. FHWA is performing some work directly related to urban areas that deals primarily with computer simulations of surface street operations and design considerations for bicycles and pedestrians.

Research gaps related specifically to urban street networks include noise mitigation, construction techniques in urban residential areas, construction techniques for confined spaces in urban commercial areas, storm water models, aesthetic design issues, better and less disruptive urban lighting, access and mobility issues related to urban work zones and construction management, urban utilities, and freight movement and delivery of goods in urban centers.

Infrastructure Preservation

FHWA is currently funding several materials technology research projects, addressing such topics as predictors for the performance of jointed plain concrete pavements, mix designs for micro surfacing, and corrosion control research for reinforced concrete structures. NCHRP and other research programs have completed or are currently conducting research in the management and decision-making processes and preservation strategies. Several states perform research on preservation strategies for pavement, bridges, and other infrastructure elements.

Gaps were identified in the following areas related to infrastructure preservation: performance-related specifications for construction and maintenance activities, performance and prediction models, integration of pavement preservation strategies into pavement management systems, quality control/quality assurance criteria for pavement preservation data collection, and field testing of performance models.

Strategic Focus Area 2: Make a Quantum Leap in Highway Safety

After soliciting research needs from numerous stakeholders and highway research experts, the committee identified two promising research approaches within the strategic focus area of making a quantum leap in highway safety. The first was to devote significant effort and resources to addressing one or more common crash types, such as run-off-the-road crashes (which account for about one-third of highway fatalities) or intersection crashes (which account for almost one-quarter of highway fatalities). The second reflects a research gap mentioned frequently during the outreach process: the conduct of a comprehensive, in-depth study of what really causes crashes.

The committee reviewed existing highway safety research and technology programs to assess the state of the art in each of these areas and identify research needs. The main programs reviewed were those of FHWA, the National Highway Traffic Safety Administration (NHTSA), and NCHRP. In addition, a search of the TRIS database, including the TRIS Research in Progress database, revealed work being conducted in state DOTs, universities, and other countries. Summaries of the results of these analyses are provided in the following subsections.

Run-off-the-Road Crashes

The two major areas of research related to run-off-the-road crashes are the Intelligent Vehicle Initiative (IVI) and more traditional roadside safety research. The IVI program is run by the Intelligent Transportation Systems Joint Program Office at FHWA and focuses on the use of ITS technologies (particularly in-vehicle) to increase highway safety. In the road departure area, this means systems to warn the driver that the vehicle is likely to leave the lane. Adaptive cruise control (to adjust vehicle speed on the basis of road geometry) is a potential technology as well. This work is being done in cooperation with vehicle manufacturers and suppliers, who are doing much of the research and development for in-vehicle systems. DOT efforts are focused on defining performance requirements, identifying locations for application, developing standards, supporting operational test and evaluation, and performing human factors research to ensure the safety of IVI systems. Traditional roadside safety research is carried out by FHWA, NCHRP, and state DOTs. This research addresses such topics as roadway geometry; lane delineation; and roadside features and obstacles, including terrain features, barriers, guardrail, trees, and utility poles. This research usually results in design standards aimed at reducing the likelihood and severity of run-off-the-road crashes. In addition, FHWA is developing the Interactive Highway Safety Design Model (IHSDM), which integrates safety considerations into roadway design. Additional run-off-the-road research is needed to address the issue of lower-speed roads and to integrate cooperative infrastructure systems into the IVI program. Some plans already exist to extend work into these areas if the necessary resources are made available to these programs.

Intersection Crashes

The IVI program has an intersection collision avoidance segment under which systems to warn drivers about possible dangers at intersections will be developed. IHSDM is used to analyze safety at intersections on two-lane rural highways. Other intersection-related work addresses red light running (including the use of automated enforcement), traffic calming, and pedestrian and bicycle safety. FHWA is conducting some human factors research in support of IVI to better understand precrash behavior at intersections, as well as human factors research related to traffic calming and CORSIM (a traffic simulation model).

The intersection safety problem is highly complex, involving vehicles; infrastructure; operations; and all road users, including pedestrians and bicyclists.

As a result of this complexity, the IVI Business Plan indicates that cooperative vehicle–infrastructure solutions are necessary and suggests that operational testing will not take place before 2006, with deployment closer to 2014. FHWA's Infrastructure Plan for IVI acknowledges the need for more research and development in this area. Also, IHSDM has focused on rural two-lane roads but needs to be expanded to address larger roads with more complex intersections. Driver simulation models for signalized and unsignalized intersections were identified as a specific research gap, needed to study new geometric design and control approaches for intersections. Two populations of drivers are especially at risk for intersection crashes: teens and the elderly. Intersections are particularly complex situations to negotiate, requiring attention to several things simultaneously. Both teens and the elderly have difficulty multitasking while driving. Since both the teen and elderly populations are growing more rapidly than those of other age groups, these demographic facts add urgency to the intersection crash problem.

Crash Causation

Various efforts have been made to improve the understanding of highway crashes and the factors that appear to cause them. Crash causality has been analyzed by the ITS program, through IVI, and the General Accounting Office, as well as some state DOTs and a pooled-fund study being conducted by the southeastern states. The analysis element of FHWA's safety research program, the Highway Safety Information System, performs studies based on data provided by eight state DOTs. NHTSA also performs crash analysis. The agency's Fatality Analysis Reporting System uses state DOT, police, and other data to study fatal crashes; while its National Automotive Sampling System looks at various types of crashes using two systems—the General Estimates System, which examines a nationally representative sample of crashes using information from police reports, and the Crashworthiness Data System, which performs detailed analyses of 5,000 crashes a year, supplementing police reports with on-site investigation and other data. NHTSA is also conducting a special study to investigate the use of event data recorders in gathering crash data. FHWA is performing research on human factors aspects of precrash events and funded the development of the ALERT vehicle, a law enforcement vehicle equipped with advanced communications technology to aid police officers in collecting more accurate data at crash scenes. Finally, the Federal Motor Carrier Safety Administration is conducting a congressionally mandated $15 million to $20 million truck crash causation study.

All these studies have significant limitations. For instance, all are based on crash events only; none use noncrash situations as an experimental control. Very few precrash data are employed. The availability and accuracy of certain types of data—such as crash location, roadway geometry, roadside features, and other road characteristics—are inadequate for performing the types of research that would help in understanding the contribution of these factors to safety and in designing better countermeasures. (The Highway Safety Information System collects some of these data, but from very few states.) NHTSA's use of event data recorders is promising but limited at this time.

Strategic Focus Area 3: Provide a Reliable Highway System

The emphasis of this strategic focus area and the associated research topics considered by the committee underwent a number of transformations in the course of the outreach process. As a result, the review of existing research efforts and depth of analysis of gaps were somewhat less extensive than for the other strategic focus areas, which were more clearly defined earlier in the process. Two potential research areas were considered: providing real-time information to customers and reducing congestion from nonrecurring incidents. These evolved to the focus on travel time reliability discussed in the report.

Strategic Focus Area 4: Provide Highway Capacity in Support of the Nation's Economic and Social Goals

Much work has been and continues to be done in the area of air quality modeling, including an approximately $5 million program of NCHRP research. The water quality area appears to be dominated by highway runoff studies. Several studies examine wetland impacts and assessment of the functional values of wetlands. There are several small studies of social and economic impacts of highways and a number of projects addressing data and systems for environmental decision making, including more than $2 million in NCHRP projects. NCHRP is also conducting a study of technologies to improve the consideration of environmental concerns in transportation decisions. This study involves a review of nearly 20 technologies in 5 categories to ascertain their usefulness with regard to environmental considerations in transportation.[2] A few studies can be found in areas related to noise, environmental justice, archeology, wildlife, and context-sensitive design. The Transit Cooperative Research Program has performed relevant studies of land use, sprawl, livable communities, planning, and the impact of demographic and social trends on travel. There are probably hundreds of studies being done by government agencies and universities on more scientific aspects of the environment; however, the F-SHRP literature search focused on research oriented mainly toward information and tools that would be useful for transportation agencies.

Three major gap areas were identified. The first relates to air quality issues that are expected to intensify in the future but have not been adequately researched, including greenhouse gases, air toxics, and particulate matter (PM) 2.5 (or even PM 1.0). The second is the need for tools focused on nonurban and small urban areas. The third pertains to the need for more systemwide data, analysis, and decision support tools, including analysis of secondary and cumulative impacts of new highway capacity (for example, issues of land use and sprawl and areawide assessment of environmental impacts as opposed to site-specific assessments); linking environmental data and analysis with asset management; integration of analysis across various areas (air, water, habitat, noise, community, economics) by developing a common rationale and framework that can link the various performance measures used in each of these areas; and integration of these analyses earlier in the planning and design processes (including the development of tools for improving public involvement and communicating information about impacts and alternatives).

[2] The five categories of technologies reviewed are geospatial database technologies, remote sensing technologies, transportation impact modeling technologies, decision science technologies, and visualization / simulation technologies.

Study Committee Biographical Information

C. Michael Walton, *Chair,* is Professor of Civil Engineering and holds the Ernest H. Cockrell Centennial Chair in Engineering at The University of Texas at Austin. In addition, he has a joint academic appointment in the Lyndon B. Johnson School of Public Affairs. He has participated in many National Research Council (NRC) activities, and served as Chairman of the Executive Committee of the Transportation Research Board (TRB). Dr. Walton is a founding member of the Intelligent Transportation Society of America (ITS America) and is a fellow of the American Society of Civil Engineers and the Institute of Transportation Engineers. He is a registered professional engineer. He holds a bachelor of science degree in civil engineering from the Virginia Military Institute and master's and Ph.D. degrees in civil engineering–transportation from North Carolina State University. He is currently Chairman of the Research and Technology Coordinating Committee, a TRB committee that performs a continuing review of the research and technology programs of the Federal Highway Administration (FHWA). Dr. Walton was elected to the National Academy of Engineering (NAE) in 1993.

Bradley L. Mallory, *Vice Chair,* has been Secretary of the Pennsylvania Department of Transportation since 1995. He previously served as counsel to the law firm of Dechert Price & Rhoads. From 1977 to 1989, he held a variety of positions at the Pennsylvania Department of Transportation, including Director of Strategic Planning and first Deputy Secretary for Aviation, Rail Freight, and Ports and Waterways. Mr. Mallory is a graduate of Dickinson College and the Dickinson School of Law. He is currently Vice President of the American Association of State Highway and Transportation Officials (AASHTO).

Joel D. Anderson has been Executive Vice President of the California Trucking Association (CTA) since 1992. He joined the association in 1977 as a regulatory specialist. He subsequently served as Assistant Executive Vice President of Industry Economic Development and was responsible for the association's research, educational, and regulatory activities. Before joining CTA, he was an economist for the California Public Utilities Commission. Mr. Anderson holds a bachelor of arts degree in economics from the University of California, Los Angeles, and has a college teaching credential in transportation and logistics. He is a member of TRB's Research and Technology Coordinating Committee.

E. Dean Carlson has been Secretary of the Kansas Department of Transportation since 1995. He is currently President of AASHTO. Mr. Carlson began his career at FHWA (then the Bureau of Public Roads) in 1958 and held positions in engineering, planning and research, and safety in a variety of locations before assuming duties as the agency's Region 7 Administrator in Kansas City in 1985. He returned to Washington as FHWA's Associate Administrator for Engineering and Program Development in 1989 and was named Executive Director in 1990, a position he held until 1994. Mr. Carlson graduated from the University of Nebraska in 1958 with a bachelor of science degree in civil engineering and did postgraduate work at the University of Texas from 1969 to 1971. He is currently Vice Chairman of the TRB Executive Committee. He was elected to NAE in 2001.

Frank L. Danchetz has served as Chief Engineer of the Georgia Department of Transportation since 1993. Previously he held several other positions at the Georgia Department of Transportation, including Head of the Office of Environment and Location and Director of Planning and Programming. He is a registered professional engineer in Georgia, Vice Chair of the AASHTO Standing Committee on Highways, and a member of the AASHTO Standing Committee on Research. He received a bachelor of civil engineering degree from the Georgia Institute of Technology. Mr. Danchetz is a current member of TRB's Research and Technology Coordinating Committee.

Henry E. Dittmar is currently President and Chief Executive Officer of the Great American Station Foundation. Prior to assuming this position he was Director for the Transportation and Quality of Life Campaign at the Surface Transportation Policy Project (STPP). Previously, he was Director of STPP. He has also served as Manager of Legislation and Finance for the Metropolitan Transportation Commission in Oakland, California, and as Director of the Santa Monica Airport. Mr. Dittmar holds a bachelor of science degree from Northwestern University and a master of arts degree from The University of Texas at Austin, where he also worked as a research associate in the Center for Transportation Research. He has been active on several AASHTO and TRB committees, including the Research and Technology Coordinating Committee. Mr. Dittmar is a strong spokesman on environmental issues related to transportation.

Francis B. Francois is currently a private consultant. He retired in February 1999 after 18 years as Executive Director of AASHTO. Previously he was a member of the County Council of Prince George's County, Maryland, an elected position in which he was involved in transportation, public works, environmental, and community development issues. As a registered patent attorney, he engaged actively in a patent and trademark law practice before joining AASHTO. Mr. Francois has been very active in local government associations. In his capacity as AASHTO Executive Director, he was a supporter of and contributor to many TRB activities, including the TRB Executive Committee and the Strategic Highway Research Program. Mr. Francois holds a bachelor of science in engineering degree from Iowa State University and a law degree from The George Washington University. He was elected to NAE in 1999.

David R. Gehr is Director of Strategic Planning for Parsons Brinckerhoff, Inc. Prior to assuming this position, he had held several positions at the Virginia Department of Transportation since 1971, including Director of Operations, Assistant Chief Engineer, and Assistant Commissioner for Operations; in 1994 he assumed the position of Commissioner. Mr. Gehr has served in the United States Army. He has also served on the Board of Directors of ITS America and as Chairman of the I-95 Corridor Coalition. He received a bachelor of science degree in civil engineering from the Virginia Military Institute and has done graduate work in transportation planning and in systems engineering.

Susan Martinovich has been Assistant Director/Chief Engineer at the Nevada Department of Transportation since 1996. Her previous experience with the Nevada Department of Transportation has included structural design of bridges and project development and management responsibilities in roadway design. She serves on the AASHTO Standing Committee on

Highways and Standing Committee on Highway Traffic Safety and is Vice Chair of the Subcommittee for Design. Ms. Martinovich holds a bachelor of science degree in civil engineering from the University of Nevada at Reno. She is a registered professional engineer in Nevada and California. She serves on the National Cooperative Highway Research Program panel for the Innovations Deserving Exploratory Analysis program.

Herbert H. Richardson is Director of the Texas Transportation Institute, Associate Vice Chancellor for Engineering for the Texas A&M University System, and Professor Emeritus of Mechanical Engineering at the Massachusetts Institute of Technology (MIT). His previous academic experience includes serving as Director of the Texas Engineering Experiment Station, Dean of Engineering at Texas A&M University, Chancellor of Engineering for the Texas A&M University System, and Head of the Mechanical Engineering Department at MIT; he has held professorial appointments at both universities. Dr. Richardson's professional experience also includes private-sector research, consulting, and service as Chief Scientist in the Office of the Secretary, U.S. Department of Transportation. He received bachelor's, master's, and doctor of science degrees in mechanical engineering from MIT. He is a registered professional engineer in Texas and Massachusetts. He has participated in many NAE and NRC activities, including the NAE Council and the TRB Executive Committee. Dr. Richardson was elected to NAE in 1980.

Henry G. Schwartz, Jr., is Chairman of Sverdrup Civil, Inc., directing the transportation, public works, and environmental activities of this national engineering and construction firm. A registered professional engineer, Dr. Schwartz joined Sverdrup Corporation in 1966 and was named President of Sverdrup Civil, Inc., in 1993. His career has focused on civil and environmental research, planning, design, and project management. Dr. Schwartz serves on the Advisory Boards for Carnegie Mellon University, Washington University (St. Louis), The University of Texas, and the Academy of Science of St. Louis Board of Directors. He is Founding Chairman of the Water Environment Research Foundation and has served as President of the Water Environment Federation and as a member of the Civil Engineering Research Foundation Board of Directors. Dr. Schwartz currently is President of the American Society of Civil Engineers. He received a Ph.D. from the California Institute of Technology and master of science and bachelor of science degrees from Washington University; he also attended Princeton University and Columbia University. He was elected to NAE in 1997.

Thomas R. Warne is President and founder of Tom Warne and Associates, a management and marketing consulting firm. From 1995 to 2001 he was Executive Director of the Utah Department of Transportation. Prior to joining the Utah Department of Transportation, he spent 12 years with the Arizona Department of Transportation, where he served as Deputy Director and Chief Operating Officer. Mr. Warne has served as President of AASHTO. He has also served in the United States Army Corps of Engineers. Mr. Warne received an undergraduate degree in civil engineering from Brigham Young University and holds a master's degree in civil engineering from Arizona State University. He is a registered professional engineer and author of the book *Partnering for Success.*

David K. Willis is President and Chief Executive Officer of the AAA Foundation for Traffic Safety, an independent, publicly funded affiliate of the American Automobile Association. Before joining the AAA Foundation, he was Senior Vice President and Chief Operating Officer of the ATA Foundation, Inc., a public policy research organization affiliated with the American Trucking Associations, Inc. Earlier he managed the public policy and analysis and statistical staffs of the former Motor Vehicle Manufacturers Association. Mr. Willis is a member of the Research and Technology Coordinating Committee and of TRB's Committee on Safe Mobility of Older Persons. He did his undergraduate work at Stanford University and holds master's degrees from the University of California, Los Angeles (public administration), and the University of California, Berkeley (public policy).