

September 3, 1999

The Honorable Neal Lane  
Assistant to the President for Science and Technology  
Office of Science and Technology Policy  
Washington, D.C. 20500

Dear Dr. Lane:

At the request of Dr. Fenton Carey, Executive Secretary of the National Science and Technology Council (NSTC) Committee on Technology, the National Research Council (NRC), acting through the Transportation Research Board (TRB), convened the Committee for Review of the Federal Transportation Science and Technology Strategy (Phase 2) (see Attachment 1 for a list of the committee members). This is the second year of Phase 2. In the first year, the committee was asked to review the 11 partnership initiatives included in the strategy at that time. In the second year, the committee was asked to perform a more detailed review of two of those initiatives:

- Next Generation Surface and Marine Transportation Vehicles (referred to as the “Next Generation Vehicles Initiative” in this report)
- Monitoring, Maintenance, and Rapid Renewal of Physical Infrastructure (referred to as the “Physical Infrastructure Initiative” in this report)

The committee carried out its task by reviewing NSTC documents, including the *National Transportation Science and Technology Strategy* (Strategy) and relevant portions of the *Transportation Technology Plan* and the *Transportation Strategic Research Plan*; examining other background materials specific to each of the partnerships; and holding a meeting in Washington, D.C., on June 14–15, 1999. During the open session of the meeting, the committee heard from Mortimer Downey (Deputy Secretary, U.S. Department of Transportation [DOT]) and Fenton Carey (Associate Administrator for Research, Technology and Analysis, DOT Research and Special Programs Administration) about what the study’s sponsors hope to learn from this review. The committee then divided into two subcommittees, one to review each initiative, and heard from a number of presenters about programs, technologies, and issues related to that initiative. (A list of presenters is provided in Attachment 2.) It should be noted that this letter report is a product of the entire committee, although the specific recommendations in the sections pertaining to each partnership initiative come primarily from the subcommittees that reviewed that initiative.

This report begins with some general observations that apply to both partnership initiatives. The specific questions comprising the committee’s charge for each initiative, observations and

recommendations for each initiative, and a listing of members of the respective subcommittees, are presented in subsequent sections of the report.

## **GENERAL OBSERVATIONS**

Transportation makes a critical contribution to the nation's economy and to the quality of life of its citizens. At the same time, transportation poses significant environmental and safety issues. New technologies and concepts are fundamental to achieving advances in transportation, both by increasing its supportive role and by reducing its environmental and safety impacts. Research is needed to discover, investigate, and develop these innovative technologies and concepts.

The needs are great, however, and the resources limited. In this context, strategic research and development planning becomes essential. The value of such planning is reaffirmed in the Transportation Equity Act for the 21<sup>st</sup> Century (TEA-21), which requires DOT to engage in a surface transportation strategic planning process for research. Given the importance of transportation and of strategic research and development planning, the committee offers the following general comments that apply to both of the strategic partnership initiatives and to the overall strategic research and development planning endeavor.

### **Partnerships**

The initiatives reviewed by the committee are referred to as "partnership initiatives." Certainly, partnerships can be an effective way of achieving the broad and ambitious goals of the NSTC Strategy, which include safety, mobility and access, economic growth and trade, protection of the human and natural environment, and national security; however, it is evident that neither initiative has yet achieved a partnership in the usual sense of the word. Ordinarily, a partnership has several features that may be more or less formal, but usually include the following:

- Specific individuals or groups committed to the effort
- Some mechanism that formalizes the commitment (such as a memorandum of understanding, a cooperative agreement or contract, or a governing body with representation from the partners)
- Mutually agreed-upon goals and objectives
- Assigned resources
- Budgets and work plans specifying such items as sources and allocation of resources, schedules for activities, and milestones for products and outcomes

Neither of the initiatives the committee reviewed has these characteristics at this time.

### **System-level Perspective**

In dealing with any particular technology, it must be recognized that its development and use take place within a broad system that includes other technologies (both products and processes), as well as human, institutional, economic, political, and other factors. The importance of viewing a technology within a broad system context applies to innovations under both

partnership initiatives. For example, the Superpave® innovation that was presented to the members of the committee who reviewed the Physical Infrastructure Initiative involved materials, methods, equipment, procurement issues, industry buy-in, and training of agency and industry staff to use a whole new approach to the design, specification, and construction of asphalt pavements. If any piece of this system had been neglected, the implementation of the core technology (the binder and mix design methodology) would likely have failed. Vehicle–highway interaction, discussed under the review of the Next Generation Vehicles Initiative, is another issue that illustrates the system-level perspective necessary in addressing innovation.

### **The Innovation Process**

Just as it is essential to look at individual technologies within a system context, it is important for the partnership initiatives to consider the entire innovation process, from enabling research through the actual use of an innovation in the market. Consideration should be given to the incremental changes as well as the “quantum leap” changes that must take place. The organizational or institutional changes that are often required in conjunction with technological innovation should also be addressed. Consideration of the overall innovation process can help identify potential partners and stakeholders and their respective roles in the partnership initiative. For example, universities and national laboratories could play a more significant role in the enabling research elements of an initiative, with each type of institution handling the research most suited to its mission and capabilities; industry could be more involved in the commercialization of new products; and federal, state, and local governments could address public-sector institutional and regulatory issues. At the same time, the federal government can provide funding to accelerate precompetitive research and development. The initiatives reviewed by the committee appear to be oriented more toward deployment of existing technologies than toward research. While this emphasis may be intentional, research should be addressed more explicitly as an integral part of the strategies for achieving partnership goals.

### **Learning**

Research efforts in different areas can learn from each other. These two initiatives can gain useful lessons not only from each other and the other partnership initiatives, but also more generally from successful research programs that have been undertaken in the transportation industry. Examples pertaining to these two initiatives include the heavy-duty vehicle programs in the Next Generation Vehicles Initiative, which could learn from similar efforts in passenger vehicles under the Partnership for a New Generation of Vehicles (PNGV), and opportunities for PAIR-T to learn from the American Association of State Highway and Transportation Officials (AASHTO) Lead State program and other instances of Strategic Highway Research Program (SHRP) implementation. Appropriate structures should be established to facilitate this learning by promoting awareness of what is being done in other programs and by fostering communication among technical staff of different programs for which such learning opportunities exist. This awareness and communication should, of course, obtain among programs that are ostensibly part of the same partnership initiative. It was apparent from the committee’s review, however, that this was not the case.

## NEXT GENERATION SURFACE AND MARINE TRANSPORTATION VEHICLES

The Strategy describes the goal of this partnership initiative as follows:

Develop internationally competitive, domestically produced transportation vehicles that achieve unprecedented gains in fuel efficiency and in both environmental and operational performance, including reduced greenhouse gas emissions.

This partnership addresses the problems of petroleum dependence, global warming, and pollution through research leading to the development of highway vehicles, ships, locomotives, and aerospace vehicles that are better designed and more efficient. It has four thrusts: (1) continue the PNGV and Advanced Technology Transit Bus activities and supplement them by also focusing on medium- and heavy-duty-vehicles; (2) demonstrate and develop the marine application of fuel cells; (3) support the development, test, and demonstration of non-electric high-speed rail technology; and (4) develop and demonstrate the next generation of aerospace vehicles, including aircraft with more efficient and cleaner engines.

### Context

This proposed partnership initiative was apparently inspired by PNGV, which is a formal arrangement between the U.S. government and the United States Council for Automotive Research (USCAR, a consortium of DaimlerChrysler, Ford Motor Company, and General Motors Corporation). PNGV has defined milestones aimed at developing by 2004 a preproduction prototype of an advanced midsize automobile, with “up to three times the fuel efficiency of comparable 1994 models.”<sup>1</sup> The Next Generation Vehicles Initiative has similar objectives for trucks, buses, locomotives, ships, and aerospace vehicles.

### Committee’s Charge

The specific questions posed to the committee were as follows:

1. What framework and process would help ensure better integration of related enabling research programs managed in separate federal agencies?
2. How could the partnerships take better advantage of the relevant enabling research under way throughout government, industry, and academia?
3. How could merit review be used to improve the performance of these partnerships and related enabling research?

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<sup>1</sup> National Science and Technology Council, *Transportation Technology Plan*, Committee on Technology, Subcommittee on Transportation Research and Development, Washington, D.C.: Executive Office of the President, 1998, p. 57.

The following committee members reviewed this initiative: H. Norman Abramson (subcommittee chair), William G. Agnew, Deborah A. Boehm-Davis, Patrick F. Flynn, Robert E. Gallamore, Supramaniam Srinivasan, Steve T. Scalzo, and Dale F. Stein.

## **Review Approach**

As stated earlier, the Next Generation Vehicles Initiative includes programs focused on highway, marine, rail, and aerospace vehicles. The committee did not believe it could give adequate attention to programs in all these areas in the time available for the review. Therefore, the subcommittee restricted itself to a detailed review of the programs that bear on heavy-duty highway vehicles (trucks and buses) and engines.

Heavy-duty vehicles are vital to the nation in many ways. They promote economic activity, national security, and mobility by carrying much of the nation's freight and a portion of the traveling public. At the same time, they consume a large and growing share of the nation's petroleum and emit a corresponding share of its pollution. Research and development to advance vehicle technology holds promise for improving the fuel efficiency and environmental impacts of this sector while enhancing safety and lowering costs. The subcommittee heard presentations on the programs of four agencies that carry out research and technology development in these areas and will be participating in the Next Generation Vehicles Initiative: the 21st Century Truck Initiative of the U.S. Army's Tank-automotive and Armaments Command (TACOM); the Heavy Vehicle Technologies Program of the U.S. Department of Energy; the Electric and Hybrid Vehicle Technology Program of the Defense Advanced Research Projects Agency (DARPA), which is being transitioned into the Advanced Vehicle Program of the Federal Transit Administration (FTA); and FTA's Advanced Technology Transit Bus Initiative.

## **Findings and Recommendations**

With respect to the programs reviewed by the subcommittee, the use of the term "partnership" to describe this broad array of agency efforts is inaccurate and inappropriate. The four agency presentations revealed substantial differences in organization and approach. Each agency program is based on loosely connected efforts conducted by various participants. Most of the programs are carried out by contractors who become "partners" by virtue of either being involved in related activities or sharing in the program costs. These contractors generally pursue their own interests, without having common goals and objectives. For example, one agency lists more than five dozen partners in the public and private sectors, but all of those partners have their own (sometimes competing) programs and activities.

This situation is in sharp contrast to the commonly accepted notion of a partnership in business. In that setting, partners share not only the investments, but also the risks and potential rewards of ventures, with agreed-upon and clearly stated goals and objectives.

With the above general comments in mind, the committee offers the following specific recommendations.

## **Recommendation 1. Improving Coordination and Communication**

***1a. Conducting Strategic Planning for Heavy Vehicles.* Participants in this initiative should carry out a systematic program of strategic planning to establish a broader set of goals to be pursued that are agreed upon by all participants and address all relevant national issues. The resulting strategic plan should be widely publicized.**

The initiative's goals appear to be defined rather narrowly. The heavy-duty vehicle programs reviewed by the subcommittee appear to focus strictly on environmental issues (lowering of vehicle emissions) and fuel efficiency, with little attention to other national concerns, such as safety, mobility, cost (a strong barrier to market acceptance), economic growth and trade, and national security.<sup>2</sup> In fact, the heavy-duty vehicle programs appear to emphasize emission reductions above all else. This emphasis may reflect the fact that diesel engines (which dominate the heavy-duty vehicle market) are already highly efficient, but are seriously threatened by regulatory trends toward lower emissions of nitrogen oxides (NO<sub>x</sub>) and particulate matter. (Lower emissions and fuel efficiency are to some extent competing goals for diesel engines.)

While it is true that this focus on emissions and fuel efficiency is consistent with the goals stated in the NSTC *Transportation Technology Plan*, a systematic strategic planning exercise would surely reveal other opportunities to improve the heavy-duty vehicle system and address additional national goals. The resulting strategic plan should establish a coherent set of goals that better reflects the role of heavy-duty vehicles in transportation and the economy, as well as the environment in which the proposed demonstration vehicles will have to operate. A more comprehensive strategic approach could also improve coordination and cooperation among agencies and industry participants, as discussed in other recommendations that follow.

***1b. Coordinating Research, Development, and Demonstration.* The National Science and Technology Council (NSTC) should develop an effective process for coordinating the activities of sponsors, industry, national laboratories, and universities.**

The initiative lacks a process for coordinating the various research, development, and demonstration activities in support of heavy-duty vehicle technology. The absence of comprehensive and coherent strategic goals discussed under recommendation 1a appears to contribute to this fragmentation. Goals would most appropriately be developed with the participation of all stakeholders from both industry and government.

The presentations of the various agencies revealed little collaboration or real coordination across programs for existing activities. Only one of the four agencies proposed a structure for integrating the activities of participants. This proposal appeared to elicit little support or input from the other agencies.

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<sup>2</sup> TACOM may be an exception to this statement in that it has a well-defined and -implemented program for the development of heavy-duty vehicles that meet military requirements. Carryover of some of this technology to the civilian sector is secondary, and its incorporation in the Next Generation Vehicles Initiative needs to receive greater emphasis.

Even less coordination is evident between the heavy-duty vehicle initiatives and other NSTC transportation activities. The operating characteristics of highways, for example, interact strongly with those of vehicles, yet planning in these two areas appears to be unrelated. The federally sponsored initiative to develop intelligent transportation systems (ITS) is also apparently being ignored in planning for heavy-duty vehicles, even though ITS technologies offer some of their strongest potential benefits for the operators of those vehicles. At an even more basic level, no attempt has been made to develop and apply a common protocol for measuring the performance of demonstration vehicles. DOT would serve these efforts well by developing and applying a common protocol for measuring and comparing the performance of heavy-duty demonstration vehicles across all agencies and contractors.

An even more telling example of fragmentation is the failure to interact adequately with PNGV. (PNGV itself offers an example of effective coordination, although it may not represent a workable model for the heavy-duty vehicle sector.) In its efforts to develop a midsize automobile with significantly higher fuel economy, PNGV is pursuing hybrid electric vehicles with the diesel engine as a candidate power plant. Several of the heavy-duty vehicle activities reviewed by the subcommittee, for example, are nearly identical with those encountered in the development of light-duty hybrid electric vehicles in PNGV. Although there appear to have been some interactions between the PNGV diesel engine developers and the heavy-duty diesel engine manufacturers, the subcommittee's review revealed little or no interaction between the developers of vehicle systems and subsystems (such as hybrid power systems, power trains, and auxiliary systems). Fostering such interactions could be quite beneficial.

One approach to facilitating interactions among industry, government, and universities would be a technology mapping exercise aimed at identifying the key technology developments necessary to achieve agreed-upon goals. The focus on systems analysis discussed under recommendation 2 below could help in this process. Involving all the key players in the private sector, including, for example, the fuels industries (since an appropriate fuel and the associated infrastructure could be critical to the successful commercialization of advanced vehicles), would foster the necessary dialogue and assist in identifying the key research areas.

***1c. Involving Industry in Shaping Technology Activities. The NSTC should establish a continuing dialogue with industry on the technology goals of the heavy-duty vehicle aspect of the initiative to better define the boundaries of competition and cooperation.***

Industry has hesitated to work together on the technology of heavy vehicles, a situation that contrasts with the industry cooperation seen in light-vehicle technology under PNGV. The ability to structure PNGV, formed in 1993 between the government and the domestic automotive companies, was aided by the existence of a consortium—USCAR—that could engage in precompetitive research. The heavy-duty vehicle industry is different. For example, the dividing line for precompetitive research and development is closer to the market in this industry, and the need to protect proprietary information has prevented engine manufacturers, for whom technology rules the market, from joining freely in the initiative. The NSTC has therefore focused the heavy-duty vehicle programs on “vertical partnerships” (in which an engine maker,

for example, may cooperate with a vehicle manufacturer and other suppliers without having to share information with a direct competitor).

The need for rational evolution of this sector, with an appropriate balance of environmental, efficiency, and economic concerns, appears to warrant the formation of a credible high-level collaboration like USCAR. Among its other benefits, this process and the associated dialogue would help define the areas of research that are considered “precompetitive” (and therefore appropriate for cooperation) and those that are to remain proprietary.

## **Recommendation 2. Exploiting Enabling Research Through Systems Analysis**

**The transportation subcommittee of the NSTC should place strong emphasis on modeling and simulation of vehicle systems in its heavy-duty vehicle activities, and use the results of those efforts to identify and support high-priority areas of enabling research.**

The heavy-duty vehicle programs reviewed by the subcommittee are generally aimed at developing demonstration vehicles using existing technology. This focus on existing technology has prevented systematic efforts to identify and address the most important technical barriers, which could be overcome through research (for example, at universities and federal laboratories). Modeling and simulation of vehicles as systems, including their operational requirements, would help identify these technical barriers. Non-technical issues, such as cost-benefit analysis, land use impacts, and financial impacts (fuel taxes), could also be addressed. Without such analysis it will be difficult to establish priorities for areas of enabling research that could make the greatest contribution to the success of the partnership initiative. While one of the agencies reporting to the subcommittee is effectively using modeling and simulation in its development work, providing such system models to all contractors would aid them in their development of demonstration vehicles.

## **Recommendation 3. Achieving Stable Funding**

**DOT and the Office of Science and Technology Policy should use strategic planning and interagency coordination to improve funding stability.**

The transportation research and development programs associated with the Next Generation Vehicles Initiative are funded from individual agency budgets in response to the various agency missions. This arrangement may be unreliable for the initiative in the long term because it is subject to the agencies’ shifting priorities. The resulting uncertainty makes it difficult to secure stable support from legislators and consistent support and participation by industry and academic researchers.

To be successful in an inherently unstable budget environment, these programs must offer internal stability and continuity to the extent possible. The strategic planning and coordination discussed earlier under recommendation 1, including well-defined milestones and merit reviews, could serve as the basis for realistic multiyear budget projections that would make investing in



these programs more attractive. PNGV, for example, was established as a 10-year public–private partnership and has achieved impressive technical progress during the past 6 years. It includes a technical roadmap, technical targets, and milestones toward achieving a preproduction prototype vehicle, and leverages activities across a number of agencies, the national laboratories, and the private sector. Although the various agency programs face year-to-year budget appropriations, the program has goals and schedules that can be used to estimate needed resources.

#### **Recommendation 4. Evaluating the Initiative’s Results**

**A process for merit review should be established for evaluation of the Next Generation Vehicles Initiative. This process could take one (or both) of two forms:**

- **Regular objective measurements of progress toward well-defined milestones (goals to be achieved by specified times)**
- **Review of the initiative’s success in meeting its overall goals and of the value of the outcomes achieved**

**In either case, evaluation criteria should include not only the achievements of agencies, but also the initiative’s success in exploiting partnerships and capitalizing on enabling research. One or more review committees should be established to evaluate the entire initiative, cutting across the individual projects and agencies involved.**

None of the presentations heard by the subcommittee described procedures for merit review that could be used to evaluate the overall success of the initiative. This is not surprising given that the partnership is embryonic at best at this point. Individual projects reviewed by the subcommittee exhibited an uneven use of merit review. Some of the agencies described peer review activities for judging the quality of ongoing projects; none presented plans for reviews aimed at evaluating the outcomes of the projects.

PNGV uses a rigorous system of review, some elements of which might be applicable to the heavy-duty vehicle programs. For example, when PNGV was formed, the Declaration of Intent specifically noted that there would be an external review of the program by an independent group, such as the National Academy of Sciences. The National Academy of Sciences/NRC subsequently formed the Standing Committee to Review the Research Program of the Partnership for a New Generation of Vehicles. That committee has conducted five reviews of the program, monitoring progress and making recommendations, as appropriate.<sup>3</sup> The interaction between industry and government on PNGV technical teams has also contributed greatly to the review and evaluation of technologies and their potential for automotive applications.

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<sup>3</sup> National Research Council, *Review of the Research Program of the Partnership for a New Generation of Vehicles*, Fifth Report, Washington, D.C.: National Academy Press, 1999.

In summary, the Vehicle Initiative needs to develop partnerships through a strategic planning process involving all participants, an effective coordination process, and a targeted effort to engage in dialogue with industry to define the boundaries of competition and cooperation. These coordination efforts should be used to improve funding stability. The initiative should emphasize modeling and simulation of vehicle systems to identify high priority areas for enabling research. A process for merit review should be established.

## **MONITORING, MAINTENANCE, AND RAPID RENEWAL OF PHYSICAL INFRASTRUCTURE /PAIR-T**

The NSTC Strategy describes the goal of this partnership initiative as follows:

Accelerate the comprehensive renewal and advancement of the Nation's aging transportation infrastructure using stronger, cheaper, and environmentally superior materials and more cost-effective delivery systems; reduce waste, pollution, and emissions generated in the production of infrastructure materials.

This partnership, also called PAIR-T (Partnership for the Advancement of Infrastructure and its Renewal-Transportation), will create an environment that fosters an unprecedented level of collaboration and synergy on infrastructure research, demonstration, testing, evaluation, and technology transfer to State and local agencies. The partnership will collaborate on developing new technologies, accelerating market acceptance of existing products, and removing barriers to efficient technology transfer.

### **Context**

Transportation infrastructure is essential to the nation's economic prosperity and quality of life. Much of that infrastructure is in need of repair or rehabilitation to maintain its performance or meet new performance standards demanded by users. Managers of the infrastructure are challenged to effect significant renewal of facilities with minimal disruption to users. Innovative methods and technologies offer promise to help meet this challenge. The pace of adoption of these technologies is slow, however, and subject to many barriers.

The need for and the difficulties associated with innovation in public infrastructure have been a concern of government, industry, and academia for a number of years. Many studies have been conducted to address these issues, and several efforts have been made to expedite innovation. Clearly there is a need to accelerate the introduction of technologies that can improve the public service provided by transportation infrastructure. Yet this innovation takes place within a complex context of public policy goals, other technologies, institutions, economics, politics, and human resource issues. Attempts to expedite innovation must include consideration of the impact on these other elements.

### **Committee's Charge**

The committee was asked to review the Physical Infrastructure Initiative. The NSTC *Transportation Technology Plan* proposes that PAIR-T be the mechanism for pursuing this initiative. PAIR-T is the transportation element of a broader initiative, PAIR, of the Civil Engineering Research Foundation (CERF), aimed at promoting improvement in many forms of public infrastructure. The specific questions posed to the committee were as follows:

1. What are the critical gaps, bottlenecks, or barriers in the innovation process for physical infrastructure?
2. Which of these would be the most effective focus for this partnership to expedite innovation?
3. What role should each of the following groups play in this focus area: federal government, state government (departments of transportation), universities, industry?
4. How can the efforts of these groups be best coordinated?

The committee was not asked to comment specifically on PAIR-T. Nevertheless, in the process of addressing the above issues, the committee did question the appropriateness of PAIR-T as the main mechanism for carrying out the NSTC initiative. The committee's concerns are presented below in the section on findings and recommendations. While the recommendations presented in that section apply to the Physical Infrastructure Initiative, the committee makes some specific comments regarding the potential role of PAIR-T in this initiative.

The following committee members reviewed this initiative: James Lammie (subcommittee chair), Lawrence W. Cole, Karl H. Frank, Carl Haas, Lowell B. Jackson, C. Ian MacGillivray, Michael J. Markow, and Carl L. Monismith.

## **Review Approach**

In the case of the Physical Infrastructure Initiative/PAIR-T, the committee did not review a set of federally funded research programs. Instead, the committee examined a very broad and complex phenomenon (innovation in transportation infrastructure) to ascertain how well the Physical Infrastructure Initiative would contribute to the objective of expediting this innovation.

There are four elements to the approach used by the subcommittee to ensure that broad and balanced information would inform its deliberations. First, subcommittee members themselves came from varied backgrounds (private, public, and academic) related to infrastructure design, construction, and management. Several subcommittee members have studied the innovation process and served on NRC and other committees that have addressed this issue, while other members have been personally involved in developing and/or implementing new infrastructure technologies. Second, to ground its discussions in real-world experiences, the subcommittee invited speakers to present case studies of actual innovation attempts; two cases of innovations that were successfully implemented and two cases of innovations that encountered barriers were presented.<sup>4</sup> Third, to avoid generalizing simply from these four cases, the subcommittee invited a panel of speakers representing federal agency, state agency, and academic perspectives on

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<sup>4</sup> The successful innovations were high-performance concrete for highway structures and the Superpave® system for asphalt pavement design. The innovations that have not yet achieved widespread adoption were a method for applying carbon composite jackets for seismic retrofitting of bridges and a polycarbonate stop sign.

innovation. Fourth, again to provide broader context, the subcommittee drew upon a background paper on innovation in highway infrastructure prepared by TRB staff to brief the committee before the meeting (see Attachment 3).

## **Findings and Recommendations**

PAIR-T was presented as a private- and public-sector partnership among infrastructure stakeholders. Its objective is to “supplement, not supplant” the many initiatives in the private and public sectors that address the need for proactive infrastructure repair and renewal using innovative products and practices. PAIR-T seeks to create a climate that fosters private- and public-sector collaboration and leverages limited national resources.

The effort to promote infrastructure repair and renewal through innovation and partnerships is critical to the nation’s economic vitality and quality of life. The committee recognizes the criticality of this effort. The question is whether and how PAIR-T can achieve this goal. In general, the PAIR-T goals are timely and worthwhile; however, several issues need to be addressed in the areas of program definition, relationship to other efforts, involvement of stakeholders, and funding.

The committee spent a good deal of time trying to identify exactly what PAIR-T might do. According to the PAIR Implementation Plan,<sup>5</sup> a vast array of activities, including raising public awareness, developing legislation, and formulating policy statements, is to be undertaken. The committee does not believe PAIR-T can or should attempt to meet all the objectives described under the Physical Infrastructure Initiative in the NSTC *Transportation Technology Plan*. Many other players—federal, state, local, academic, and private-sector—and many other effective efforts are contributing to the achievement of those objectives. At the same time, there are gaps to be filled. The committee believes PAIR-T can be a significant contributor to the NSTC initiative if it focuses on one or more of the critical gaps in infrastructure innovation, rather than assuming the leadership role in the overall effort.

It is hoped that the recommendations presented below, organized according to the questions that formed the committee’s charge, will contribute to further efforts to refine and develop the Physical Infrastructure Initiative.

### **Recommendation 5: Critical Gaps, Bottlenecks, or Barriers in the Innovation Process for Physical Infrastructure**

**Other efforts being made to expedite innovation in infrastructure should be explicitly identified by the Physical Infrastructure Initiative, and the relationship between PAIR-T and these other efforts should be clearly**

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<sup>5</sup> An implementation plan focused specifically on PAIR-T was not presented to the committee. The PAIR Implementation Plan referred to in the report was developed by CERF to direct the broader PAIR program, although it gives some emphasis to the transportation portion of PAIR.

**defined. PAIR-T needs to articulate clearly what gaps it proposes to fill and how it proposes to do so. The initiative as a whole would benefit from identifying the relationships among efforts to promote infrastructure innovation. In view of the suggested reduction in PAIR-T's role, it becomes imperative that the NSTC initiative more actively involve the other players in this field.**

The PAIR Implementation Plan makes broad statements about the importance of innovation and its lack, but shows little understanding of the issues involved in infrastructure innovation, and does not acknowledge the roles of other players and the efforts being made elsewhere (such as the AASHTO Lead State program and other initiatives mentioned in Attachment 3). An analysis of needs, opportunities, and capabilities, which would reasonably be expected in any business plan, is missing from the PAIR plan.

In the absence of this detailed analysis and for the purposes of addressing the questions in its charge, the committee used the information and analysis included in Attachment 3. This paper outlines many of the challenges and success factors involved in infrastructure innovation and draws from a number of studies in this area. The Physical Infrastructure Initiative should explicitly consider the content of this paper in further developing its activities.

In addition, the committee emphasizes a contrast that arose in reviewing the case studies presented to the subcommittee. The successful innovations were technology *systems* that included materials, equipment, methods, specifications, and training. Moreover, they were developed with close cooperation among federal and state highway agencies, suppliers, manufacturers, and contractors and were very much supported by the federal and state agencies. The unsuccessful (though technically worthwhile) innovations were products or processes developed by private entrepreneurs who then tried to sell them to state and local agencies. If a product fits into the existing system of an agency, it is likely to be adopted, but if other elements of the system (such as specifications, training, or procurement practices) need to be adjusted, the private entrepreneur often does not have the resources, contacts, authority, or incentive to affect these other elements. It appears that AASHTO and the Federal Highway Administration (FHWA) are effective in disseminating innovations that have emerged from within the public sector, where they can influence the overall system, but cannot easily promote innovations arising from private industry. The private entrepreneur, on the other hand, often does not have the resources required to investigate the need for and promote changes in other parts of the system in which a product or process must fit. Therefore, the product or process often fails to be widely adopted.

In assessing what gaps it might fill, PAIR-T could also look at different transportation modes and draw upon experience in other countries. PAIR-T might find additional ways to contribute in, for example, adapting to U.S. practice certain improvements that have been demonstrated overseas, or pursuing a selected line of expertise in the transit, maritime, rail, or aviation modes as well as in the highway sector.

#### **Recommendation 6: Effective Focus for This Partnership to Expedite Innovation**

**6a. PAIR-T should focus on those aspects of private–public partnership in infrastructure innovation that have not been successfully addressed by existing groups and programs.**

Existing groups and programs do not appear to be very successful in dealing with the private sector (supporting innovations originating from private entrepreneurs; developing private–public partnerships; recruiting support, financial and otherwise, from private industry). PAIR-T might consider such activities as studying innovative contracting methods (for example, design–build and performance specifications) that offer the promise, as yet not fully demonstrated, of facilitating innovation; promoting business practices that enhance the environment for innovation (for example, by developing model contracts); bringing together groups (especially from the private sector) to create a funding umbrella for new ideas (for example, to cover the incremental costs of innovation); and providing information and guidance to private entrepreneurs on how to navigate the public-sector innovation process.<sup>6</sup>

**6b. The committee discourages this partnership from engaging in specific product endorsements, although entrepreneurs may favor this type of activity.**

There was some suggestion from entrepreneurs who addressed the subcommittee that they would favor a national-level endorsement to facilitate use of their products among state and local agencies nationwide. While this is a tempting way to promote rapid innovation, the objectivity of the initiative’s work will be critical to building its credibility, and product endorsement could undermine such efforts. Alternative mechanisms for product endorsement should be sought.

**Recommendation 7: Roles for Federal Government, State Government, Universities, Industry**

**The Physical Infrastructure Initiative should devote substantially more effort to developing relationships with other stakeholders and affirmatively including other relevant organizations—such as AASHTO, the American Concrete Pavement Association, the American Road and Transportation Builders Association, the Construction Industry Institute, the National Asphalt Pavement Association, and others—as real partners with ownership in the innovation process.**

While the innovation process can be described, it varies by type of innovation because of the different economic, institutional, legal, and regulatory influences involved. For this reason, every innovation is different and requires the proper unique team of federal, state, industry, and

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<sup>6</sup> In the PAIR-T presentation, CERF indicated that it would be developing two workshops for DOT: one on procurement reform, and one on either risk management or asset management. The committee supports the value of these workshops and recommends that the second workshop focus on risk management. This would be an appropriate follow-up to the workshop on procurement reform, since changes in procurement methods often bring about a reallocation of risk. In addition, the committee was informed that AASHTO will be sponsoring a conference on asset management in the fall of 1999, so it may be worthwhile to avoid duplicating that effort.

academic interests. The Physical Infrastructure Initiative appears to have had insufficient involvement of these stakeholders. While PAIR-T ultimately falls under the umbrella of the American Society of Civil Engineers, a long-respected organization to which many members of the transportation community belong, CERF is less well known and less well integrated into the transportation community. PAIR-T, in particular, is virtually unknown outside of a small community in Washington, D.C. Therefore, significant effort must be made to establish productive relationships among all relevant players from which the most effective niche for PAIR-T will emerge.

### **Recommendation 8: Coordination of the Efforts of These Groups**

**8a. The prospectus for the Physical Infrastructure Initiative should next be presented to a stakeholder forum, with alternative roles for PAIR-T being considered as well. A broad-based coordination council comprising all the major players should be formed.**

Ownership of the initiative by all major stakeholders will be critical to its success. Once the more detailed analysis recommended above has been completed and the focus areas of PAIR-T have been more clearly identified, the plan should be presented as a proposal to a forum of major stakeholders, convened by a neutral party. The question of whether PAIR-T should be the focal point or leader of the effort should be open to the discussion of the stakeholders, with the definition of a different role for PAIR-T being a possible outcome. A coordination council comprising all the major players should be developed to further guide and promote PAIR-T.

**8b. Financial support should be generated through the development of relationships with stakeholders.**

The collaborative facilitation in the initiative's objectives cannot be sustained without an independent funding source. Particular emphasis should be placed on attracting "new money" to the infrastructure innovation process, rather than competing with existing programs for federal and state funds.

In summary, the Physical Infrastructure Initiative would benefit from a comprehensive analysis of other efforts to expedite infrastructure innovation and from developing relationships with all infrastructure stakeholders. These activities, along with a stakeholder forum, will help identify critical gaps and appropriate roles for all stakeholders, including PAIR-T, and generate financial support for new activities to fill these gaps.

### **CONCLUDING COMMENTS**

While the committee's review focused exclusively on the Next Generation Surface and Marine Transportation Vehicles Initiative and the Monitoring, Maintenance, and Rapid Renewal of Physical Infrastructure Initiative, the findings and recommendations of this review may prove

helpful in advancing other partnership initiatives included in the NSTC Strategy. In particular, the NSTC could examine how well other initiatives perform in the following areas:

- Development of true partnerships among all the relevant stakeholders
- Importance of taking a system-level perspective on new technologies
- Consideration of the entire innovation process, from enabling research through implementation
- Technology scanning, whereby agencies review research in a variety of areas that could be applied to a subject of interest
- Technology mapping, in which careful analyses are performed to indicate those points in specific systems that offer the highest potential for leveraging so the research to be undertaken can be directed toward critical problems
- Efforts to learn from related activities

Partnership initiatives that perform better in one or more of these areas could provide helpful insights and examples for other initiatives.

The committee is pleased to have had the opportunity to continue to provide feedback on the National Transportation Science and Technology Strategy and hopes that its comments and recommendations will prove useful. The committee looks forward to continued advancement toward the important goals of the strategy.

Sincerely,

Joseph Sussman,  
Chair, Committee for Review of the Federal Transportation Science and Technology Strategy  
(Phase 2)



## Attachment 1

### Committee for Review of the Federal Transportation Science and Technology Strategy (Phase 2, Year 2)

**Joseph M. Sussman**,<sup>1, 2</sup> *Chairman*, Japan Rail East Professor and Professor of Civil and Environmental Engineering at the Massachusetts Institute of Technology (MIT), and Director of MIT's Association of American Railroads Affiliate Laboratory Program

**H. Norman Abramson** [NAE],<sup>1, 2</sup> *Vice Chairman*, Executive Vice President (retired) of Southwest Research Institute

**James Lammie** [NAE], *Vice Chairman*, Director of the Board, Parsons Brinckerhoff, Inc.

**William G. Agnew** [NAE],<sup>2</sup> Director (retired), Programs and Plans, General Motors Research Laboratories

**Deborah A. Boehm-Davis**, Professor of Psychology, George Mason University

**Lawrence W. Cole**, Vice President—Engineering and Research, American Concrete Pavement Association

**Patrick F. Flynn** [NAE], Vice President for Research, Cummins Engine Company, Inc.

**Karl H. Frank**, Professor of Civil Engineering and Phil M. Ferguson Centennial Teaching Fellow in Civil Engineering, The University of Texas at Austin

**Robert E. Gallamore**,<sup>2</sup> Assistant Vice President, Communications Technologies and General Manager of the Positive Train Control Program, Transportation Technology Center, Inc.

**Carl Haas**,<sup>3</sup> Louis T. Yule Fellow and Associate Professor of Civil Engineering, The University of Texas at Austin

**Lowell B. Jackson**, Independent Consultant

**C. Ian MacGillivray**,<sup>2</sup> Director, Engineering Division, Iowa Department of Transportation

**Michael J. Markow**, Principal, Cambridge Systematics, Inc.

**Carl L. Monismith** [NAE],<sup>3</sup> Robert Horonjeff Professor of Civil Engineering Emeritus, University of California, Berkeley

**Steve T. Scalzo**, Senior Vice President, Operations, Foss Maritime Company

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<sup>1</sup> Served on Phase 1 of the study.

<sup>2</sup> Served on Phase 2 of the study.

<sup>3</sup> Served on the committee that conducted an Enabling Research Workshop.

**Supramaniam Srinivasan**, Visiting Scientist, Center for Energy and Environmental Studies,  
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**Dale F. Stein** [NAE],<sup>3</sup> President Emeritus, Michigan Technological University

## **Attachment 2**

### **Presenters**

#### **Next Generation Surface and Marine Transportation Vehicles**

Henry Kelly  
Office of Science and Technology Policy

Michael Gage  
Calstart-Westart

Paul Skalny  
U.S. Army-TACOM

James Eberhardt  
U.S. Department of Energy

Robert Rosenfeld  
Defense Advanced Research Projects  
Agency

Shang Hsiung  
Federal Transit Administration

Tony Yen  
Federal Transit Administration

#### **Monitoring, Maintenance, and Rapid Renewal of Physical Infrastructure**

Peter Kissinger  
Civil Engineering Research Foundation

Paul Mack  
New York State Department of  
Transportation

Charles Goodspeed  
University of New Hampshire

Gloria Ma  
XXSys

George Kochanowski  
All-Sign Products

Richard Wright,  
National Institute of Standards and  
Technology (retired)

David Hensing  
American Association of State Highway and  
Transportation Officials

David Schultz  
Northwestern University

## Attachment 3

### Innovation in Infrastructure

Ann M. Brach  
TRB Staff

*Prepared as briefing material for the committee prior to its meeting.*

#### Introduction

The need for and the difficulties associated with innovation in public infrastructure have been a concern of government, industry, and academia for a number of years. Significant opportunities for innovation exist in this arena. The wide range of areas for innovation (materials, methods, software, etc.) and recent advances made by other industry sectors in these areas, coupled with the extent of public infrastructure, its importance in our lives, and the pressing need for its renewal, all suggest this potential. Yet innovation in public infrastructure appears to occur very slowly. A number of studies have examined this phenomenon, and several efforts have been made to expedite innovation. This background paper summarizes a number of the challenges to innovation in infrastructure and the factors that appear to be associated with successful innovation. Several efforts to expedite innovation are also described. The paper ends with a selected bibliography of studies and reports on the topic. This paper is not meant to provide a comprehensive synthesis, but merely an introduction to the topic. Moreover, the focus is on highway infrastructure, which was the committee's emphasis during this review.

#### Context

The challenges and positive factors for innovation in public infrastructure need to be understood in the context of the public policy decisions and tradeoffs that characterize this arena. Because of its nature as a public good, highway infrastructure is not adequately regulated by ordinary market forces. It is usually placed under the stewardship of the public sector, which owns, operates, or at least regulates it. However, the private sector has always played a significant role as designers, builders, manufacturers, suppliers, and providers of financial services. The traditional system of providing highway infrastructure has developed in response to a number of public policy goals: to provide the infrastructure as broadly as possible, to do so at a reasonable cost, to apportion this cost in an equitable manner, to allow for broad participation by the private sector in competing for highway contracts, to ensure that qualified contractors win the jobs, and to ensure that the price paid for their services is both fair to the contractor and a responsible use of public funds, among others. These goals help explain some of the challenges to innovation. Those who attempt to expedite innovation need to consider the impact on these goals and whether new public policy tradeoffs are warranted.

#### Challenges to Innovation and Possible Approaches To Address Them

**Fragmented and Decentralized Nature of the Industry.** There are 50 states and thousands of local governments that own and operate highways, each with its own procurement regulations, specifications, organizational structure, and even scope of responsibility. There are also

thousands of private firms of all sizes, from local to international, that provide products and services to these government entities. This characteristic of the industry inhibits widespread implementation. Several efforts are under way to help streamline the innovation process, for example, by providing centralized product evaluation (Highway Innovative Technology Evaluation Center [HITEC], National Transportation Product Evaluation Program NTPEP), or by funding exploratory work or implementation (Innovations Deserving Exploratory Analysis [IDEA], Strategic Highway Research Program [SHRP] implementation). Some of these efforts are described later in this paper. However, even efforts to centralize product testing and evaluation do not guarantee that individual state and local agencies will accept the results or use the products.

**Low-Bid System.** The practice of awarding highway contracts to the lowest qualified bidder, based on materials and methods specifications, tends to leave little room for a contractor to introduce innovation. If the innovation does not follow the specifications exactly, it is not allowed; if it costs more, the contractor will not win the bid, even if improved performance warrants the increased cost. Innovative procurement approaches are being used (e.g., design–build, incentive–disincentive, warranties), but there has been some concern about the impact of some of these approaches on competition, particularly if they make it more difficult for small firms to bid. In some cases, authorities have had to deal with public perceptions that tax dollars were being misused when contractors received nontraditional payments (such as incentive payments) under innovative procurement schemes.

**Material and Methods Specifications.** As noted above, prescriptive specifications are ordinarily part of the low-bid system. They ensure that all bids are for the same end product and provide a basis for determining whether that product has been delivered. A way to overcome this difficulty is to develop and use performance specifications that indicate the performance desired, instead of prescribing the technologies to be used. However, it has been challenging to establish measures of performance for complex, long-lived facilities.

**First-Cost Criterion.** Agencies have traditionally focused on the “first cost” or construction cost of a facility in determining the low bidder. This focus excludes the use of any technology that increases the first cost even if it reduces the cost of maintaining and using the facility over its lifetime. Attempts have been made to use life-cycle costs in comparing technologies, at least for parts of a project (the pavement or bridge deck, for instance). One difficulty has been determining how to calculate the life-cycle cost. (Should user costs be included or just agency costs? How should the time value of money be treated?) Another difficulty is more political in nature. If the amount of money available for highway work is fixed for a given year, funding projects that have a higher first cost means not being able to start as many projects—and satisfy as many constituents—that year.

**Procurement Procedures.** Procurement procedures are designed to prevent agency personnel from favoring particular contractors or suppliers. These procedures can be slow and cumbersome even when they are not directly prohibitive. In some special cases, such as the rapid reconstruction of infrastructure in California after an earthquake, procurement procedures have been significantly—even drastically—streamlined because of a clear public good to be achieved. It may be possible to expand such a public-good argument by emphasizing the user

and social costs associated with deteriorating or poorly performing infrastructure. At the same time, however, explicit consideration must be given to the tradeoffs inherent in this approach since it could lead to adverse impacts in such areas as competition, the use of small firms, and the risk of unfair practices.

**Prohibition of Proprietary Products.** A related aspect of the procurement process is that proprietary products are usually not allowed because they limit competition and do not fit into the materials and methods specification system. There are usually some exceptions to rules against proprietary products (including at the federal level), but such exceptions ordinarily allow the product to be used only once or in a very limited number of cases.

**Tort Liability.** Public agencies are often concerned about product liability when they use (or allow their contractors to use) a propriety product or one that does not adhere to clear standards, guidelines, or approvals from national entities such as the Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO), or ASTM.

**Reallocation of Risk.** In addition to the risk inherent in trying anything new, technological and methodological innovations can often cause risk to be reallocated among stakeholders in a project. For instance, some innovative procurement procedures (such as warranties and use of performance specifications) shift greater control over, and therefore greater responsibility for, product quality from the transportation agency to the contractor. Unwillingness or inability to accept increased risk can be an impediment to implementing an innovative approach.

**Vested Interests.** In some geographic areas and with some product types, particular industries or firms exert significant political influence over agencies' technology choices. Thus a willingness to innovate will be thwarted by pressure to use technologies offered by those industries or firms.

**Institutional Issues.** Because of their responsibility to the public, as well as the incentive structure they face, highway agencies tend to be very risk averse. At both the individual and agency levels, there is little reward for success in innovation and potentially huge penalties for failure. In addition, new technologies often require new expertise, which is difficult for many public agencies to attract, train, or retain because of salary differentials with the private sector, downsizing of public agencies, and outsourcing to the point where agency staff are no longer doing technical work that would be attractive to experts in the field. The resulting degradation of agency expertise leads to increased reluctance of the agency to entertain new ideas.

### **Factors That Support Innovation**

Innovation—getting a new idea or product used in a real-world application—is a complex phenomenon that does not easily lend itself to process diagrams and straightforward causal relationships. However, research and experience indicate some factors that appear to encourage successful innovation. Some of these are as follows:

- **Meeting a pressing need**—As obvious as it may sound, many times innovations fail because, however good the idea, it does not address one of the pressing needs of the customer. Highway agencies are large, complex organizations that provide a wide variety of services, many of which are critical to the everyday functioning of society. Leaders at all levels of these agencies must prioritize concerns and carefully allot limited resources to those considered most critical. It may not be apparent from the outside, but adoption of new technology is very resource intensive for an agency. The necessary resources can be devoted only to technologies that address those concerns that have top priority for the secretary, commissioner, or chief engineer.
- **Providing for person-to-person contact**—Technology is not typically transferred through the written word or sales presentations; a certain amount of personal trust is needed before substantial investments will be made.
- **Providing for person-to-technology contact**—Opportunities to use the technology or see it used first-hand increase comfort with new ideas.
- **Addressing system/context issues**—Technologies are usually part of a context or system (technical, institutional, legal, political, economic). Innovation is successful when the technology fits into the existing system or when necessary adjustments to the system have been addressed up front.
- **Getting the customer involved**—Related to the above points, the customer/user of an innovation should be involved in the process of developing the innovation so that real needs and context issues are addressed.
- **Obtaining management support**—A frequently mentioned factor in successful innovation is the support of top managers. Such support can take the form of funding, human resources, or encouragement, among others.
- **Performing test and evaluation**—Many good ideas fail upon application because they were not adequately tested in real-world situations. Such testing is usually the least interesting or glamorous part of the innovation process, but it is critical for success. It is also an excellent opportunity for customer involvement through pilot projects, evaluation panels, and the like. Also important is finding out what evaluation criteria customers use and how they measure performance so that the performance of an innovation can be presented in terms that are meaningful to the intended user.
- **Fostering an agency environment of innovation**—Agencies that reward innovation, accept a reasonable amount of failure (which is unavoidable), value employees who have and improve expertise, and provide resources for all stages of the innovation process (including the less glamorous ones) will be more likely to innovate and to accept the innovations of others.

### Examples of Efforts To Expedite Innovation<sup>1</sup>

**HITEC**, run by the Civil Engineering Research Foundation, develops nationally recognized and impartial evaluation plans for unique products for which no standard evaluation methods exist.

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<sup>1</sup> Descriptions of HITEC, NTPEP, and IDEA are taken from TRB Special Report 249, *Building Momentum for Change: Creating a Strategic Forum for Innovation in Highway Infrastructure* (1996).

**NTPEP**, run by AASHTO, evaluates standard products for which test methods or protocols have already been developed. The evaluations are undertaken by a single entity serving an entire region or the nation.

**IDEA** programs, managed by the Transportation Research Board, investigate and seek to introduce new technologies, methods, or processes through the development and testing of nontraditional and innovative concepts, including the application of concepts from other technology sectors. There are four IDEA programs: highway-related innovations are handled by NCHRP-IDEA, transit-related innovations by TCRP-IDEA, innovations related to intelligent transportation systems by ITS-IDEA, and innovations related to high speed rail by High Speed Rail-IDEA.<sup>2</sup>

**SHRP** was a 5-year, focused program of highway research. Special funding was designated in highway legislation to promote the implementation of SHRP products. SHRP implementation activities are characterized by intensive user involvement—from the top management level (the SHRP Implementation Task Force and the Long-Term Pavement Performance Committee, which included state secretaries of transportation and chief engineers) to the technical level within state departments of transportation (SHRP state coordinators and funding of SHRP implementation activities in every state). A highlight of SHRP Implementation is the Lead State program, in which a small number of states begins using a new technology and then coaches other states, passing on lessons learned. In addition, AASHTO made early and extensive efforts to develop specifications for SHRP products so they could be incorporated more easily into state procurement processes.

**FHWA** is very involved in the SHRP implementation efforts. The agency is also conducting other efforts to promote innovations emerging from its own laboratories, as well as from other sources, public and private, domestic and international.

**The Local Technical Assistance Program (LTAP)** is an FHWA-administered program that funds centers in each state and several tribal centers that transfer highway technologies to local and tribal governments.

### **Reports and Studies Related to Infrastructure Innovation**

*Partnerships for Innovation: Private-Sector Contributions to Innovation in the Highway Industry*, NCHRP Synthesis of Highway Practice 149, Transportation Research Board, December 1989.

*Technology Transfer in Selected Highway Agencies*, NCHRP Synthesis of Highway Practice 150, Transportation Research Board, 1989.

*Highway Research: Current Programs and Future Directions*, Special Report 244, Transportation Research Board, 1994.

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<sup>2</sup> NCHRP = National Cooperative Highway Research Program; TCRP = Transit Cooperative Research Program.



Harvey M. Bernstein and Andrew C. Lemer, *Solving the Innovation Puzzle: Challenges Facing the U.S. Design & Construction Industry*, ASCE Press, 1996.

*Facilitating the Implementation of Research Findings: A Summary Report*, NCHRP Report 382, Transportation Research Board, 1996.

*Building Momentum for Change: Creating a Strategic Forum for Innovation in Highway Infrastructure*, Special Report 249, Transportation Research Board, 1996.

*Managing Product Liability To Achieve Highway Innovations*, NCHRP Synthesis of Highway Practice 265, Transportation Research Board, 1998.

*Partnership for the Advancement of Infrastructure and Its Renewal through Transportation (PAIR-T)*, White Paper, Civil Engineering Research Foundation.

*The Role of Procurement and Contracting Approaches in Facilitating the Implementation of Research Findings*, NCHRP Project 20-34, Transportation Research Board (in preparation).

*FHWA and Technology Transfer: Adopting a Strategy To Measure Success*, Special Report, Transportation Research Board (in preparation).