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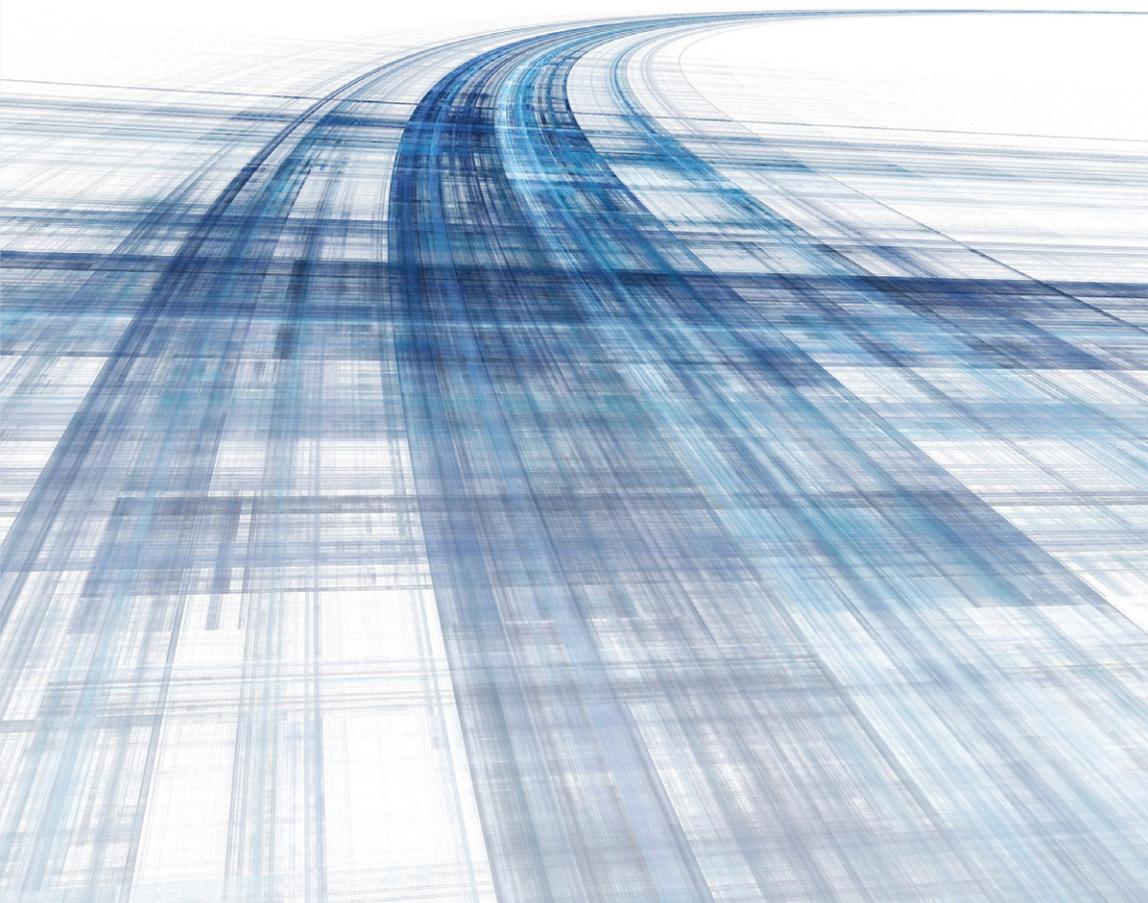
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The Essential Federal Role in Highway Research and Innovation



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The Essential Federal Role in Highway Research and Innovation

Research and Technology Coordinating Committee
TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES



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

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Preface

The U.S. Department of Transportation's Federal Highway Administration (FHWA) is tasked with improving mobility and safety on the nation's highways through national leadership, innovation, and program delivery. The agency's highway research, development, and technology (RD&T) program is, however, only one among many involved in highway innovation, with state and university programs and technology companies also playing important roles in the nation's overall highway research effort. One consequence of this complex and decentralized research "ecosystem" is that the intertwined and interdependent roles and responsibilities of the various participants are often unclear to the many stakeholders who build, maintain, and operate the highway system, as well as to its multiple users. Even highway professionals and seasoned observers sometimes struggle to understand who does what research for whom, the benefits of such research, and the sources of the funding. In light of this complexity, an objective overview of the roles of all the participants in the nation's highway RD&T ecosystem is important for informing the reauthorization of the current surface transportation authorizing legislation, Moving Ahead for Progress in the 21st Century (MAP-21). Without such understanding, budget pressures could result in essential parts of the nation's highway RD&T being unintentionally affected because of a lack of appreciation for how the system functions as a whole.

For more than 30 years, the Research and Technology Coordinating Committee (RTCC), operating under the auspices of

the National Academies' Transportation Research Board (TRB), has served as an independent adviser on national and federal highway research. The work of RTCC has been supported by FHWA, and the committee's letter reports to the agency, issued once or twice a year, have provided tactical advice on highway research topics, funding, and research management. In addition, RTCC has periodically (typically once every 6 or 7 years) issued reports assessing the state of highway research at national and federal levels and highlighting strategic issues of importance to policy makers.

The present report continues RTCC's tradition of issuing periodic, strategically focused reports. In particular, it aims to inform the impending reauthorization of MAP-21 by providing background and context for decisions about future federal funding of highway RD&T. The report draws on RTCC's advice over the years and synthesizes findings and recommendations from earlier reports about what the federal role should be in promoting innovation on the nation's highways.

The review of this report was overseen by National Academy of Sciences member Susan Hanson, Clark University (emerita). Appointed by the National Research Council, she was responsible for making certain that an independent examination of the report was carried out in accordance with institutional procedures and that all review comments were carefully considered. The purpose of this review was to provide candid and critical comments to assist TRB in making the report as sound as possible and to ensure that it 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 review process. Responsibility for the final content of this report rests entirely with the authoring committee and the institution. The committee thanks the following individuals for their review of the report: E. Dean Carlson (NAE), Carlson and Associates, Highlands Ranch, Colorado; A. Ray Chamberlain (NAE), consultant, Fort Collins, Colorado; John Halikowski, Arizona Department of Transport-

tation, Phoenix; Albert Teich, George Washington University, Washington, D.C.; and C. Michael Walton (NAE), University of Texas at Austin. Although the reviewers provided constructive comments and suggestions, they were not asked to endorse the committee's conclusions, nor did they see the final draft before it was released.

Stephen R. Godwin and Jill Wilson drafted the report under the guidance of the committee. Karen Febey, Senior Report Review Officer, managed the report review process. Norman Solomon edited the report, Jennifer J. Weeks prepared the prepublication edition for web posting, and Juanita Green managed the book production under the supervision of Javy Awan, Director of Publications. Timothy Devlin assisted with meeting arrangements and communications with committee members.

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Executive Summary

Highways are the arteries of the U.S. economy and society. Each year, motor vehicles travel nearly 3 trillion miles on these roads, enough for more than half a million trips from the earth to the moon and back. Travel on the nation's nearly 9 million lane miles of roads accounts for 86 percent of all person trips and more than 75 percent of the value of goods shipped by all modes.

For all its success, the highway system is under great strain. This vast and aging asset, valued at nearly \$2.8 trillion, is not keeping pace with demand as bridges and roadways deteriorate, roads become increasingly congested, and more than 30,000 lives—90 percent of the nation's transportation fatalities—are lost each year. Moreover, the funds available to federal, state, and local governments responsible for roads fall far short of what is needed to maintain the system, much less to expand it to meet the needs of a growing population and an increasingly globally connected economy. The user fees that provide for most highway investment continue to decline in real terms because of improved vehicle fuel economy and resistance to increases in these fees, even to account for the erosion of purchasing power caused by inflation. This situation portends a future of continued constrained resources.

Innovation can help bridge the gap between available resources and the actions needed to maintain the performance of the highway system, but public agencies often hesitate to introduce new technologies and processes that involve risk and uncertainty. Barriers to innovation can be overcome, but not

without significant time and effort. In this context, the Federal Highway Administration (FHWA) has an essential role in fostering national deployment of innovations based on its own research and development and that of other highway research programs. The agency is also critical in the nation's highway research, development, and technology (RD&T) transfer through its investment in long-term, high-risk research and through the filling of gaps not covered in state department of transportation and other federal highway-related research programs. Examples of past successful innovations described in the report have reduced the time needed to deliver highway improvements, increased throughput, and improved safety, while reducing costs. These innovations have been developed with limited funding, with a level of federal funding for highway-specific research that is a mere fraction—only one-third of 1 percent—of the annual cost of maintaining the nation's highways.

FHWA's RD&T role in the future will be critical in two other particularly important ways. First, the nation may soon realize profound improvement in safety through the connected vehicle initiative under development by government and industry. FHWA is the lead federal agency in developing and deploying safety applications to provide safety messages between infrastructure and vehicles. The safety alerts to motorists will depend on FHWA leadership in applying national standards to the variety of traffic signaling systems in use around the country. Second, FHWA is poised to work with states and local governments in deploying the innovations developed through the second Strategic Highway Research Program (SHRP 2), a congressionally authorized 9-year, \$223 million federal–state investment. SHRP 2 has developed dozens of innovations to renew aging infrastructure more quickly and cost-effectively, improve the reliability of travel time, provide capacity consistent with environmental protection, and improve safety. The benefits of this significant investment will be delayed or lost if FHWA's central role in fostering deployment is not continued.

In the committee's judgment, reductions in FHWA's human

and financial resources for RD&T will hamper the agency's ability to continue to fulfill its essential roles and responsibilities. Other participants in national highway RD&T are unlikely to fill any void that is created. If substantial reductions do occur, the pace of innovation on the nation's highways will likely slow to a crawl at a time when public expectations for improved safety and greater reliability, as well as reduced revenues for maintenance and upkeep, are placing growing demands on the national highway system.

The nation needs to ensure that FHWA has the resources to carry out its essential role in RD&T. FHWA has the national perspective, leadership, and ability to carry out these responsibilities to the benefit of the nation, now and in the future.

| 1 |

Challenges and Opportunities

Suppose two vehicles are approaching an intersection, one traveling in the north–south direction, and one in the east–west direction. Suppose also that they are electronically “aware” of each other, either via a vehicle-to-vehicle link or via the linkage of both vehicles to the infrastructure. Given this awareness, there is a smaller probability of a crash at that intersection, even if, for example, one of the drivers runs a red light. (Sussman 2008)

The traffic lights of tomorrow will actively manage congestion. The humble traffic signal is gaining some new responsibilities. . . . Eventually, signals will simply ask cars where they’re going, and change traffic plans accordingly. (Barry 2014)

If a modern car can be made smart enough to spot when a tire is underinflated, the oil is running low, or a brake light has failed, why not do the same for bridges . . . give them the ability to monitor their own condition and issue a warning when a problem starts to emerge? (*Economist Technology Quarterly* 2010)

Improving highway safety, reducing congestion, and maintaining aging infrastructure are among the challenges facing the U.S. highway system. As the above examples illustrate, there is no shortage of creative ideas for addressing these challenges in an increasingly connected world where vehicles can communi-

cate with each other and with highway infrastructure and where “smart” bridges and pavements sense problems such as cracking and alert engineers that remedial action is needed. However, extensive research, development, testing, and deployment of innovations are necessary before these ideas can become a reality. Whereas roads becoming “smart” is the next step in the evolution of highways, the roads of today are already far more sophisticated than those of earlier generations, and they might more properly be thought of as corridors that include the roadway, as well as the roadside—for illumination, signage, crash protection, and many other features. In metropolitan areas they may include sound walls to buffer noise from tires and engines, drainage systems to capture and filter runoff to protect local streams, median plantings for aesthetics and habitat, and bicycle routes. In rural areas, highways include rest areas, medians maintained with native plants and flowers, and even specially designed wildlife crossings to avoid fragmentation of habitat. These features have been added on the basis of research, development, testing, and dissemination of proven innovations.

This report discusses the Federal Highway Administration’s (FHWA’s) role in highway research and innovation and explains why this role will be critical in transforming the nation’s aging and overstressed network of highways into one that is safer, more reliable, and more resilient. These improvements will be essential in supporting the nation’s economic growth and competitiveness and enhancing Americans’ quality of life, particularly given the expected 20 percent growth in population and 80 percent growth in gross domestic product over the next 25 years (TRB 2013).

CHALLENGES

The nation’s highways today are required to meet demands not anticipated in the 1960s and 1970s, when many of these roads were planned and constructed. There are about 3½ times as many vehicles on the road as there were in 1960, and the total

number of vehicle miles traveled in a year has increased four-fold during the same period.¹ In particular, highway planners and designers underestimated the rapid growth in freight movement by motor carriers and the size and weights of vehicles that would be permitted. The increased traffic volumes have not only resulted in wear and tear on highway infrastructure but also have led to congestion in many metropolitan areas, which severely hampers the movement of travelers and goods. The total cost of congestion in 2011, mostly because of 5.5 billion hours of wasted time, was estimated at \$121 billion. Of this total cost, \$10 billion came from wasting 2.9 billion gallons of fuel (Schrank et al. 2012). The expected 45 percent increase in freight movement by motor carriers by 2045 will place additional demands on an already stressed system (U.S. Department of Transportation 2015, 51).

Almost all the nation's transportation fatalities (about 94 percent) occur on highways, and most involve passenger vehicle crashes (TRB 2013). About 90 people per day on average are killed on U.S. roads and more than 6,000 are injured (NHTSA 2014), even though roads and the vehicles on them are far safer now than they were 50 years ago. Despite the increasing volumes of traffic, the fatality rate, defined as the number of fatalities per 100 million vehicle miles traveled, has fallen from about 5.1 in the early 1960s to about 1.1 today.² Further reduction in the numbers of deaths and injuries on the nation's roads is one of the major challenges for the future, particularly as the U.S. population ages. Those 65 and older are expected to make up about 20 percent of the nation's population in 2030 (U.S. Census

¹ National Transportation Statistics, Table 1-11, Numbers of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances (http://www.rita.dot.gov/bts/sites/rita.dot.gov/bts/files/publications/national_transportation_statistics/html/table_01_11.html); Motor Vehicle Traffic Fatalities and Fatality Rate: 1899–2003 (<http://www.saferoads.org/federal/2004/TrafficFatalities1899-2003.pdf>); FHWA Historical Monthly VMT Report (https://www.fhwa.dot.gov/policyinformation/travel_monitoring/historicvmt.cfm).

² Motor Vehicle Traffic Fatalities and Fatality Rate: 1899–2003 (<http://www.saferoads.org/federal/2004/TrafficFatalities1899-2003.pdf>); National Highway Traffic Safety Administration Fatality Analysis Reporting System data tables (<http://www.fars.nhtsa.dot.gov/Main/index.aspx>).

Bureau 2014), and aging baby boomers are expected to have a profound effect on the safety of the nation's roadways. According to one estimate, drivers over the age of 75 have a fatality rate 2½ times the national average, and for drivers over the age of 85 the rate increases to 5½ times the national average (Stutts and Potts 2006).

Public awareness of environmental issues has also increased dramatically since the 1960s, with a resulting change in expectations of how highways and the vehicles on them should interact with the environment and adjacent communities. Measures to mitigate environmental impacts have profoundly changed highway construction projects and added to their cost, as illustrated by the example of Maryland's Intercounty Connector project in suburban Washington, D.C.; environmental mitigation costs for this project were estimated at about \$15 million per mile (Skinner 2008). In addition, the increased vehicle emissions resulting from congestion raise concerns in the context of efforts to reduce the risks associated with climate change. The devastation caused by Superstorm Sandy and by the deadly mudslides in Washington State illustrates the vulnerability of parts of the nation's highway infrastructure to extreme weather events. One of the challenges facing those responsible for the nation's highways is to improve the efficiency and cost-effectiveness of measures to maintain, rehabilitate, and improve aging roadways while increasing the resilience of highway infrastructure to flooding and other weather-related events.

The challenges facing infrastructure owners will be compounded by revenue shortfalls for highway agencies. The nation's 2.7 million miles of paved roads have an estimated value of \$2.8 trillion (Bureau of Economic Analysis, Fixed Asset Tables, Nonresidential Detailed Estimates, as cited by Winston 2013), with a cost for maintenance and improvement that is correspondingly large. The National Surface Transportation Finance Commission estimates that long-term funding needs to maintain highways at \$131 billion (in 2008 dollars) compared with revenues of only \$76 billion. Improving conditions would

require \$176 billion (National Surface Transportation Infrastructure Financing Commission 2009, Exhibit 2-26). The federal fuel tax, at 18.4 cents per gallon, has been unchanged since 1993; since that time the purchasing power of Highway Trust Fund revenues has declined by more than one-third (National Surface Transportation Infrastructure Financing Commission 2009). Increases in vehicle fuel economy have reduced revenues even as travel has increased, and this trend is likely to continue, with fuel economy for light-duty vehicles projected to double by 2025. In the face of unwillingness to raise user fees, funding constraints for highways appear likely to continue. Innovation cannot close all gaps, but it can help assets serve longer and perform better at lower financial, safety, and environmental costs.

OPPORTUNITIES

The development of a wide range of advanced and affordable sensors, including Global Positioning System receivers, has opened up possibilities for transforming the way people and goods move on the nation's roads. A connected vehicle network in which advanced technology operates the highway transportation system by electronically linking vehicles to one another and to infrastructure offers a range of benefits, including improved safety, reduced energy costs, increased roadway capacity, and greater mobility for those who cannot currently drive (Denaro et al. 2014). Some of these benefits will require fully automated vehicle operation on all roads, a challenging requirement seen by most experts as a long-term goal. Other benefits may well be realized within the next 10 years, and some are already here. In the area of safety, for example, a number of automakers now offer lane-departure warning systems in their vehicles; they alert the driver if the vehicle begins to move out of its lane on freeways or arterial roads and may even help it get back on track.

Research into connected vehicles is not limited to the United States. The United Kingdom (U.K.) government has provided funding to test driverless cars in four English cities, and the

world's first large-scale test of driverless cars will put 100 self-driving Volvo cars on the streets of Gothenburg, Sweden, in 2017. Researchers in the Netherlands are investigating the electronic coupling of vehicles into platoons as a means of increasing road capacity and reducing energy use.³

Advanced sensors have also opened up possibilities for smart highway infrastructure. Wireless sensors mounted on a bridge, for example, can measure vibration, strain, and temperature—information that is passed to a computer for analysis and that allows continuous monitoring of the bridge's structural integrity. Again, research in this area is not limited to the United States. The Cambridge Center for Smart Infrastructure and Construction, funded by the U.K. government through its Engineering and Physical Sciences Research Council and Innovate U.K., has developed an energy harvester that generates electricity from traffic-induced bridge vibrations, thereby allowing wireless sensors to remain in place longer without the need for charging or replacing battery packs (Cardno 2014).

The U.S. highway system stands to benefit not only from research into connected vehicles and smart infrastructure but also from the application of results from previous research initiatives. The nation has invested \$223 million over the past 9 years in the second Strategic Highway Research Program (SHRP 2); the results of this research could save many lives, rehabilitate aged facilities faster with less disruption, greatly reduce congestion associated with accidents and incidents, and speed the provision of new highway capacity while preserving the environment.⁴ For example, the time taken to renew infrastructure can be accelerated by prefabricating bridge elements and by encouraging communication and coordination between highway agencies and utility companies to avoid unnecessary delays. While there are practical examples of the benefits to be derived from such approaches (TRB 2009b), there are also considerable

³ Transportation Research Board 2015 Annual Meeting, Session 412: National Road Vehicle Automation Research and Demonstration Programs from Around the World.

⁴ SHRP 2 (<http://www.trb.org/AboutTRB/SHRP2.aspx>).

barriers to innovation in the highway sector, such as the lack of incentives, strong disincentives, and risk aversion in the public sector, as described in Chapter 3. Consequently, widespread and successful implementation of SHRP 2 products is likely to require a sustained effort over an extended period. Meanwhile, the United States' competitors are moving ahead with similar efforts. The European Union's (EU's) Horizon 2020 Framework program, for example, is supporting efforts to develop more efficient highway infrastructure, with the goal of achieving zero traffic disruption from inspection, construction, and maintenance by 2030.⁵

Whereas federal investment in U.S. research, development, and technology (RD&T) is static or declining, U.S. competitors and trading partners view enhancing their transportation systems through research as a strategic investment. The EU, for example, plans to spend more than €6 billion (about \$7.1 billion) on transportation research during the 7-year period from 2014 through 2020. This investment in innovation for “smart, green and integrated transport” also aims to enhance the competitiveness of European transport manufacturers and service providers (McKinnon 2015). The U.S. Department of Transportation's annual research budget (U.S. Department of Transportation 2013), along with transportation RD&T funding by states, is about \$1.2 billion across all modes, or roughly equivalent to that of the EU (see Table 3-1, page 36, and related discussion). The EU funding, however, is on top of all transportation RD&T by all its member nations.

ORGANIZATION OF REPORT

As Congress prepares to reauthorize the Moving Ahead for Progress in the 21st Century Act (MAP-21), which funds federal highway and transit investments, lawmakers will need to make

⁵ *Horizon 2020 Work Program 2014–2015: Smart, Green and Integrated Transport* (http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/main/h2020-wp1415-transport_en.pdf).

decisions affecting the nation's ability to improve its highways in response to demands for economic growth and competitiveness, health and safety, resilience, access, and environmental protection. Chapter 2 discusses the role of the federal government, operating through FHWA, in supporting the innovations that have transformed the highways of the 1960s and 1970s into the safer, faster, and greener highways of today. Chapter 3 describes the federal role in the broader context of the nation's organizationally complex highway RD&T endeavor, and Chapter 4 examines FHWA's RD&T role in meeting future challenges.

| 2 |

Highway Research

A PROVEN ROUTE TO THE FUTURE

Today's highways perform differently from those of the 1960s and 1970s. There are about 3½ times as many vehicles on the roads as there were in the 1960s, and the road network itself is more extensive and incorporates features aimed at expediting traffic flow and reducing risks to users. Thirty years ago, a driver crossing narrow medians of an Interstate highway had a good chance of avoiding conflict with vehicles in the opposing lanes because of light traffic, but today, chances are high that a collision with another vehicle would result. Experience in Missouri has demonstrated the effectiveness of median cable barriers, which catch and decelerate a vehicle and prevent it from entering the opposing lanes. The installation of 179 miles of median cable barrier on Interstate 70 reduced cross-median fatalities by more than 90 percent, from 24 in 2002 to two in 2006 (Chandler 2007). Many states subsequently expanded their use of median barriers as a highly effective safety measure.

Other highway innovations may be less visible to users but have been useful in allowing those responsible for the nation's roads to improve overall performance in a period of constrained budgets. Examples include new bridge and pavement materials that require less frequent maintenance and renovation and that have longer service lives, thereby reducing operating costs. New materials and innovative construction techniques have also resulted in more effective ways of building new roads and bridges and of rehabilitating aging infrastructure and in environmental benefits. For example, experience in Virginia has shown that the lower temperatures and reduced fumes associated with warm-

mix asphalt are advantageous for work crews during paving, while the reduced energy consumption during production and reduced plant emissions offer further advantages compared with hot-mix asphalt (Diefenderfer and Clark 2011).

In addition to the benefits gained through technological innovations, innovative procurement strategies have allowed state departments of transportation (DOTs) to reduce considerably the overall duration of major construction projects without compromising the quality of the final product and allowed private contractors more opportunities to introduce innovative processes and products. A better understanding of the behavior of travelers in general, and highway users in particular, has informed the development of transportation policies and helped make more effective use of the most congested parts of the nation's highway network.

RESEARCH AND INNOVATION

RD&T has fueled innovation across the nation's road network since the early 1950s, when the nation's highway organizations joined forces to develop advances in pavement design (*TR News* 1996). Today, a wide variety of research activities are conducted under the auspices of programs responding to the needs of the numerous jurisdictions responsible for the highway system (see Chapter 3). These activities cover numerous disciplines and range from investigations aimed at gaining more comprehensive knowledge and understanding of a subject (e.g., the relationship between a pavement material's properties and its composition), through the design and development of prototypes and processes (e.g., robust, low-cost transponders for road pricing applications), to practical implementation of research results (e.g., the incorporation of advanced design and measurement techniques into state DOT construction standards).

The federal government plays a major role in the national RD&T enterprise, both through its support of research conducted by other organizations (such as universities and contractors)

and through its own RD&T activities. FHWA has been instrumental in furthering innovation in the highway sector, as illustrated by the examples in the following section.

HIGHWAY INNOVATIONS FOSTERED BY FHWA

Doing More with Less: Stronger Bridge Materials Result in Major Cost Savings

When Hurricane Katrina made landfall in Louisiana on August 29, 2005, the accompanying storm surge severely damaged the I-10 Twin Span Bridge across Lake Pontchartrain, which links New Orleans and Slidell. Rising water and battering waves shifted a number of the bridge's 255-ton concrete spans off their piers and misaligned others, leaving the 5½-mile structure impassable. Emergency repairs allowed a phased reopening of the bridge between October 2005 and January 2006, but because I-10 is a vital transportation artery, the Louisiana Department of Transportation and Development (DOTD) decided that the repaired structure needed to be replaced by a new, more robust bridge capable of withstanding surges driven by hurricane-force winds (Lee and Hall 2011). Construction of the new \$800 million bridge began in August 2006 and was completed in September 2011. The project took advantage of a new high-strength, high-performance concrete (HPC) material offering improved performance and an accompanying reduction in cost.

To help overcome concerns about the use of new HPC materials for bridge construction, FHWA's HPC Technology Delivery Team, created in 1997, has assisted a number of state DOTs in the design and construction of HPC bridges and encouraged others to try HPC in their highway bridges (FHWA 2005). The team's goal is to improve the durability and cost-effectiveness of the nation's transportation infrastructure through the use of HPC and to educate users about topics such as structural design and specifications, mix design and proportioning, and costs (for example, see Russell et al. 2006).

The Louisiana DOTD has gradually been introducing high-

strengthen HPC into its bridge construction program to develop an in-depth understanding of how this material behaves in the field. For example, the successful construction of the Charenton Canal Bridge, which opened to traffic in 1999, demonstrated that an HPC bridge could be designed and built in Louisiana with the use of locally sourced materials to limit transportation costs (LTRC n.d.). Use of HPC on the new I-10 Twin Span Bridge saved a minimum of \$16 million because of the need for less concrete and fewer girders (LTRC n.d.). In addition, the Louisiana DOTD expects the new bridge to have a minimum service life of 75 years instead of the standard 50-year service life for concrete structures because the new concrete is less permeable to water and thus more resistant to environmental degradation. The extended service life will provide savings in life-cycle costs over and above the savings in construction costs.

Diverging Diamond Interchange: Quicker, Cheaper, Safer

With increasing traffic volumes, congestion has worsened at many highway junctions. As a result, drivers, pedestrians, and cyclists experience longer delays and greater risks when they cross busy intersections. To address these issues, FHWA researchers are exploring innovative designs with the potential to alleviate congestion and enhance safety at intersections and interchanges.

One of FHWA's researchers heard a talk about an innovative interchange concept at a 2003 symposium and, inspired by the findings, set out with colleagues at the Turner-Fairbank Highway Research Center (TFHRC) to study how the diverging diamond interchange (DDI) might work.¹ Models indicated that, by moving through traffic and left-turning vehicles to the left side of the road at highway intersections through signalization, the design offers operational, safety, environmental, and cost benefits. FHWA's driving simulator experiments at TFHRC further confirmed the potential safety benefits, even for drivers

¹ See the diverging diamond interchange website: <http://www.divergingdiamond.com>.

unfamiliar with the new interchange design, and allowed engineers to address problems with sight distance that might not have been noticed otherwise (FHWA 2007).

The first DDI in the United States, located at I-44 and MO-13 in Springfield, Missouri, was completed in June 2009. The project aimed to alleviate congestion on the heavily traveled Kansas Expressway (MO-13) at I-44, which historically had mile-long traffic backups and serious left-turn crashes. By rehabilitating the MO-13 bridge over I-44, Missouri DOT was able to complete construction in 6 months at a cost of \$3.2 million. In contrast, a conventional interchange would have required a new, much larger bridge, which would have raised the cost to about \$10 million and the construction time to 12 to 18 months (Bared and Saiko 2010). Important safety benefits were realized almost immediately, with an 80 percent reduction in injury crashes and a 53 percent reduction in all crashes in the first year of operation (McCarthy et al. 2013).

More than 30 DDIs have been built in the United States since 2009. State DOTs and other jurisdictions across the country have realized important savings in cost and construction time, and road users have enjoyed fewer delays and improved safety. Meanwhile, FHWA researchers continue to evaluate the impacts of DDIs and identify strategies to improve safety and accommodate pedestrians and cyclists (FHWA 2014b).

Design-Build Project Delivery: Shortening the Time from Concept to Concrete

In the mid-1990s, during preparation for the 2002 Winter Olympics in Salt Lake City, the Utah DOT was under pressure to reduce the time needed to complete its I-15 corridor reconstruction project. Mindful not only of the high-profile Olympic deadline but also of the public's desire to minimize the period of severe traffic congestion accompanying the construction work, the Utah DOT decided to use a contracting method known as design-build (DB) to expedite the project and speed construction.

At the time, a number of state DOTs were testing and eval-

uating alternative contracting methods, including DB, under FHWA's Special Experimental Project Number 14 (SEP-14)—Innovative Contracting. SEP-14 was established in 1990 with the objective of exploring opportunities for expediting highway projects through the use of alternatives to the traditional design–bid–build (DBB) contracting approach. Under DBB, design and construction are conducted sequentially under two separate contracts, and cost is the single criterion determining the winning bid. In contrast, under DB, the design and construction phases of a project are combined into a single contract, which is usually awarded on either a low-bid or a best-value basis. By eliminating the need for a second procurement process and allowing for some overlap of design and construction (activities that are conducted sequentially under DBB), DB can reduce overall project duration, sometimes considerably. In addition, use of a best-value criterion for contract award allows state and local agencies to consider a range of factors, including social and economic impact, safety, public perception, and life-cycle costs.

The Utah DOT's I-15 project was one of about 300 transportation projects proposed for DB contracting under SEP-14; located in 32 states, the projects were worth nearly \$14 billion. The project outcomes confirmed the time-saving advantages of DB. By 2002, for example, the Florida DOT had awarded 49 DB projects for nearly \$500 million worth of work and estimated that DB cut the traditional delivery period by 30 percent (Gransberg et al. 2008). The Utah DOT's I-15 project also demonstrated the benefits of DB for large highway projects. Construction on the \$1.63 billion project began in April 1997 and was completed 4 years 4 months later, in July 2001²—a major time saving compared with the estimated 10 years needed to complete the project under traditional contracting methods.³

² Project Profiles, I-15 Corridor Reconstruction Project. FHWA Office of Innovative Program Delivery (http://www.fhwa.dot.gov/ipd/project_profiles/ut_i15_corridor.aspx).

³ Bolling, D. Undated. An Innovative Contracting Overview. PowerPoint presentation available at <http://www.ic.usu.edu>.

FHWA conducted a comprehensive national study evaluating the effectiveness of DB contracting in response to a request in the 1998 Transportation Equity Act for the 21st Century (SAIC et al. 2006). By analyzing DB projects completed under SEP-14, the agency was able to assess the impacts of DB on project duration, cost, and quality and was able to provide guidance to transportation agencies about the types of project likely to benefit from a DB approach. The knowledge gained from SEP-14 projects has helped institutionalize the DB contracting process, which was rarely used by state DOTs 15 years ago but is now a common approach for saving time on large highway construction projects.

Road Pricing Offers Opportunities to Manage Congestion

Congestion in many major metropolitan areas of the United States has become a growing source of frustration for motorists, with those traveling at peak times sometimes needing to allow 60 minutes for trips that take only 20 minutes in lighter traffic (TRB 2013). There are now more than 250 million registered highway vehicles on U.S. roads, a number that has grown by more than one-third over the past 20 years.⁴ Opportunities to expand highway capacity to accommodate these vehicles are limited by construction costs, which average \$10 million per new lane mile in urban areas (FHWA 2006), and by the need to avoid adverse impacts on local communities.

More than 50 years ago, Nobel Prize–winning economist William Vickery suggested managing traffic congestion by charging drivers more to use overcrowded roads at peak times. Customers have long been used to paying more for hotel rooms, airline tickets, and electricity when demand is high, but in the 1960s the idea of point-of-sale charges for roadway use conjured up visions of “a clutter of toll booths, an army of toll collectors, and traffic endlessly tangled up in queues” (Vickery 1963). However, Vickery suggested that “with a little ingenuity, it [might be] pos-

⁴ <http://www.fars.nhtsa.dot.gov/>.

sible to devise methods of charging for the use of city streets that are relatively inexpensive, produce no interference with the free flow of traffic, and are capable of adjusting the charge in close conformity with variations in costs and traffic conditions.”

Today, technological innovation has allowed Vickery’s vision of traffic flowing freely through an adaptive charging system to become a reality with the implementation of all-electronic tolling and dynamic pricing on express lanes, also known as high-occupancy toll (HOT) lanes. Examples include the I-95 and I-495 express lanes in Virginia; the SR-91 express lanes in Orange County, California; the I-15 HOT lanes in San Diego, California; and the I-394 express lanes in Minnesota. An antenna above a “priced” lane communicates with a transponder (e.g., an E-ZPass tag) in a vehicle, collecting information that allows each vehicle to be identified and the toll charged to a particular customer.

However, demonstrating that pricing is effective in reducing congestion and can gain public acceptance is a separate challenge. In 1991, the Congestion Pricing Pilot Program [renamed the Value Pricing Pilot Program (VPPP) in 1998] was established by Congress to demonstrate whether and to what extent roadway congestion can be reduced with pricing strategies. As part of this program, FHWA entered into agreements with states and cities to explore strategies for managing congestion, including tolling demonstrations. Between 2008 and 2012, approximately \$65 million in federal funding supported value pricing projects in 12 states (California, Connecticut, Florida, Illinois, Maryland, Minnesota, New Jersey, North Carolina, Oregon, Texas, Virginia, and Washington) and in two cities (New York City and Washington, D.C.).

Projects and studies conducted under the VPPP have provided many valuable lessons.⁵ Most important, they have demonstrated that congestion can be reduced in highway corridors

⁵ http://www.ops.fhwa.dot.gov/congestionpricing/value_pricing/index.htm.

when pricing is implemented. For example, peak-hour traffic on the SR-91 express lanes in Orange County, California, typically moves at more than 60 mph, whereas traffic on the unpriced lanes travels at average speeds of 15 mph or less. Thus, travelers on the express lanes can save as much as half an hour on a single 10-mile trip at peak times (FHWA 2006).

Road pricing proposals have frequently raised equity concerns because of the fear that low-income drivers may be priced off the road. However, broad generalizations about the fairness of priced lanes are misleading (TRB 2011), and lessons from the VPPP indicate that equity concerns are being addressed through better planning and public outreach. Moreover, experience has shown that motorists across all income groups are willing to pay for a faster, more predictable, and stress-free ride that gets them to work, medical appointments, and child-care pickup on time and that frees more personal time for friends, family, and recreational activities (FHWA 2006).

While the concept of road pricing has been present for more than half a century, FHWA's work with states and cities through the VPPP has been essential in demonstrating that pricing is now a practical and widely acceptable option for managing congestion.

CONCLUSION

The federal government, through FHWA, has played a vital role in providing the steady stream of innovations needed to support improvements in the nation's highways. Today's roads are faster, safer, and greener than those of the 1960s and 1970s, in large part because of FHWA's RD&T activities and those of other research organizations that FHWA has promoted through technology transfer. In addition to performing its own research and supporting research conducted by others, the agency has coordinated activities across the complex and diverse highway RD&T enterprise. It has been instrumental in encouraging the risk-averse public-sector organizations responsible for the

nation's roads to embrace innovations that offer benefits for users and infrastructure owners alike.

Strategies that have proved effective in the past cannot guarantee future success. Nonetheless, it appears highly likely that FHWA, if provided with the appropriate resources, can continue to play a vital role in fostering the innovations needed in meeting the challenges of the highway system of the 21st century. The various organizations conducting highway RD&T are described in Chapter 3, and some of the innovations, and FHWA's anticipated role in their development and implementation, are described in Chapter 4.

| 3 |

Highway RD&T Program Organization and Focus

The first section of this chapter provides a brief overview of the federal and state RD&T programs and their funding levels and describes how the various programs interconnect and reinforce one another. The second summarizes the many barriers to innovation in public infrastructure agencies and thus explains why RD&T programs to overcome these barriers are so important for innovation in the highway sector.

| PROGRAMS

Responsibilities for the road network in the United States are highly decentralized. The nation's nearly 4 million miles of roads are the responsibilities of states and tens of thousands of other jurisdictions, including metropolitan planning organizations (MPOs), cities, counties, and towns (FHWA n.d., Table HM-60). The 47,000 miles of Interstate highways, of greatest federal interest, make up about 2.5 percent of the total road network and account for about a quarter of total annual motor vehicle miles traveled (FHWA n.d., Table VM-1); they are owned, maintained, and operated by the 50 states. The other roughly 730,000 miles of intercity highways are the responsibilities of states, except within metropolitan areas, where MPOs influence funding decisions. Counties, towns, and other jurisdictions are responsible for the remaining 3.2 million miles of arterial and local roads; these jurisdictions typically depend on their state DOTs for technical assistance.

Complex Set of Research Programs

Jurisdictions face differing challenges in building, maintaining, and operating roads because of the wide variations in climate, soil conditions, topography, sources of pavement aggregates and recycled materials, traffic, and levels of development. Thus, the Bureau of Public Roads, the forerunner of today's FHWA, in establishing federal research in support of road development in 1936, decided that a coordinated program of federal research supplementing state research addressing unique state issues made better sense than a centralized federal research program for highways. The same basic program structure exists today, but it has been enhanced and amplified as the road network has become more pervasive and integrated with the U.S. economy and society. A complex array of highway research programs has developed in response to the needs of the various agencies and jurisdictions responsible for different aspects of the nation's road network.

RD&T Funding

Most highway research in the public sector is driven by federal surface transportation legislation, which authorizes a small array of research programs related to highway transportation (Table 3-1, page 36). In addition to funding FHWA research and development (R&D), the current authorizing legislation funds research at the Federal Motor Carrier Safety Administration (FMCSA) on motor carrier safety and regulation; the Federal Transit Administration (FTA), mentioned here because transit buses rely on roads; the National Highway Traffic Safety Administration (NHTSA) on motor vehicle and driver safety; and the Office of the Secretary of Transportation—Research. The latter administers the Intelligent Transportation Systems (ITS) program of multimodal surface transportation R&D and the University Transportation Centers (UTC) program, which provides competitively awarded grants to universities based on proposals for conducting intermodal research, educating transportation professionals, and training future researchers.

**TABLE 3-1 Federal Funding for Highway-Related Research
(FY 2013 enacted)**

Federal Highway Administration	191.4
Federal Motor Carrier Safety Administration	8.5
Federal Transit Administration	41.6
National Highway Traffic Safety Administration	62.8
Office of the Secretary of Transportation—Research	2.6
Intelligent Transportation Systems	100.0
University Transportation Centers	72.5
State Planning and Research	184.7
TOTAL	664.1

NOTE: Figures are dollar amounts in millions enacted for FY 2013.

SOURCE: FHWA and U.S. Department of Transportation RD&T Strategic Plan, Table 1.

Funds allocated to federal transportation administrations (FHWA, NHTSA, FMCSA, FTA) address the specific (nonoverlapping) missions of these agencies. In addition, federal authorizing legislation requires states to set aside 2 percent of federal aid for capital improvements for planning and research, of which one-quarter must be spent on research. As described below, State Planning and Research (SP&R) provides the core funds that states rely on for their individual and collective research activities.

Highway RD&T

The focus of this report is on highway RD&T for construction, operation, safety, planning, environmental mitigation, and policy—activities that are primarily the responsibility of FHWA, the states, MPOs, and many other jurisdictions. Both FHWA and states fund applied highway-specific RD&T, and much federal ITS and UTC research is also specific to highways. FHWA's RD&T activities focus on its core mission responsibilities: infrastructure, safety, operations, planning and environment, and

TABLE 3-2 Federal and State Highway-Specific RD&T

FHWA Highway R&D	115.0
Exploratory Advanced Research	8.0
FHWA Highway R&D	
Infrastructure	36.0
Safety	10.0
Operations	11.0
Planning and Environment	13.5
Policy	6.0
Innovative Program Delivery	2.0
Corporate	5.6
Strategic Initiatives (cross-cutting)	20.0
Small Business Innovation Research	2.9
Technology and Innovation Deployment Program	62.5
Training and Education	24.0
State Planning and Research^a	184.7
TOTAL	386.2

NOTE: Figures are dollar amounts in millions for FY 2013.

^a In 2011, states were estimated to have spent about \$80 million (additional) state funds on highway R&D.

SOURCE: FHWA.

policy (Table 3-2, above). FHWA also funds training programs and devotes roughly \$60 million annually to assist in implementing innovations that flow from FHWA, state, and other highway R&D programs.

The ITS R&D program is primarily focused on the connected vehicle initiative, a collaboration among the federal government, automobile original equipment manufacturers, and public-sector infrastructure owners. ITS is funding R&D aimed at allowing communication of safety-related information between vehicles (vehicle to vehicle or V2V) and among vehicles and traffic signals and other infrastructure (vehicle to infrastructure or

V2I). The ITS program exemplifies the type of long-range, high-risk research that the federal government is uniquely suited for because it requires persistence over many years, collaboration between government and industry at the national level, and national standardization of communication technologies and applications.

The UTC program funds both inter- and cross-modal R&D and provides education and training for the development of future transportation professionals and researchers. Much of the research covers more than one mode or addresses cross-modal issues. However, the focus of a substantial share of the research projects is on highway issues because most UTCs are required to match federal funding dollar for dollar and many UTCs receive their match from their state DOT. The Research and Technology Coordinating Committee's (RTCC's) most recent major report found that the majority of UTC research projects at the time were addressing highway research topics (TRB 2008).

States use federal SP&R funds primarily for highly applied R&D addressing unique, state-specific issues and interests. In addition to the \$184.7 million in federal funds authorized for this purpose in FY 2013, the states spend some of their own funds on highway RD&T. Most states simply meet the federal 80–20 matching requirement, but others exceed it. The most recent estimate, based on a biennial National Science Foundation survey of state R&D spending, indicates an additional allocation of about \$80 million of state funds to highway research in FY 2011.¹ Besides supporting their individual research initiatives, states combine their efforts by pooling their funds on topics of common interest. The largest and longest-standing example is the National Cooperative Highway Research Program (NCHRP) (a \$39 million program in FY 2013), but many other less formal pooled-fund projects are under way at any given time, often including FHWA as a funding partner with a subset of states. NCHRP's work has often been described as conduct of

¹ <http://www.nsf.gov/statistics/nsf14311/pdf/tab13.pdf>. Accessed Feb. 12, 2015.

the analysis and synthesis of research that is the final step before translation of the results into specifications and standards for highway construction and operation. NCHRP also produces guidelines, software and analytical tools, and manuals for all aspects of highway transportation. Finally, as noted, states also often provide matching funds for universities participating in the UTC program.

The \$382 million invested annually in highway-specific RD&T may appear to be a large amount, but in the context of the \$130 *billion* required to maintain the nation's highways each year, the annual RD&T budget is modest. It represents 0.3 percent of the annual cost of maintaining the system. In the context of the asset value of the nation's highways, the annual federal highway RD&T budget is almost vanishingly small—only 0.014 percent.

One other major highway research program deserves mention. Although the research has been completed at the time of this writing, SHRP 2 has produced dozens of innovations that are lined up to be deployed to the states. Previous surface transportation legislation [the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)] authorized SHRP 2, which invested \$223 million over the past 9 years in research that developed innovations in four areas:

- Providing highway capacity more expeditiously while protecting the environment,
- Renewing aging infrastructure more quickly,
- Improving system performance and reliability, and
- Improving safety.

The innovations flowing from SHRP 2 are being implemented by early adopters and will be promoted more intensively and broadly to the states through FHWA's Technology and Innovation Deployment Program.

At first sight, the array of highway-related and highway-specific research programs summarized above may appear to be

overly complex and potentially duplicative. However, in practice, the programs address specific, distinct missions, and the highway-specific research programs are coordinated and organized to avoid duplication. FHWA's R&D programs focus on federal initiatives designed to benefit the nation as a whole. They include high-risk advanced exploratory research unlikely to be undertaken by nonfederal organizations and projects of a scale, complexity, and duration that exceed what any but the largest states could manage. FHWA's technology transfer and training programs are designed to foster deployment of tested and proven technologies and processes to states, MPOs, cities, and counties that own and operate roads. The state programs focus on state-specific topics, as well as topics of collective interest to all states or groups of states. The states' largest pooled-fund project, NCHRP, is closely coordinated with FHWA's program. The UTC R&D program is often tied to state DOT interests because of the DOT provision of state matching funds, and the students graduating from UTC programs often find employment in transportation agencies. To avoid duplication across all these programs, each program submits all of its research projects into a national database, the Research-in-Progress database maintained by the Transportation Research Board, and research program managers are required by federal regulation to consult this database before they initiate new projects.

| BARRIERS TO INNOVATION

Risk aversion in the public sector is well known—institutions and public officials are understandably leery of taking risks since, in contrast to the private sector, rewards are few but failure can have severe consequences for public support of agencies and for individual careers. Highways are capital-intensive and long-lived, which makes officials conservative with regard to design, materials, and construction. In addition, with the exception of some toll roads, highways are funded with public tax dollars and contracts are awarded through competitive bidding processes.

Highway agencies have long labored to ensure that contracts are awarded in a fair and transparent process that avoids opportunities for corruption. In such circumstances, officials tend to follow familiar procedures and avoid the unknown.

Several reports over the years have identified and discussed barriers to innovation in the highway sector (TRB 1996; TRB 1999; TRB 2001). The following are some of the main issues identified in these reports:

1. Normal human resistance to change;
2. Lack of incentives, strong disincentives, and risk aversion in the public sector;
3. Slow dispersion of innovations across a fragmented sector with 50 states, 342 MPOs, and tens of thousands of county and municipal public works departments with responsibilities for roads;
4. Lowest-bid contractor selection for transparency in contract award that does not necessarily represent best value for the long term;
5. Slow processes of field testing, standards development, and specifications development; and
6. Need for manuals, guidance, and extensive training to prepare workforces for new approaches.

These barriers are discussed in the reports referenced above, and the fuller treatment in previous reports need not be repeated here. The main point to take from this list is that several interrelated barriers make adoption of innovation in the highway sector a substantial, but not insurmountable, challenge. Public processes are slow moving, and that is understandable because they involve public funds. Even when innovations have been proved through field tests and adoption by one or more jurisdictions, dispersion can occur slowly because of the decentralized ownership of roads, lack of awareness by both public officials and private contractors, and the need to train the transportation workforce in new concepts and approaches.

Nevertheless, innovations are occurring in the highway sector and not just in the performance of materials. They are occurring in procurement processes and construction techniques that speed project delivery. As described in Chapter 2, for example, the DB approach allows contractors to propose innovations during the design phase that specification-based bidding makes difficult. Highway agencies have learned how to carry out DB and other new contracting methods through bidding processes that give contractors more freedom to innovate while maintaining transparency in bid awards (Molenaar and Tran 2015). Innovations that give contractors more opportunities to transform their processes have themselves accelerated adoption of innovations that speed construction. This is only the beginning of what will be needed in the face of a vast aging infrastructure and great shortfalls in funding for system maintenance at every level of government.

The typical role of federal research agencies is to fund basic or precompetitive research and then assume that the private sector, motivated by profit interest, will pick up these ideas and develop them into marketable products. This model is inadequate for the highway sector because the sector is largely owned and operated by public agencies. Supporting the development of good ideas is not enough to overcome the barriers to innovation. Also required are efforts to obtain buy-in from states and other infrastructure owners, including field trials and demonstration projects to prove that new concepts work, extensive technical assistance to all levels of government, development of curricula and training programs, and preparation and dissemination of manuals and guidebooks. Because of its scale and national scope, FHWA is uniquely qualified to carry out these tasks, as it has done throughout its history.

SUMMARY

Many research programs address highway performance and safety in some fashion; these programs relate to the missions

of the specific agencies (highway construction, maintenance, operation, and safety; motor carrier safety; transit operations; and motor vehicle safety). Highway-specific RD&T is primarily conducted by FHWA and the state DOT research programs, with supporting initiatives in the ITS and UTC programs. The decentralized nature of the programs follows the decentralized nature of responsibilities for roads. Arguably, research programs that are managed by the owners of infrastructure, primarily states for interstate and intercity highways, are more likely to be responsive to their immediate needs. The highly applied, problem-solving nature of individual state DOT research programs and NCHRP is true to this mission. Even so, the decentralized nature of the programs may seem “messy” and overly complex at first sight. FHWA plays an important leadership and coordination function across highway-specific research agencies, and policies and regulations ensure appropriate focus and avoidance of duplication.

Barriers to innovation among highway agencies are substantial, largely because of the agencies’ public role and the need for transparency in the award of highway funds derived from taxes paid by users. Innovations tend to spread slowly and to be hard won, which testifies to the importance of a strong push from FHWA and the states through effective technology transfer and deployment programs.

The modest annual federal investment in highway-specific RD&T of \$382 million to address and overcome the barriers to innovation is a bargain, representing only 0.3 percent of the annual cost of maintaining the highway system.

| 4 |

Current and Future FHWA Role

The first section of this chapter summarizes the essential role that RTCC has recommended that FHWA play in RD&T and provides examples of payoffs from FHWA efforts in RD&T. In the second, RTCC identifies two particularly important missions that FHWA will be required to fulfill in the future, in addition to its other RD&T responsibilities.

| CURRENT ROLE

The FHWA RD&T program is one among many. Over the years, RTCC has recommended that FHWA focus its efforts in areas that correspond to its capabilities and complement the programs of the states and other federal agencies (TRB 2001):

1. Investing in long-term, high-risk research;
2. Filling research gaps and addressing issues with national implications; and
3. Supporting technology transfer (including training and education).

The following sections briefly summarize why these areas of RD&T are uniquely suited to the federal role.

Investing in Long-Term, High-Risk Research

In all areas of science and technology, the federal government's role is recognized as one of pursuing new knowledge through basic research programs in agencies such as the National Science

Foundation, the National Institutes of Health, the Department of Defense, and the Department of Energy. Because highway research, and transportation research more generally, spans many disciplines and fields, it is not surprising that there is little basic research in this area. Instead, many highway innovations depend on breakthroughs in chemistry, materials, mathematics, organizational performance, and other fields. Traffic flow theory, for example, draws on basic research in game theory and fluid flow theory, while ITS draws on research into sensors and control (TRB 2014). However, there is a role for advanced research that actively seeks out, synthesizes, and translates emerging knowledge from the basic sciences for application in highway transportation. RTCC has long recommended that FHWA invest in such research because of the federal role in investing in research that may not lead directly to new products in the short term (TRB 1994; TRB 2001). FHWA's Exploratory Advanced Research (EAR) program was funded at \$11 million annually by Congress during SAFETEA-LU and is being continued at about \$8 million during MAP-21. The program is risky and long term by its nature, and it engages in areas of research that state DOTs are unlikely to pursue. Such research might appear to be natural for the UTC program. However, universities receiving matching funds from state DOTs are likely to be driven by state DOT interests in near-term, applied research with immediate application (TRB 2008). In view of the EAR program's exploratory nature and short history, discussion of its benefits is premature. However, RTCC views it as an essential component of FHWA's RD&T portfolio.

Among funding agencies, only FHWA has the resources and ability to conduct long-term research dedicated to highways that explores fundamental relationships. FHWA is under less pressure than are state DOT research programs to deliver products to solve immediate problems and is better able to invest for the long term in search of larger payoffs that serve national goals. The Long-Term Pavement Performance (LTPP) program, a federal-state partnership of more than 29 years,

has collected data on highway pavement performance across a wide range of topographic, climate, and traffic conditions, with subsurface conditions, materials, construction, and other characteristics taken into account (TRB 2009a). Even as late as the 1980s, pavement design was based on empirical relationships between loading and deterioration without regard for other characteristics, such as variations in climate, materials, subsurface conditions, and traffic. The first Strategic Highway Research Program (SHRP) recommended a long-term program that would conduct a large-scale experiment to collect pavement performance data to account for a wide range of possible contributors to pavement deterioration. The program began as part of the first SHRP in 1987, and Congress funded the program through FHWA's RD&T program in subsequent authorizations. Now recognized as the world's best collection of research-quality pavement data,¹ the LTPP data have proved essential to states in recent years as they have transitioned from design based on empirical relationships to design based on scientific and engineering principles. States now rely extensively on LTPP data to calibrate pavement models to account for local conditions, which has led to more cost-effective designs.² The benefits of the LTPP database to pavements have been so fundamental and extensive that FHWA has embarked in recent years on a similar program for bridges, the Long-Term Bridge Performance program.

¹ See Richter summary of research breakthroughs in pavement management at <http://www.trb.org/AboutTRB/KeyResearchAchievements.aspx?srcaud=AboutTRB>. "The program's single most significant product to date, as well as the largest source of information for current and future research, is the LTPP database. The database contains more research-quality data than have been collected anywhere before on the rate, type, and extent of pavement deterioration due to age, traffic loads, and weather, together with information on the design features and construction methods used to construct or rehabilitate the pavements. LTPP data has contributed to more cost-effective highway pavements by providing more realistic pavement design models; improved understanding of how and why pavements perform as they do; high-quality data on which to base pavement management and rehabilitation decisions; guidance to support selection of the most cost-effective pavement design features for a given set of design constraints; and a knowledge base on which to develop educational curricula for future generations of pavement practitioners."

² See Feldman summary of research breakthroughs in rigid pavement design at <http://www.trb.org/AboutTRB/KeyResearchAchievements.aspx?srcaud=AboutTRB>.

Filling Research Gaps and Addressing Issues with National Implications

FHWA plays a unique role in highway RD&T by identifying and filling research gaps that have broad application across the country. An example is the role that FHWA played in the development of the *Highway Safety Manual* (HSM) and a series of technical tools, collectively referred to as “SafetyAnalyst,” that assist states in identifying and prioritizing roadway safety improvements through use of the latest findings from highway safety research. In 1999, highway safety professionals conceived the idea of developing a manual, analogous to the *Highway Capacity Manual*, that would bring together the latest scientific knowledge about road design elements (e.g., number of lanes, median width, intersection control features) and safety. The HSM itself is one of the key breakthroughs in safety research over the past 20 years:

The Highway Safety Manual (HSM) is a major breakthrough in how safety is considered. The HSM provides practitioners with information and tools to consider safety when making decisions related to design and operation of roadways. The HSM assists practitioners in selecting countermeasures and prioritizing projects, comparing alternatives, and quantifying and predicting the safety performance of roadway elements considered in planning, design, construction, maintenance, and operation. Prior to the HSM, there was no widely accepted tool available to quantitatively assess the impact of infrastructure decisions on safety.³

The HSM incorporates SafetyAnalyst technical tools that FHWA helped develop over several years by participating with many states in a pooled-fund effort to conduct research and analysis. The tools developed through this effort are helping

³ See Fitzpatrick summary of research breakthroughs in operational effects of geometrics, at <http://www.trb.org/AboutTRB/KeyResearchAchievements.aspx?srcaud=AboutTRB>. Accessed Feb. 15, 2015.

states identify roadway segments with higher-than-expected crash rates and cost-effective safety countermeasures. Thus, SafetyAnalyst allows states to make more effective use of available resources by focusing on particularly hazardous locations where the payoffs in terms of improved safety are potentially the greatest. Engineers in Ohio, for example, have used SafetyAnalyst to identify problem locations more accurately. As a result, in 2010 they focused their attention on 350 particularly hazardous locations covering 95 miles, whereas in previous years they had typically studied about 600 locations covering 900 miles. Ohio is therefore using FHWA-developed tools to identify and target facilities with much higher fatality, injury, and crash rates (Hughes and Council 2012).

FHWA's assistance in the development of the HSM and SafetyAnalyst illustrates the role that RTCC envisioned when it recommended in 2008 that FHWA invest roughly half of its RD&T funding in this area (TRB 2008).

Supporting Technology Transfer

The success of R&D in highway transportation is measured not by numbers of reports published but by the practical implementation of research results. As noted in Chapter 3, the decentralization of the responsibility for U.S. roads and the strong aversion to risk in the public sector mitigate against the adoption of innovative technologies and approaches. FHWA has long recognized the importance of technology transfer, which is an agency mission that dates back to FHWA's earliest predecessor organization, the Office of Road Inquiry, established in 1893. In 1998, FHWA restructured its headquarters offices to enable the agency to be more effective in facilitating innovation by creating cross-office integrated product teams, as needed, with responsibility and accountability for the delivery of specific technologies, programs, and other products (TRB 1999). In its 1999 report on technology transfer, RTCC urged FHWA to develop a strategy for its technology transfer efforts and to develop strong partnerships with the agencies at the state and local

levels that implement innovative technologies and approaches (TRB 1999). In MAP-21, Congress recognized the importance of FHWA's efforts to assist in the deployment of new technologies and processes by authorizing \$62.5 million annually for this purpose. With funding made available under this program, FHWA has introduced its Every Day Counts (EDC) initiative and has planned for and begun assisting states in the implementation of products emerging from SHRP 2.

EDC, conducted in concert with the American Association of State Highway and Transportation Officials (AASHTO), is an effort "to identify and rapidly deploy proven but underutilized innovations to shorten the project delivery process, enhance roadway safety, reduce congestion and improve environmental sustainability" (FHWA 2014a, 2). At the time of this writing, FHWA has promoted three rounds of innovations by first gaining support from leaders of state DOTs and then supporting implementation through videos, guidebooks, manuals, and other publications. In support of all of its technology transfer efforts, FHWA develops curricula and offers extensive training to state DOT and other highway agency staff through the National Highway Institute and fosters innovation in local government and tribal transportation departments through local technical assistance programs.

During the waning years of SAFETEA-LU, FHWA began planning, in concert with AASHTO, for the deployment of technologies emerging from SHRP 2. During MAP-21, FHWA has been offering grants to states to assist in the implementation of SHRP 2 products and is poised to accelerate deployment of these innovations as more SHRP 2 products have become available and proved ready for implementation.

| FUTURE ROLE

FHWA's role in RD&T—investing in advanced research, filling research gaps and addressing emerging issues with national implications, and supporting technology transfer—will remain

vitaly important in the future, and it may become even more important than it has been over the past decades. The challenges facing the highway system will only grow with time in the face of declining real resources. They include increased levels of highway travel associated with population and economic growth on a system that is barely expanding and the need to renew, replace, and make more resilient a vast aging infrastructure built up over the past several decades. Meeting these challenges will require transferring new knowledge from basic research to practical highway applications, taking advantage of new technologies to address congestion and safety, and assisting states and local governments with implementation. RTCC perceives two particularly important areas where FHWA's role will be essential: (a) development and standardization of the infrastructure components of the connected vehicle initiative and (b) implementation of the innovations developed through SHRP 2.

The U.S. Department of Transportation's connected vehicle initiative, developed in collaboration with the automobile industry and infrastructure owners, promises to be the most effective highway safety program in many years. In past decades, occupant protection regulations and technology have been introduced and refined; these have dramatically reduced the severity of injuries when crashes occur. Building on advances in information processing and communications technologies, the connected vehicle initiative may dramatically reduce crashes themselves through V2V and V2I communications. The V2V initiative may even serve as a bridge to widespread vehicle automation in future decades. NHTSA estimates that more rapid warnings to drivers of impending collisions from just two of the many possible V2V applications, once they are fully deployed, could save up to 1,000 lives, reduce the severity of tens to hundreds of thousands of injuries, and avoid even more crashes altogether (Harding et al. 2014). The infrastructure component of the connected vehicle initiative would include receipt and transmission of information from traffic signals and roadside

beacons to vehicles.⁴ Whereas NHTSA is taking the lead on V2V, FHWA is taking the lead in V2I. Because of the lack of standardization in traffic control devices, the exercise of national leadership by FHWA will be essential in engaging stakeholders, providing a national perspective, and ensuring standardization of safety alerts to motorists so that the potentially significant safety benefits of V2I can be realized. The lack of standards can inhibit the pace of innovation. It has taken decades, for example, to make toll transponders interoperable on the east coast of the United States because individual toll authorities began electronic toll collection with different proprietary systems.

As mentioned in Chapter 3, SHRP 2 has recently concluded its 7-year program of R&D and produced dozens of innovations and fresh approaches for renewing infrastructure more rapidly with less disruption to motorists, providing additional capacity while avoiding harm to the environment, improving travel time reliability, and improving safety. The National Research Council committee charged by Congress with reporting on implementation of SHRP 2 technologies identified FHWA as the one organization “best positioned to administer SHRP 2 implementation” because of its experience with implementation of products from the first SHRP and its close relationship to the states (TRB 2009b). Lack of incentives, barriers to implementation, and lack of capability and resources make any other organization unlikely to provide the necessary technology push so that the nation will reap the benefits of the substantial investment in SHRP 2 research.

| SUMMARY

The essential future role for FHWA is a natural extension of its current role: investing in long-term, high-risk research; filling gaps and addressing issues of national significance that are not addressed by other programs; and supporting the transfer

⁴ An overview of the Cooperative Intersection Collision Avoidance Systems program and research in support of it appears at <http://www.its.dot.gov/cicas/> (accessed Feb. 25, 2015).

of proven innovations emerging from all research programs to public-sector owners of highway infrastructure. FHWA plays an essential role for the following reasons:

- FHWA is better positioned than are individual states to take a longer view in R&D. This allows the agency to conduct advanced research to harvest breakthroughs in basic research for application in transportation; conduct long-term pavement and bridge experiments to collect necessary data to improve infrastructure performance; and carry out complex, long-term R&D with the automobile industry and infrastructure owners in the connected vehicle initiative, which will help avoid vast numbers of crashes in the future.
- FHWA, with its national perspective, can lead states in the development and transfer of tools and processes, such as SafetyAnalyst, DDIs, and pricing of high-occupancy lanes, that improve safety and system capacity at less cost.
- With its economies of scale and offices in each state, FHWA is uniquely positioned to identify and support the implementation of innovations by states and local agencies.

The opportunities for carrying out this role are particularly promising in V2I development and standardization and in deployment of the products from SHRP 2 research. Only FHWA has the national perspective, leadership, resources, and ability to invest for the long term to carry out these responsibilities to the benefit of the nation as a whole.

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ABBREVIATIONS

FHWA	Federal Highway Administration
LTRC	Louisiana Transportation Research Center
NHTSA	National Highway Traffic Safety Administration
TRB	Transportation Research Board

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Study Committee

Biographical Information

Michael D. Meyer, *Chair*, is Senior Advisor, Parsons Brinckerhoff, Inc., and a Principal with Modern Transport Solutions in Atlanta, Georgia. He previously was Director of the Georgia Transportation Institute, Professor of Civil and Environmental Engineering, and former Chair of the School of Civil and Environmental Engineering at the Georgia Institute of Technology. From 1983 to 1988, Dr. Meyer was Director of Transportation Planning and Development for Massachusetts, where he was responsible for statewide planning, project development and engineering, traffic engineering, and transportation research. Before that, he was a professor in the Department of Civil Engineering at the Massachusetts Institute of Technology (MIT). Dr. Meyer has written more than 180 technical articles and has authored or coauthored numerous texts on transportation planning and policy. His publications have examined many issues in transportation, such as land use–transportation interactions, freight and logistics planning, and climate change. He is the recipient of numerous awards, including the Transportation Research Board’s (TRB’s) W. N. Carey, Jr., Award for Distinguished Service in 2009. He was Chair of TRB’s Executive Committee in 2006. Dr. Meyer has a BS in civil engineering from the University of Wisconsin, an MS in civil engineering from Northwestern University, and a PhD in civil engineering from MIT. He is a registered professional engineer in the state of Georgia.

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Timothy A. Henkel is an Assistant Commissioner and directs the Modal Planning and Program Management Division at the Minnesota DOT. He manages the Offices of Passenger Rail, Transportation System Management, Freight and Commercial Vehicle Operations, Transit, Aeronautics, Transportation Data and Analysis, and Research. Mr. Henkel's 30-year transportation career includes work with local governments and the private sector, and he has held numerous Minnesota DOT responsibilities, including executive leadership of multimodal planning, program management, and project development and delivery. Mr. Henkel chairs the FHWA Transportation Asset Management Expert Task Group and the Minnesota Council on Transportation Access, and he is Vice Chair of AASHTO's Standing Committee on Planning and Transportation Asset Management Subcommittee. He received a bachelor of science degree from Bemidji State University and a certificate in civil engineering and land surveying from Dunwoody College.

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Michael R. Morris has been on staff in the Transportation Department of the North Central Texas Council of Governments, the MPO for the Dallas–Fort Worth area, since 1979. The MPO serves the region by developing transportation plans and programs that address the transportation needs of a rapidly growing metropolitan area. Mr. Morris became the Director in 1990. As the Director of Transportation, he is also responsible for coordinating plans, programs, and projects to improve mobility and reduce vehicle emissions. He received a master's degree in civil engineering from the State University of New York at Buffalo in 1979 and is a registered professional engineer in the state of Texas. Several groups including the Institute of Transportation Engineers, the Association of Metropolitan Planning Organizations, and the Texas Transportation Commission have recognized him. He previously served as Chair of TRB's Executive Committee and as a National Associate of the National Academies. Mr. Morris has served on several TRB study committees.

Harold (Skip) Paul is the Director of the Louisiana Transportation Research Center, which is sponsored jointly by the Louisiana DOTD and Louisiana State University. Mr. Paul has been serving the Louisiana DOTD for more than 35 years in the research section and, since 1986, the Louisiana Transportation Research Center. He has been the Director of the center since March 2006. Mr. Paul has also served as an Engineer-in-Training; Bituminous Research Engineer; Materials Research Engineer; and Associate Director, Research. As a researcher, he has more than 45 publications in the journals of TRB, the Association of Asphalt Paving Technologists, and other organizations. Mr. Paul has also served TRB on NCHRP panels and in a number of volunteer leadership positions, culminating in his service as the Technical Activities Council Chair from 1999 to 2002. He was named a National Associate of the National Academies in 2001 and was the recipient of TRB's W. N. Carey, Jr., Distinguished Service Award in 2013. He is a former board member of the Association of Asphalt Paving Technologists and has participated in many FHWA advisory groups. Mr. Paul is a graduate of Lehigh University. He holds a bachelor of science degree in mechanical engineering and a bachelor of arts degree in English. He is a licensed engineer in the state of Louisiana.

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The RTCC concludes that FHWA plays an essential role in exploratory, advanced research; addresses national priorities that other highway RD&T programs do not address; and facilitates adoption of innovations at the state and local level through technology transfer. The RTCC notes that FHWA, along with its other responsibilities, will play a particularly important role in ensuring the standardization of safety alerts to motorists between infrastructure and vehicles as part of the national connected vehicle initiative, as well as assisting transportation agencies in implementing the many innovations developed in the second Strategic Highway Research Program.

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