U.S. Army Corps of Engineers
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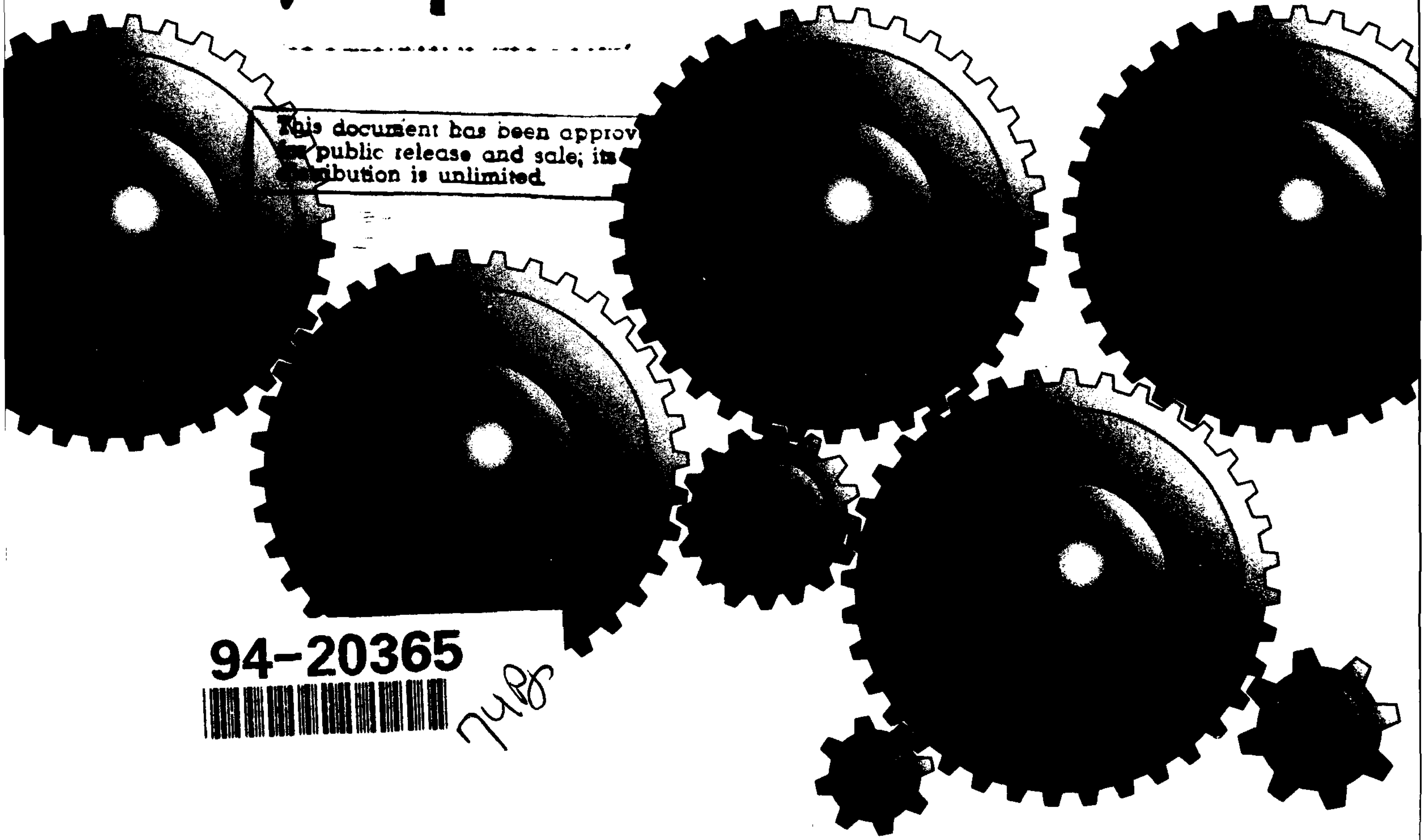
U.S. Army Corps of Engineers
Construction Engineering
Research Laboratories

Challenges and Opportunities for Innovation in the Public Works Infrastructure - Volume I



74 pg

Federal Infrastructure Strategy Program

June 1993

IWR Report 93-FIS-2

Federal Infrastructure Strategy Reports

This is the second in a series of interim reports prepared to support the Federal Infrastructure Strategy Initiative, a 3-year program to explore the development of an integrated multi-agency Federal infrastructure strategy.

The Federal Infrastructure Strategy is a dynamic program involving many Government departments and agencies. The series of reports which chronicle the strategy's development reflect the desire to publish interim documentation as results become available. Theses documents will be used to facilitate the dialogue within the Federal and non-Federal infrastructure communities as policy deliberations continue.

The program will culminate with a final report to be published at the end of 1993. The interim documentation contained herein is not intended to foreclose or preclude the program's final conclusions and recommendations. Within this context, comments are welcome on any of these reports.

This report documents the results of an in-depth study and workshop which developed methods which could be applied to overcome barriers to innovation and the use of innovative technology within the nation's public works infrastructure.

The first report published as part of the Federal Infrastructure Strategy Program was:

> The Federal Infrastructure Strategy Program: Framing the Dialogue - Strategies, Issues and Opportunities (IWR Report 93-FIS-1)

The next three reports planned for publication as part of the program are:

> Challenges and Opportunities for Innovation in the Public Works Infrastructure, Volume II (IWR Report 93-FIS-3)

> Infrastructure in the 21st Century Economy: A Review of the Issues and Outline of a Study of the Impacts of Federal Infrastructure Investments (IWR Report 93-FIS-4); and

> Federal Public Works Infrastructure R&D: A New Perspective (IWR Report 93-FIS-5).

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THE FEDERAL INFRASTRUCTURE STRATEGY PROGRAM

CHALLENGES AND OPPORTUNITIES FOR INNOVATION

IN PUBLIC WORKS INFRASTRUCTURE

VOLUME I

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June 1993

IWR Report 93-FIS-2

FOREWORD

This report was prepared for the U.S. Army Corps of Engineers Institute for Water Resources as part of a 3-year program to explore the development of an integrated Federal infrastructure strategy. This program, The Federal Infrastructure Strategy, was initiated as one of the President's budget items for Fiscal Year (FY) 1991 and approved by Congress. The U.S. Army Corps of Engineers (USACE) was selected to act as program facilitator, and other various Government departments and agencies are participating. The program is overseen by the USACE Directorate of Civil Works, and the Institute for Water Resources (IWR) has detailed management responsibility.

This report, the first of several planned in-depth studies of various complex infrastructure issues, focuses on the topic of innovation in the management of public works infrastructure. Innovative approaches will be essential to successfully address the numerous problems facing the public works infrastructure. However, little effort has been dedicated to identify and promote mechanisms to effectively transfer technological and management innovations from Government research centers to the nation's public works infrastructure.

On 3-4 March 1992, the U.S. Army Construction Engineering Research Laboratories (USACERL), Champaign, IL, conducted a workshop on the challenges and opportunities of promoting innovation in the public works infrastructure . The workshop, "Challenges and Opportunities for Innovation in Public Works Infrastructure," included participants from academia, Government, and industry. This two-volume report is a product of that workshop. Volume 1 summarizes the findings of an extensive literature search on innovation and infrastructure. Volume 2 comprises the proceedings of the workshop, including transcripts of the papers presented, discussion summaries, and related resources. The report also includes the authors' recommendations, based on the findings of the literature search and the workshop.

The authors would like to express their deep sense of gratitude to all who participated in the workshop: Prof. Arthur Baskin, University of Illinois; Dr. James A. Broaddus, Construction Industry Institute (CII); Mr. Joel Catlin, American Water Works Association (AWWA); Prof. J.M. De La Garza, Civil Engineering Dept., Virginia Polytechnic Institute and State University; Prof. John P. Eberhard, Carnegie-Mellon University; Mr. Michael B. Goldstein, Dow, Lohnes & Albertson; Dr. Francois Grobler, USACERL; Prof. Neil Hawkins, University of Illinois; Dr. Andrew C. Lemer, Building Research Board; Prof. Stephen Lu, University of Illinois; Mr. Carl Magnell, Civil Engineering Research Foundation (CERF); Mr. Benjamin Mays, Government Finance Officers Association; Mr. William D. Michalerya, Center for Advanced Technology for Large Structural Systems, Lehigh University; Prof. Fred Moavenzadeh, Center for Construction Research and Education, Massachusetts Institute of Technology (MIT); Prof. Joe Murtha, University of Illinois; Mr. Thomas Napier, USACERL; Prof. Peter Nowak, Dept. of Rural Sociology, University of Wisconsin; Mr. Charles Seemann, from Deutsch, Kerrigan & Stiles; Dr. Louis R. Shaffer, USACERL; Mr. Kyle Shilling, IWR; Mr. Jesse Story, Federal Highway Administration; Mr. Richard A. Sullivan, American Public Works Association (APWA); Mr. Jim Thompson, IWR; Mr. Jeff Walaszek, USACERL; Prof. Michael Walton, Transportation Research Board (TRB); Prof. Thomas D. White, Purdue University; and Mr. Ronald Zabilski, Stone & Webster Engineering Corp. It was an honor to have hosted, interacted with, and learned from them. All of them have made an impressive contribution toward helping the nation harness innovation in the imposing cause of dealing with infrastructure challenges.

The authors gratefully acknowledge the opportunity given by IWR to address this vital issue. Special thanks are due to Mr. Kyle Schilling, Director of IWR, and Mr. Lim Vallianos and Mr. James Thompson, project monitors.

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EXECUTIVE SUMMARY

This report was prepared for the Federal Infrastructure Strategy Initiative, a 3-year program to explore the development of an integrated Federal infrastructure strategy. The program was initiated as one of the President's budget items for Fiscal Year (FY) 1991 and approved by Congress for execution by the U.S. Army Corps of Engineers (USACE) Directorate of Civil Works. The Corp's Institute for Water Resources (IWR) has detailed management responsibility under the direction of Dr. Eugene Z. Stakhiv, Chief, Policy and Special Studies Division and Mr. Robert A. Pietrowsky, Program Manager. As an initial effort of this program, IWR tasked the U.S. Army Construction Engineering Research Laboratories (USACERL) to conduct an in-depth study and workshop on innovative approaches to managing the nation's public works infrastructure.

The objective of this report is to summarize the proceedings of the workshop, "Public Works Infrastructure Innovation: Barriers, Opportunities, and Challenges," and provide recommendations on how to enhance the transfer of innovative technology and management practices to improve the declining condition of the nation's public works infrastructure. Innovative approaches will be essential to address the problems facing the public works infrastructure. However, little effort has been dedicated to identify and promote mechanisms to effectively transfer technological and management innovations from Government research centers to the nation's public works infrastructure.

This report is presented in two volumes. Volume 1 is based on findings from an extensive literature review performed to identify the barriers, incentives, and opportunities for the promotion of innovation in the public works infrastructure. Volume 2 comprises the proceedings of the workshop "Challenges and Opportunities for Innovation in the Public Works Infrastructure," conducted on 3-4 March 1992 at the U.S. Army Construction Engineering Research Laboratories, Champaign, IL. This workshop convened a group of distinguished experts on the topic to discuss vital issues related to innovation and infrastructure and develop recommendations for promoting innovation in the management and sustainment of the nation's public works infrastructure. Participants included experts from academia, Government, and industry.

This report focuses on four critical areas of concern. First, it examines barriers to infrastructure innovations and innovation adoption processes. Second, a model for a national strategy on Infrastructure Research and development (R&D) and Technology Transfer—the IRTT model—is proposed for implementation. Third, based on short-term recommendations extracted from the IRTT model, the process of technology dissemination is examined in detail, with a review of models for technology transfer (or "innovation diffusion"). Finally, it recommends a mechanism for the transfer of currently available innovative approaches by incorporating and expanding three technology transfer models: The Rogers model, the Shaffer model, and the NASA (National Aeronautics and Space Administration) model.

From a survey of current literature, seven major categories of barriers were selected for discussion: (1) cultural values and social perceptions, (2) Governmental structure and regulations, (3) risk and liability, (4) public and private partnership issues, (5) funding, (6) size and type of infrastructure projects, and (7) education and research systems, and technology transfer. The workshop presentations and group discussions generated similar list of barriers. A list of six barriers developed from both the literature survey and workshop discussions is shown in Table A. These barriers are considered the most critical based upon both their importance and the practicality of methods available to penetrate them. Both importance and practicality must be considered together because it is essential to address all areas where positive results can be obtained quickly. These six barriers are discussed in the paragraphs that follow.

Table A: Barriers to Innovation Transfer

Barrier	Methods to Overcome
Lack of a Federal initiative (focus) for defining the policy and vision for national infrastructure technology (R&D). Diverse and fragmented governmental structure and private sector organizations dealing with infrastructure; fragmented R&D efforts throughout the nation.	Create a comprehensive Federal initiative to establish a national infrastructure policy that will: (1) Act as a catalyst for innovation; (2) Keep abreast of international R&D for new technologies; (3) Foster intergovernmental partnerships between State and local governments to oevelop improved fiscal and political tools for promoting innovation.
Inadequate technology transfer mechanisms. Lack of public- and private-sector R&D cooperation; lack of R&D partnerships between the public and private sectors.	Develop adequate technology transfer mechanisms and commit necessary resources to support them; greater leadership from all levels of Government in support of R&D programs, and development of incentives to reward R&D investment by the private sector.
Lack of public awareness. Public opposition; discordance with widespread cultural values; "not invented here" syndrome; emphasis on short-term benefits, not long-term benefits to the nation.	Active partnership with community groups; building awareness and support groups; communicate with Congress; create mechanisms to resolve controversy; effective education related to key technologies and relevant research; communicate the importance of innovation in a national context.
Complexity of regulations. Governmental technical standards and regulations are complex and sometimes contradictory; increasing rate of legal challenges; obsolescence of regulations.	Developing flexible standards to accommodate technological and design innovation; regular review and appropriate revision of regulations affecting major technologies.
Reluctance to innovate for fear of legal liability. Conservative approaches intended to reduce potential risks; highly visible and publicized failures are penalized while successes go unrewarded; reluctance of financial institutions to fund infrastructure projects with unusual potential risks.	Risk-sharing to encourage innovation; peer evaluation of innovation; demonstrations of innovation, adequately monitored and documented; dissemination of the findings of the demonstrations to all potential users.
Inadequate organizational management for innovation adoption. Resistance to innovation that did not involve the user in defining the problem and specifying the solution; resistance to change; lack of flexibility in regulations; emphasis on short-term, high-visibility results; tendency to cut funding for "unglamorous" public works programs in favor of more visible programs.	Promote top management commitment; nurture active change agents; empower active technology gatekeepers and technology transfer task forces; comprehensive user training programs; promote Total Quality Management (TQM) of all the processes in innovation and technology transfer; innovative financing of public works projects.

Lack of a Federal Initiative Responsible for Infrastructure Policy and Vision. One of the most critical barriers is the lack of direction at the Federal level to guide the national technology strategy for the nation's public works infrastructure. When such an initiative is created with a sense of responsibility as national catalyst for infrastructure R&D and technology transfer, many barriers could be quickly overcome. Although this will not be a simple task, there are signs of a growing consensus in this direction. Examples include (1) a similar recommendation in a 1991 Office of Technology Assessment report, (2) a recent workshop conducted by the National Science Foundation on civil infrastructure systems research, and (3) growing recognition that revitalization of public works infrastructure must be a top research thrust, as discussed at the National Civil Engineering Research Needs Forum, sponsored by the Civil Engineering Research Foundation. This Federal initiative should ensure a comprehensive and integrated approach to design and construction that eliminates the antagonistic relationships motivated by the present fragmented approach. It would need to develop intergovernmental partnerships with State and local governments to develop improved fiscal and political tools for promoting innovation.

Inadequate Technology Transfer Mechanisms. An inadequate innovation and technology transfer mechanism, which results in the lack of R&D partnerships between the public and private sectors. This barrier creates a vicious cycle: opposition to new ideas or technologies because of a reluctance to try innovative approaches that do not have a proven track record. Overcoming this barrier would require development and support of an effective technology transfer mechanism to bridge the gap between the public and private sectors. Such a mechanism would include elements such as a readily accessible information clearinghouse and other support for diffusion of information among peers.

Lack of Public Awareness. Another key barrier is the lack of public awareness of the impact of national infrastructure on the nation's economy and quality of life. This barrier could be overcome by partnerships with community groups, awareness committees, and support groups. This would include creation of a mechanism to address controversies over innovative approaches. Expert panels, referees, and support for better education related to key technologies and meaningful research are three possibilities. Penetrating this barrier will also require effective communication of the importance of innovation in a national context.

Complexity of Regulations. This barrier includes increasingly stringent Government technical standards and regulation, which frequently result in complex, contradictory, or obsolete regulations that inhibit technological innovation. We recommend that the newly established central entity should consider the integrity of all relevant regulations and simplify them.

Legal Liability. Reluctance to innovate due to fear of liability was a prominent idea both in the literature survey and workshop presentations. The general consensus of the workshop participants was that this reluctance is a major problem, but difficult to attack. A concrete recommendation is not feasible without a central entity responsible for innovation and technology transfer. However, if such an entity takes strong leadership in promoting better integration of laws, regulations, and national needs, this barrier could become less formidable.

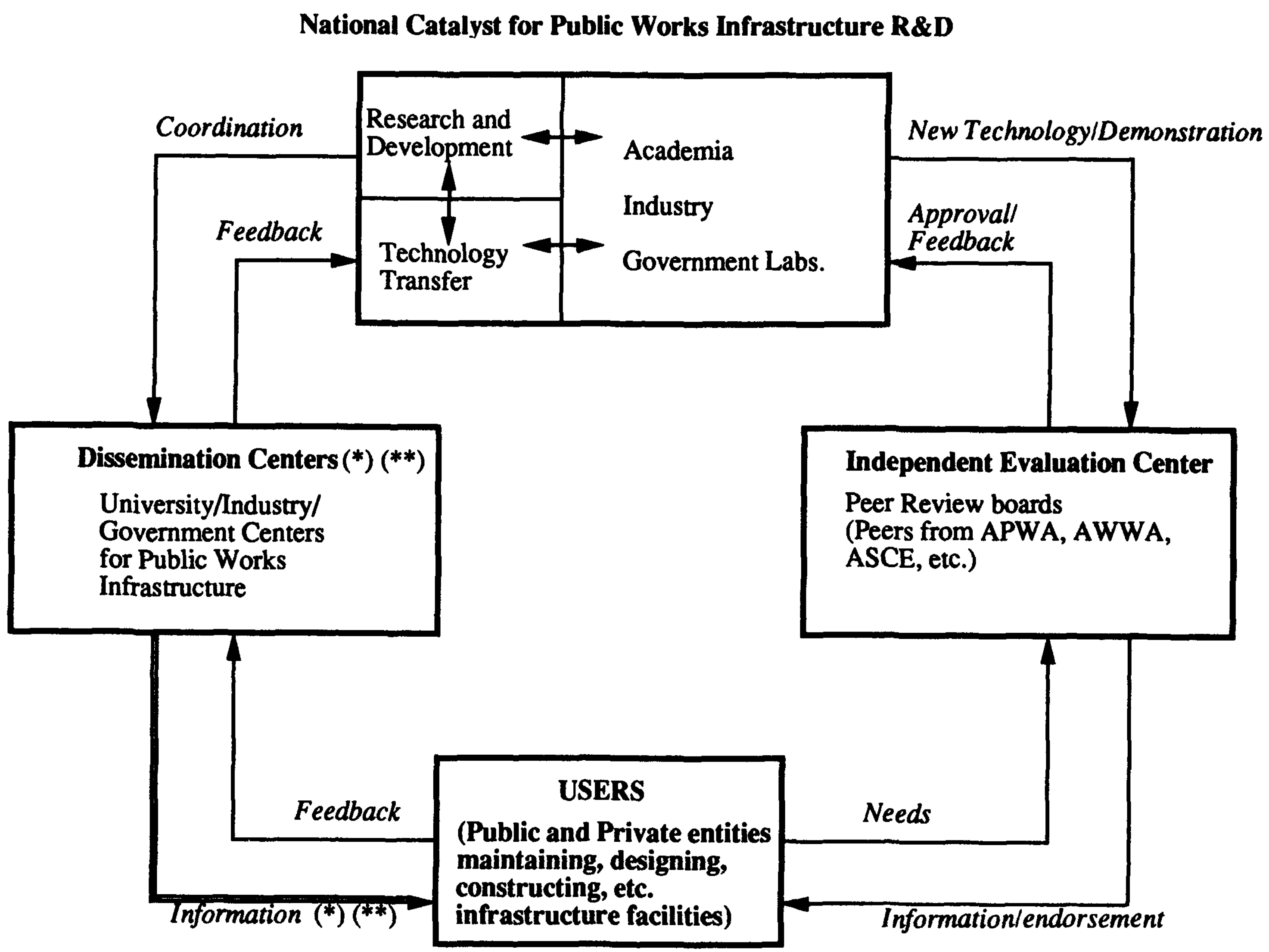
Inadequate Organizational Management for Innovation Adoption. To address inadequate organizational management for promotion and adoption of innovation, a strong effort must be made to promote commitment to innovation and technology transfer among top management in both the public and private sectors. Technology transfer task forces should be established at the organization level, and should include active change agents and technology gatekeepers. Penetrating this barrier will also require the establishment of comprehensive user training programs.

It clear that many obstacles impede the development and application of a nationwide technology transfer process. As mentioned in the literature and by workshop participants, the major barrier is the lack of a national entity or catalyst for R&D and technology transfer for the public works infrastructure. This makes it difficult to effectively identify and respond to the nation's public works needs through R&D. The current approach is fragmented, lacks vision, and suffers from insufficient interdisciplinary cooperation. This fragmentation amounts to a very inefficient use of the nation's R&D resources. Many opportunities for synergy and leveraging of research efforts are missed. In addition, there are strong disincentives to innovation that reduce the possibilities of demonstrating and implementing new technologies. These disincentives include various material and intangible risks incurred by innovators, and a lack of funds to demonstrate, implement, and use innovations.

To understand the approaches required to overcome the numerous barriers, a model was developed to represent an effective approach for developing and implementing a national R&D and technology transfer strategy for the U.S. public works infrastructure. The model, shown in Figure A, is proposed to provide an integrated approach to establish national infrastructure strategy and vision. There is an urgent need for a well planned and consistent strategy for transferring innovation to potential users in the public works infrastructure. This technology transfer effort should help close the gap that exists between providers of new technologies and the agencies responsible for operating and maintaining public works infrastructure. Key elements of the recommended approach are:

1. National Catalyst for Public Works Infrastructure R&D and Technology Transfer
   – A centralized and integrated effort of Government, academia, and private industry to promote coordinated R&D and technology transfer
   – An agency of the Federal Government.
2. Independent Evaluation Center
   – An independent testing and evaluation capability, to promote the demonstration and independent evaluation of innovative technologies
   – Based on peer review by professional scientific, technical, and engineering societies
   – Risk sharing through a formal and credible approval mechanism.
3. Dissemination Centers
   – Cornerstone of a coordinated, aggressive effort to disseminate innovative technologies
   – Facilitator of technology transfer.
4. User Communities
   – Public agencies that design, construct, and maintain public infrastructure facilities
   – Private-sector organizations that work with the public sector or serve functions parallel to those agencies in the private sector.

Longer-term actions should be directed towards constructing a Federal initiative that will have enough nationwide influence to lead R&D and technology transfer efforts for the public works infrastructure. As shown in Figure A this initiative should be responsible for coordinating and managing intermodal (cross-cutting) public works infrastructure R&D and technology transfer, and should assume a leading role in partnerships with university, industry, and Government laboratories. As recommended in the workshop discussions, this Federal catalyst for R&D **should not be a separate new bureaucracy, but should use existing processes, programs, and administrative structures** whenever possible.



(*) Recommended immediate action.
(**) In the long term these dissemination centers will become technology transfer centers, providing not only information on new technologies, but implementation assistance, support, and training.

Figure A. Strategy for Public Works Infrastructure R&D and Technology Transfer (IRTT).

Advancement of a Federal infrastructure initiative can be accomplished by expanding the responsibilities of a number of existing Federal programs. Four options are proposed:

1. Existing institutions such as the Office of Science and Technology Policy (OSTP) could be utilized to manage a Federal infrastructure R&D initiative, while the Federal Coordinating Council for Science, Engineering and Technology (FCCSET) could be used to coordinate it. The FCCSET has been an effective planning tool twords improving the coordination and efficient use of Federal R&D resources. Interagency research and education efforts brought together under FCCSET include the High Performance Computing and Communications, Advanced Materials and Processing, Biotechnology Research, Advanced Manufacturing R&D, and the U.S. Global Change Research Program. Although the FCCSET cannot manage the Federal R&D programs, the OSTP could be empowered to implement the infrastructure R&D policy and vision developed in coordination with the FCCSET. Because the OSTP and FCCSET are components of the Executive Branch, their effectiveness is somewhat limited by the lack of a comparable integrated R&D review process within the Congress. Therefore, if a complementary Congressional review process was introduced into the Office of Technology Assessment and the OSTP and the FCCSET were empowered to plan and coordinate Federal R&D programs, a proactive comprehensive infrastructure initiative could become a reality.

2. The existing framework of the Federal Laboratory Consortium could be used to identify regional R&D centers of expertise for the various infrastructure technologies within the Federal Laboratory community. These laboratories could be empowered to identify and prioritize R&D needs, and develop, evaluate, and demonstrate new infrastructure technologies.

3. A central agency could be assigned to organize and manage the overall initiative. A number of Federal agencies have experience in managing infrastructure related R&D programs that involve partnerships among Government, academia, and industry. Three agencies with cross-cutting multi-discipline infrastructure experience are the National Institute of Standards and Technology, U.S. Army Corps of Engineers (USACE), and the National Science Foundation (NSF). The USACE has experience in directing the Construction Productivity Advancement Research program (CPAR), and the NSF operates the Engineering Research Centers.

4. Another alternative could be a partnership between government bodies, academia, and industry. As proposed in the previous section, major technology transfer assistance could be provided by technology information dissemination centers. These dissemination centers could evolve from being information providers into active facilitators of technology transfer. Their role would be to assist and support the implementation of innovations, including training for the users of the innovative techniques. Currently, Columbia University, MIT, and other prominent research institutions have proposals to develop national infrastructure centers involving a partnership of universities with State and local government entities. These proposals could be the basis for establishing these and other organizations as national facilitators of technology transfer.

There is precedent among the nation's most successful global competitors for such an initiative. Japan's national process for introducing and transferring new technology includes an important role for its Public Works Research Institute, under direction of the Ministry of Construction. That process appears to provide effective coordination for Japan's public works projects.

Major support for a national technology transfer process would be required from an independent evaluation center. Such a center would coordinate peer evaluation of new concepts and demonstration projects. Literature review and workshop participants indicated that the testing and demonstration of new concepts and new technologies are central to a successful technology transfer process. In particular, tests and demonstrations help mitigate risk by proving innovative techniques before they are marketed. The evaluation of tests and demonstrations is much more valuable and credible if performed by independent and well respected experts. The National Academy of Engineering, with active participation of professional associations (such as APWA, AWWA, the American Society of Civil Engineers [ASCE], and the American Society for Testing and Materials [ASTM]) may be a good candidate for the role of independent evaluator.

Dissemination centers would be the means for actively transferring innovations tested and assessed by the independent evaluation center. These dissemination centers should evolve from mere information providers to active facilitators of technology transfer. Their role would be to assist and support the implementation of innovations. This would include training for the users of the innovative methods and technologies. Some universities are known to be interested in establishing similar centers, and have the potential to become national facilitators of technology transfer.

The other key role in a national technology transfer process would be filled by the user communities that design, construct, maintain infrastructure, and renew. This element of the model needs to be very active by communicating its needs and requirements to the independent evaluation center. Users would also need to provide dissemination centers meaningful feedback on the use and delivery of innovative methods and technologies.

Since the scope of the proposed approach is so large, it may take a long time to implement even small elements of it. For example, it would probably require years of major effort by the Federal Government to establish a central R&D catalyst and an independent evaluation center. However, there are a number of short-term goals toward which immediate actions can be taken to begin applying this model for national strategy to promoting innovation in public works infrastructure.

The short-term goal of this approach should be the establishment of dissemination centers, with special attention to the interaction between the centers and the users at the highlighted arrow in Figure A. Research and experience show that much innovative technology developed with public funding is readily available but unknown to potential users. Delivering currently available technologies to appropriate users would produce an immediate benefit for the nation. Efforts toward the short-term goal would include development of an inventory of innovative technologies, and transfer of these technologies via dissemination centers. To accomplish this, it is necessary to develop a model of available technology transfer mechanisms so the process can be facilitated efficiently. A review of available models of the process of innovation diffusion provides insights into various potential approaches. Although these models explicitly address areas beyond the public works infrastructure, they provide important insights on the factors that interfere with or favor innovation adoption. Three models are particularly helpful for understanding innovation adoption and technology transfer: Rogers' pioneering research (1983) in innovation diffusion area, the Shaffer technology transfer model (1985), and the NASA model for delivery or transfer of currently available technology (1991).

The Rogers model is constructed from the perspective of the social scientist studying innovation diffusion as a social activity. Rogers addresses the adoption of innovations both by individuals and organizations. He proposes that there are six major stages in the development of new technology by an individual: (1) recognition of a need to stimulate research activity, (2) development of fundamental scientific knowledge through application of basic research to solve a specific problem, (3) adjustment of the new technology to the specific constraints of its intended users, (4) production, packaging, marketing, and distribution of the technology, (5) adoption or rejection of the technology by users, and (6) assessment of the success of the adopted innovation in meeting the intended need.

Rogers also proposes five stages for how the potential individual user learns about a new technology and applies it in practice: (1) information about the new technology must be available to the potential individual user, (2) the user develops a positive opinion about the new technology, (3) the user adopts the technology, with participation by a change agent in demonstrating the benefits of the new technology, (4) the technology is applied in practice, and (5) the implemented technology is widely adopted or rejected by the user community, depending on its results for the first users.

Rogers asserts that organizations go through different stages than individuals in adopting new technology: (1) the organization continuously seeks innovative methods or technologies that might solve its needs, (2) an identified need is matched with existing innovation, (3) the innovation is reinvented to meet the organization's specific needs, (4) as the innovation is implemented, its applicability and use becomes clear to members of the organization, and (5) the innovation becomes part of the organization's structure.

The Shaffer model (1985) focuses directly on technology transfer, which he defines as the process by which R&D solutions are created and transferred to users to solve technological needs. It is noteworthy that Shaffer's model emphasizes communication with users from the time a problem is identified through the development and implementation of a solution. Shaffer has identified the necessity of responding effectively and efficiently to user needs by proposing a demand-driven R&D process. This model identifies seven different phases: (1) problem identification, (2) survey for existing solutions, (3) research and prototype, (4) test and evaluation, (5) development, (6) decision to adopt, and (7) implementation.

At the Stennis Space Center in Mississippi, NASA developed a six-step model for transferring existing technology to the commercial market: (1) problem identification, classification, and priority, (2) problem and technology matching, (3) market survey, (4) technology demonstration partner identification, (5) technology demonstration, and (6) feedback.

A comparison of the different various steps of the three models is summarized in Table B. These three models are highly similar, but each has a slightly different emphasis. The Rogers model emphasizes the perspective of the organization that desires to adopt the technology. The Shaffer model covers the whole process, from inception of research ideas to the implementation. The NASA model addresses the transfer of existing technology to the commercial market.

Table B: Comparison of Models for Generating and Disseminating Innovation

Categories of Comparison	Rogers Model	Shaffer Model	NASA Model
Identify Need	Seeking new technology for needs of the organization	Problem identification and its communication to research community	Identification, clarification, and prioritization of problems
Survey of Existing Technology	Matching the need with an existing technology	Identify any existing innovations that may be adaptable to user needs.	Matching problems to an existing technology
Basic and Applied R&D	Reinventing an innovation to adjust to the identified need	Research and prototyping	
Market Evaluation			Evaluation of market potential
Test and Evaluation		Test and evaluation	
Technology Demonstration Project Partner Identification			Identifying a demonstration partner
Conduct Technology Demonstration Project	Clarifying applicability to the members of organization		Establishing demonstration projects
Commercialization		Development and refinement	Feedback from demonstrations
Authorization	Use of innovation becomes routine within the organization	Authorization or decision to adopt	
Application		Implementation	

To develop a mechanism for the transfer of currently available innovative technologies, an expanded model that emphasizes delivery is proposed. This model is called the DCAT (Delivery of Currently Available Technology) model, and is displayed in Figure B. It incorporates features of the Rogers, Shaffer, and NASA models.

The DCAT model is enhanced to include the promotion of innovation and existing technology that is not used widely in the public works infrastructure. This model is an attempt to provide detailed steps for integrating related efforts in a way that complements each other to promote the delivery of technologies that are under-utilized or under-recognized.

Step 1 of the proposed model for innovation and technology transfer is to identify, clarify, and prioritize the user's needs. This corresponds to the first step of both the Rogers and Shaffer models. Another element of step 1 is the matching of the need with existing technology. This step is missing from Shaffer's model, but may be considered implicit in the act of problem identification. However, the authors consider it important to include this step as a separate one to highlight the importance of exploiting existing innovation to avoid "reinventing the wheel," which represents a major waste of effort and resources.

As noted above, Step 2 of this model is to adjust any existing innovative method or technology to meet the need clarified in Step 1. This is necessary when a perfectly applicable technology is not already available. This step may require minor changes to an existing technology. If it is necessary to make a major effort to modify the existing technology, the benefit will need to be measured against the cost of the required changes.

Step 3 is to evaluate market potential. It may be advisable to perform this evaluation concurrently with Step 2, because it may not be worthwhile to continue working on adjustment of an existing technology if there is no market potential for doing so. In this context, lack of market potential means lack of potential users of the innovation. This is not to say that basic research is unnecessary, but for public works infrastructure the need to implement appropriately modified existing technologies is more urgent for improving the state of the declining national infrastructure.

Step 4 is to conduct small-scale preliminary testing, either in the research setting or a small number of test sites. For this step, it would be ideal if the independent evaluation center described previously were established to provide independent evaluation and peer review. Assuming that establishment of an evaluation center will take some time, it will be necessary to rely on professional scientific, technical, and engineering societies or potential users for evaluation of innovative technologies.

Step 5 is to identify demonstration partners willing to try to support use of the innovative method or technology. This partner will act as a champion of the new technology—a change agent within the user community.

Step 6 is to clarify and refine the innovation or technology to satisfy the needs of the potential user.

Step 7 is to establish demonstration projects using information collected in Steps 5 and 6. The size of the demonstration will depend on the estimated benefits of the new technology. The greater the expected benefits, the larger the scale of the demonstration should be to credibly prove the technology, so it will be more widely distributed and accepted.

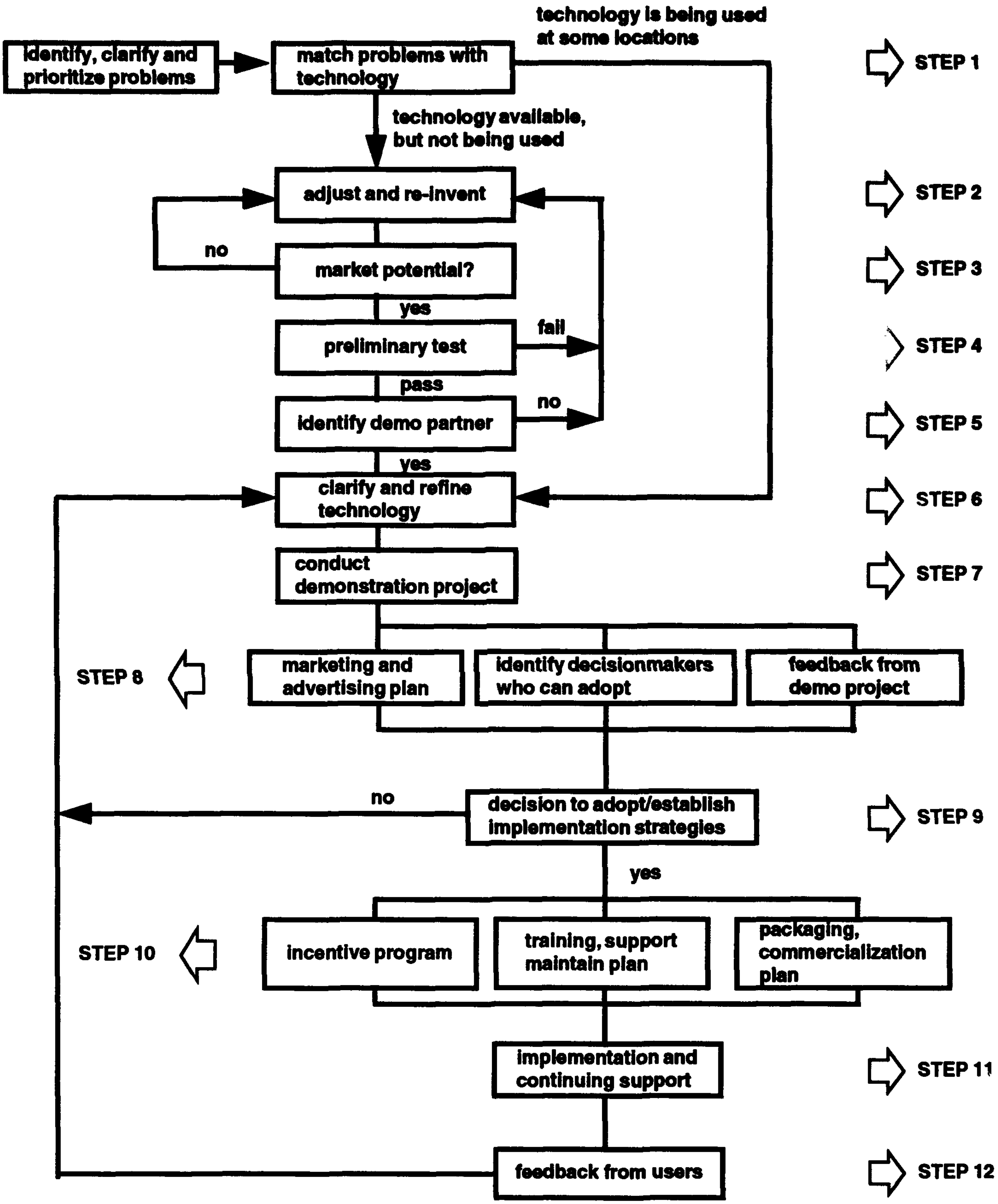


Figure B. Proposed Mechanism for Delivery of Current Available Technology (DCAT).

Step 8 is to develop a marketing communications plan for the new technology once the demonstration projects are going well and have good support from the demonstration partners. To ensure successful delivery of the innovative technology, it is very important to communicate the availability of the product to potential users. Good commercial products can fail due to inadequate marketing communications. Another element of Step 8 is to develop plans to identify and communicate with key decisionmakers. This step can be considered part of the marketing process, but it was separated to highlight the importance of recognizing the impact of these decisionmakers on the adoption of new technology. These decisionmakers are often political appointees or elected officials who tend to value short-term, high-visibility results. To convince key decisionmakers to support a new technology, it is necessary to help make them aware of it or support changes in their current performance standards to put more importance on achieving long-term benefits. A third element of Step 8 is to collect feedback from users at demonstration sites to identify potential problems and develop suitable processes to transfer the technology.

Step 9 involves adopting the technology and developing implementation strategies. Rogers called this step *routinizing*. To routinize, it is necessary to establish effective implementation strategies. Without this step, a new technology will not be used routinely.

Step 10 is to develop incentives for using the technology. These incentives can be designed for use at various levels. For example, Federal, State and local governments could offer tax incentives and low-interest loans, while private companies could establish suitable programs to encourage employees to use the new technology. A second element of Step 10 is to develop a training, support, and maintenance plan for the new technology. A third element of Step 10 is to develop a packaging and commercialization plan to enhance delivery to the user community at large.

Step 11 is to implement and provide continuing support of the new technology.

Step 12 is to collect feedback from users periodically and improve the technology as required by user needs.

Application of this model as a mechanism to deliver currently available innovative methods and technologies for public works infrastructure will greatly facilitate technology transfer, and wider use of Government-sponsored R&D products. To support the DCAT mechanism, dissemination centers should be established for various infrastructure areas, such as: (1) highways and bridges, (2) mass transit, (3) aviation, (4) water supply, (5) water resources, (6) solid waste, (7) hazardous waste, (8) communications, (9) power and energy, and (10) public buildings. Each center could immediately start collecting updated information on user needs and potentially applicable technologies that already exist, then develop improved processes for delivering it to potential users. An effective way to communicate information on available technologies to appropriate potential users may be through development of computer-based information systems containing information on available technologies not currently in wide use by public works entities. Improved on-line access to this type of information could alleviate one of the barriers identified at the workshop by Nowak—the scarcity or unavailability of information about pertinent innovations. Each center could be located at universities, Government research centers, or private industry partners, but good coordination would be necessary to continuously collect all available information on innovative methods and technologies. Strong coordination will also be necessary for uniform adoption of the 12-step DCAT process as appropriate.

The authors are confident that technology dissemination centers, as described in this report, will be highly successful in delivering available technologies to potential users by following the 12 steps outlined in Figure B.

The main body of this report (Volume 1) compiles and summarizes expert knowledge on the subject of barriers to innovation and technology transfer in the public works infrastructure. Major barriers that hinder the application of innovation in practice are identified and prioritized. Recommendations are provided to assist in developing a national strategy for promoting the use of innovative methods and technologies in public works infrastructure and to help quickly deliver currently available—but not well distributed—technologies to appropriate users.

CHALLENGES AND OPPORTUNITIES FOR INNOVATION IN THE PUBLIC WORKS INFRASTRUCTURE: VOLUME 1 – LITERATURE SURVEY, WORKSHOP SUMMARY, AND RECOMMENDATIONS

1 INTRODUCTION

The U.S. public works infrastructure provides an essential platform for most of the nation's social, economic, and political activities. The central role of the public works infrastructure, and the realization of the need to adequately maintain it, is highlighted by much-publicized infrastructure failures. A recent and costly example is the "flood" that brought political and economic life to a virtual halt in downtown Chicago. Part of an obsolete underground transportation system, now used as a path for communications and power lines throughout the Loop, collapsed and became flooded by the Chicago River. Critical infrastructure systems and facilities were damaged or rendered inoperable. Subway lines, streets, and numerous public and private buildings were shut down for days or weeks, dramatically affecting all aspects of life in the city. By estimates that are still not complete, the damage so far is valued at $1 billion. The disruption of normal activities in some areas was expected to continue for weeks or months. This event, while unique in magnitude, highlights the central role of the infrastructure to everyday life.

Although essential to the nation's health, the public works infrastructure has not received adequate attention in recent years. This is clearly illustrated by the decline of investment in public works—from almost 4 percent of the Gross National Product (GNP) in the mid-1960s to less than 3 percent in 1985.[1] If this trend continues, a public works infrastructure barely sufficient to meet current needs will fail in performing its function. This failure will become a serious drag on economic prosperity and drive down the nation's basic quality of life. For example, traffic congestion in major U.S. cities cost the nation an estimated $30 billion annually.[2]

The 1980s were an important decade for the realization of the severe problems that affect the nation's public works infrastructure, and for the building of a consensus to address these problems. In the early 1980s, several studies brought to public attention important and timely concerns about the health of various infrastructure systems and facilities.[3,4] These and other initial studies were followed by interest from different sectors. This interest developed into a general consensus on the magnitude of the problem, resulting in reports of national scope proposing much-needed corrective actions (and the initiation of a few of these proposed actions.)[5,6,7] The effort to build momentum for action has continued into the 1990s.[8,9]

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1 "Fragile Foundations," National Council on Public Works Improvement (February 1988).

2 "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

3 "America's Infrastructure—A Plan to Rebuild," Associated General Contractors of America (Washington, DC, 1983).

4 Choate, P., and S. Walter, "America in Ruins: Beyond the Public Works Pork Barrel," Council of State Planning Agencies (Washington, DC, 1981).

5 "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

6 "Fragile Foundations," National Council on Public Works Improvement (February 1988).

7 "Construction and Materials Research and Development for the Nation's Public Works," Office of Technology Assessment (June 1987).

8 "Transferring Research into Practice: Lessons from Japan's Construction Industry," Civil Engineering Research Foundation, Japan International Research Task Force (November 1991).

9 "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

One of the key recommendations for enhancing the condition of the public works infrastructure is to encourage the utilization of new technologies.[10,11,12] Technology and innovation can play a major role in extending the life of public works facilities and substantially lowering their costs. A recent report by the Congressional Office of Technology Assessment (OTA) emphasizes that no Federal agency has focused on R&D programs to make public works agencies more productive and cost effective.[13] This report also pointed out that State and local public works agencies benefit from R&D products only after a very long process of development, evaluation, and modification. This length of time, coupled with the lack of investment in public works R&D, make this area unattractive for researchers. The result is a large gap between infrastructure needs and R&D to address those needs. This report responds to the need to fill these gaps through an attempt to identify (1) the obstacles that challenge the successful generation and dissemination of innovative technologies, and (2) the opportunities that exist to promote innovation in the construction, management, and sustainment of the public works infrastructure.

The term *innovation* in this report is used with broad meaning. A successful innovation is defined as a product, process, or procedure introduced into the marketplace to significantly reduce cost or time, to improve quality, or to increase service to the public. Innovation can originate from a variety of sources, such as public or private R&D centers. Another important source of innovation originates in actual practice—practitioners in the field often develop innovative solutions to the problems they identify. Areas of innovation are as varied as the problem areas that exist in practice, including management, standards, products, materials, methods, and finance. Furthermore, innovation is relative to the potential user. Anything that is new to the potential user is considered an innovation, even if it has existed unused on the shelf for many years.

In this report, the term *public works infrastructure* is also used with broad meaning. The authors define public works infrastructure as any system under public responsibility to provide support for transportation (highway, rail, waterways, air, etc.), water supply and distribution, power generation and delivery, communications, and waste collection, treatment, and disposal. Public works infrastructure also includes environmental remediation services, since infrastructure is inseparable from the environment into which it is integrated.

Although it is difficult to estimate with certainty the impact innovation could have in rendering the public works infrastructure more efficient and effective, there are numbers that hint at the potential that exists. The California Department of Transportation has concluded that cost savings directly attributable to R&D products in practice total between 2.8 and 5.4 times the amount invested in R&D.[14] The return on R&D investment for selected innovations successfully adopted into daily use by the Army amounts to $37 for each dollar invested in the R&D phase of these products.[15] It is clear that innovation can have a dramatic impact in reducing the effort and resources required to build and maintain the public works infrastructure.

However, the United States is not taking advantage of the full potential benefit of innovation. Comparisons with other industrialized nations have been made in some areas of research spending.

10 "Transferring Research into Practice: Lessons from Japan's Construction Industry," Civil Engineering Research Foundation, Japan International Research Task Force (November 1991).

11 "Fragile Foundations," National Council on Public Works Improvement (February 1988).

12 "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

13 "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

14 "Report of Facility Research Accomplishments," California Department of Transportation (February 1987).

15 Shaffer, L.R., "Research and Technology," Constructor (February 1992).

Figures provided by the American Road and Transportation Builders Association (ARTBA) indicated in 1989 a U.S. commitment of $2 million for research on intelligent vehicle and highway systems, compared to a $750 million investment in Europe and $700 million in Japan.[16] In addition to the fundamental lack of investment, there is a problem transferring any innovations that *are* developed into practice. The rate at which innovations are adopted in the United States is very slow, with more than 20 years required in many cases to reach most users.

This report consists of two volumes. Volume 1 summarizes the challenges and opportunities for innovation in the public works infrastructure identified through an extensive literature survey. This literature survey addressed (1) specific barriers and potential challenges for innovation in the public works infrastructure and (2) recognized models of the process of generating and adopting innovations. Additionally, Volume 1 includes the authors' recommendations for overcoming the challenges and effectively exploiting the opportunities to promote innovation in the construction, management, and sustainment of the public works infrastructure.

Volume 2 of this report consists of the proceedings and working group discussions of a workshop held on 3-4 March 1992 at the U.S. Army Construction Engineering Research Laboratories (USACERL) to discuss the promotion of innovation in the public works infrastructure.

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[16] "Transportation Infrastructure." Panelists' remarks at "New Directions in Surface Transportation" Seminar, United States General Accounting Office (December 1989).

2 BARRIERS TO INNOVATION

This chapter reviews literature that focuses on barriers and potential opportunities for innovation in the public works infrastructure. The wide diversity of barriers and opportunities identified in the literature indicates that this topic may be approached from many different perspectives, with different focuses. This report classifies the identified barriers and opportunities in a manner parallel to the approach used in the National Research Council report, "Infrastructure for the 21st Century."[17] Seven categories are addressed:

1. Cultural values and social perception—the way society's values and perceptions affect infrastructure and the ability to innovate.

2. Governmental structure and regulations—the three levels of government (Federal, State, and local) responsible for public works infrastructure influence innovation through their structure and regulations.

3. Risk and liability—the major disincentives to the adoption of innovation.

4. Public and private partnership—a synergy that can foster innovation.

5. Funding—financial barriers and opportunities that substantially affect innovation in the public works infrastructure.

6. Size and type of infrastructure projects—how the unique aspects of infrastructure facilities can affect innovation.

7. Education, research, and technology transfer—issues related to the training and education of public works leaders and personnel, the development of innovations through R&D, and the transfer of those innovations into practice.

The literature describes many barriers to and opportunities for innovations. This report identifies a cross-section of the perspectives most important and pertinent to the area of public works infrastructure.

A summary of the most pertinent barriers identified in the literature, and suggested methods for overcoming them are shown in Table 1. Discussion of each category follows.

[17] "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

Table 1

Barriers to Innovation and Possible Methods to Overcome Them

1. CULTURAL VALUES AND SOCIAL PERCEPTION

Barriers

Conflict With Values. Rejection of technologies discordant with widespread cultural values (e.g., tendency of "throwaway society" to favor disposal over recycling).

Foreign Ideas. Misplaced civic pride—the "not invented here" syndrome. The reluctance to adopt new ideas that originate in other countries.

User Involvement. Resistance to innovation not involving the user in defining the problem and specifying the solution.

Traditional Culture. Fundamental cultural world-views (e.g., oriental culture's profound emphasis on long-term perspectives as opposed to western culture's increased emphasis on short-term benefits to society rather than long-term goals.

Organizational Inertia. Resistance to the "trauma" of change, "comfort" of the *status quo*, limited resources for change, lack of flexibility in regulations.

Lack of Public Awareness. Public is uninformed about infrastructure and its contribution to daily life and the economy.

Public Opposition. Disagreement on the value of a particular innovation by experts or interest groups (e.g., opposition to fluoridation of water by some scientists and citizens).

Methods to Overcome

- *Adopt innovations compatible with widespread values and perceptions.*
- *Create centers for dissemination of innovation.*
- *Frame public dialogue about innovation in a national context rather than associating it with specific regions or localities.*
- *Implement comprehensive user-training programs, conducted by professionals.*
- *Launch public awareness programs to explain the benefits of long-term planning.*
- *Foster "change agents" to champion innovative technologies.*
- *Foster public awareness through basic and continuing education programs.*
- *Pursue active partnership with community groups in capital development programs for infrastructure.*
- *Create mechanisms to resolve controversy over innovation (e.g., expert panels, referees).*

2. GOVERNMENTAL STRUCTURE AND REGULATIONS

Barriers

Diversity of Interests. With more than 80,000 local governments responsible for infrastructure, developing a research agenda with a broad impact is difficult.

Lack of Facility Standardization. Inhibits large sales volumes, which is a disincentive for the private sector to innovate.

Regulatory Constraints on Local Government. Funding and procurement by local governments is regulated by Federal and State governments, often making the process unnecessarily inflexible.

Contracting and Low-Bid Requirements. Discourages innovation in the procurement of goods and services, and restricts flexibility of innovative contractual approaches.

Table 1 (Cont'd)

Complexity of Regulations. Regulations are complex and sometimes contradictory, which often leads to an increase in litigation related to innovation.

Obsolescence of Regulations. Codes regulating major technologies may not keep up with advances in those technologies, often inhibiting innovation.

Lack of Profit Motive in Public Sector. Private business innovates to increase profits, so there is an incentive for risk. Public agencies have no mission to make a profit, so they have no financial incentive to innovate, but must visibly assume responsibility for failed innovations.

Migration to Private Sector. Skilled Government personnel capable of implementing and managing innovation are continuously moving into the private sector seeking higher wages.

Political Agendas. Frequent emphasis on short-term, high-visibility results by elected officials, compounded by lack of continuity of elected officials directly responsible for public works infrastructure.

Methods to Overcome

- *Implement diffusion networks to effectively communicate innovations among public works agencies.*
- *Standardize facility regulations that encourage quality improvement though economies of scale.*
- *Form intergovernmental partnership to help State and local governments to develop better fiscal and political tools for promoting innovation.*
- *Promote a life-cycle costing perspective to competitive bidding.*
- *Develop performance-based specifications that allow innovation in the designed solutions.*
- *Require policymakers to clarify and simplify regulations, and resolve conflicts between regulations.*
- *Require periodic review and revision of regulations that affect major technologies.*
- *Foster organizational cultures that are compatible with change, and train personnel to understand the importance of innovating.*
- *Make the public sector workplace more challenging by encouraging innovation, and introduce monetary awards for success.*
- *Performance appraisal of politically elected officials to reflect their accomplishments in implementing long-term infrastructure strategy.*

3. RISK AND LIABILITY

Barriers

Fear of Liability. Public works agencies, designers, contractors and financial institutions resort to conservative approaches to reduce potential risk.

Cost Controls. Rigid cost controls help reduce cost overruns, but can discourage the adoption of innovations for fear of incurring cost overruns.

Consequences of Failure. Failures are highly visible while successes often go unnoticed. Government agencies are more likely to penalize failed innovation than to reward successful ones.

Reluctant Lenders. Financial institutions are reluctant to fund public works with significant risks (e.g., environmental projects where regulations and scientific knowledge change rapidly).

Inadequate Demonstration. Risk aversion makes it difficult to set up field demonstrations, resulting in a vicious cycle of opposition to innovation due to reluctance to try innovations without any track record.

Table 1 (Cont'd)

Methods to Overcome ■ *Test and evaluate innovations by neutral organizations to ensure public safety and acceptance.* ■ *Implement risk-sharing analysis techniques to determine a balanced and fair distribution of risk for all participants (designer, public works agency, manufacturer, contractor, etc.).* ■ *Formulate Federal policies for technical evaluation that guarantee benefits of innovation.* ■ *Provide incentives for successful innovators (e.g., cash awards, publish reports on successes, etc.).* ■ *Share financial risks between lender and Government.* ■ *Promote thorough demonstrations and test projects to prove effectiveness of innovation, then encourage implementation in other similar applications.* ■ *Offer low-interest loans, tax incentives, and advantageous terms on Government contracts to make R&D more potentially profitable to the private sector.*
4. LACK OF PUBLIC AND PRIVATE PARTNERSHIPS ***Barriers*** **Lack of Partnerships Between Public and Private Sectors.** Opportunities for synergy and leveraging of resources are being missed. **Lack of Leadership.** Government is not taking the lead to promote partnerships with academia and private industry. **Lack of Incentives.** Potential partners have few compelling reasons to cooperate.
Methods to Overcome ■ *Create incentives for cooperation among Government, academia, and private business.* ■ *Build consensus about technological needs common to all members of user community.*
5. FUNDING ***Barriers*** **Capital Development.** Much of the public works infrastructure is administered by local governments, but they typically do not have the fiscal power to generate the funding required to apply innovative techniques. **Scarcity of Funds.** Severe budget constraints are aggravated because public works programs are frequent candidates for budget cuts in favor of other more visible programs.
Methods to Overcome ■ *Encourage funding innovations, such as special financing districts, exactions (required contribution to a public jurisdiction by developers or owners), independent public corporations to finance, construct, and operate public works facilities, and public/private partnerships.* ■ *Consider partial or total privatization of some areas in infrastructure development or management.* ■ *Empower local governments to generate funding in proportion to their level of responsibility.*

Table 1 (Cont'd)

6. SIZE AND TYPE OF INFRASTRUCTURE PROJECTS

Barriers

Cost. Extreme size, area, or required lifespan of facilities make innovation difficult or expensive.

Flexibility Concerns. Infrastructure has not been designed with expansion or changing needs in mind.

Quantification of Benefits. Lack of knowledge about expected costs and benefits because of uniqueness or complexity of infrastructure facility.

Methods to Overcome

- *Develop standardized but flexible approaches to construction based on regional needs.*
- *Conceive and develop public works infrastructure with more focus on flexibility, expandability, and innovation.*
- *Quantify expected costs and benefits of innovation on unique projects through a well designed innovation demonstration program.*

7. EDUCATION, RESEARCH, AND TECHNOLOGY TRANSFER

Barriers

Lack of Training. Low national priority on education and training for infrastructure construction, management, and sustainment.

Fragmented R&D. Little coordination among various public and private organizations conducting infrastructure R&D in relative isolation, and addressing relatively narrow concerns.

Technology Transfer Gap. Academic and Government research centers fail to widely disseminate their products to public works agencies.

Lack of Incentives. Little incentive to promote R&D efforts focused on support of local government infrastructure issues.

Methods to Overcome

- Create a national agenda for R&D in public works infrastructure area to promote better use of R&D funds.
- Promote strong university programs and student interest in infrastructure engineering and technology.
- Promote infrastructure R&D that addresses integrated (cross-cutting) issues (e.g., Federal effort to identify new technologies that offer best potential return on investment, strategies to develop and widely implement beneficial new technologies).
- Adopt innovations from other sectors (e.g., manufacturing, aerospace) into design, construction, and operation of public works.
- Develop effective technology transfer mechanisms and commit the necessary resources to support these mechanisms (e.g., peer diffusion, accessible, comprehensive information clearinghouse).
- Purchase innovations developed overseas and adapt to U.S. needs.
- Develop incentives to encourage greater R&D investment by the private sector.

Cultural Values and Social Perception

New technologies that are in conflict with widespread values or perceptions have much more difficulty being adopted. For example, there is a historical tendency for Americans to favor disposal over recycling. Although this attitude is changing, it still interferes with the adoption of innovations based on reuse (maintenance, repair, recycling, etc.) rather than new construction.[18] Another cultural factor that can interfere with the adoption of new technologies is civic pride.[19] Sometimes referred as the "not invented here" syndrome, civic pride can produce a reluctance to adopt new ideas that originate in other countries. This can be compounded by the reluctance of public works officials to adopt innovations in which they did not participate in defining the problem or specifying the solution.[20]

In comparison with western culture, oriental cultures are more inclined to accept short-term hardships to bring long-term benefits. In oriental nations this cultural value clearly promotes investment in new technologies, even when short-term payoffs are not expected.[21] In contrast, the United States and other western nations tend to consider the short-term payoff at least as important as long-term benefits.

Organization theory shows that every social organization includes elements that oppose change and cause organizational inertia. These include resistance to the trauma (real or perceived) of change, vested interest in the *status quo,* limited resources devoted to innovation, lack of flexibility in procedures or regulations. These factors can originate from within a public works agency or within a community facing possible change.

Another factor that interferes with innovation is the lack of public awareness. The public is generally uninformed about the infrastructure and its central role in the nation's economy and quality of life. Public awareness usually comes only from the painful experience of infrastructure failures (water shortages and boil orders resulting from the rupture of water mains, traffic gridlock due to road failure, etc.). This lack of public awareness is detrimental to innovation in the construction, management, and sustainment of the public works infrastructure. Public support is essential to secure adequate funding for new construction and maintenance of infrastructure facilities.[22] Public support can also be very valuable for securing funds for R&D and the adoption of innovative technologies.

Sometimes, however, the public is aware of a proposed change, but opposed to it. Public infrastructure projects, like most other public projects, have high visibility. Also, they are often more controversial than private projects, frequently involving public debates and litigation.[23] Public agencies in charge of managing infrastructure projects are often reluctant to incorporate new ideas because of this high visibility and potential public controversy. Controversy can take different forms, such as experts disagreeing on the value of a particular innovation or interest groups challenging the Government on a project's benefits. Innovations publicly perceived to adversely affect a community's quality of life are especially prone to controversy. An example that clearly illustrates how public perception of an innovation can delay its implementation is the fluoridation of water supplies. Although it was recognized for many years that water fluoridation is an effective way to prevent tooth decay, its widespread implementation took several years and much effort. The blocking of this innovation is attributed by Little

18 "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

19 "Dynamic Technology Transfer and Utilization: The Key to Progressive Public Works Management," American Public Works Association, Editors: Cohn, M.M., and M.J. Manning (1974).

20 Zaltman, G., and R. Duncan, "Strategies for Planned Change," John Wiley and Sons (1977).

21 "Transferring Research into Practice: Lessons from Japan's Construction Industry," Civil Engineering Research Foundation, Japan International Research Task Force (November 1991).

22 "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

23 Sweet, J., "Legal Aspects of Architecture, Engineering, and the Construction Process," West Publishing Company (1985).

to community feelings that the solution was imposed on the public by the Government without adequate explanation or discussion.[24] Also, opponents of this innovation included anti-fluoridation scientists. In any case, public works innovations that might be perceived to compromise a community's quality of life are very likely to face intense opposition from both the public and political leaders.

Cultural and social obstacles to innovation in the public works infrastructure can be addressed in several ways. As noted by Rogers, it is easier to adopt innovations compatible with existing cultural values and perceptions. Also, in order to overcome the social and organizational inertia thwarting innovation, a catalyst (also called a *change agent* [by Rogers] or *champion* [by Tatum]) is instrumental.[25]

There are examples of successful building of public support for public works infrastructure. The city of Phoenix, AZ, has repeatedly been successful in securing public support for bond issues that finance public works projects. The key to this support is the existence since 1957 of a citizens' bond committee representing a cross-section of the population. This committee is instrumental in communicating needs to the public, securing public support for bond issues, and monitoring spending of the monies raised.[26] An alternative approach, used successfully in other communities, is the active involvement of community groups in the capital development program. Participating groups actively help define the short- and long-term requirements of the community, promote public awareness, and build support for infrastructure issues.[27] Both approaches have been shown to be successful in helping to manage controversy and opposition to innovation. Another approach, proposed by the National Research Council, is to address existing controversies through the creation of special resolution mechanisms, such as expert panels, referees, etc.[28]

Governmental Structure and Regulations

The management of the public works infrastructure involves all levels of government: Federal, State, and local. The public works user community, consisting of more than 80,000 local government units, is clearly a diverse and fragmented group. Diversity in terms of size, needs, goals, etc., is a major obstacle in developing a research agenda of national scope and broad impact.[29,30,31] One example is the lack of attention, until recently, to intermodal transportation R&D.[32,33] Another obstacle to innovation arising from this fragmentation is the lack of standardized facility design. The lack of standards suppresses sales volume, which removes a major incentive for private-sector suppliers to innovate.[34]

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[24] "Factors Relating to the Implementation and Diffusion of New Technologies: A Pilot Study," Arthur D. Little, Inc. (Vols I, II, and III, Cambridge, MA, 1979).

[25] "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

[26] "Good Practices in Public Works," American Public Works Association Research Foundation (1988).

[27] "Good Practices in Public Works," American Public Works Association Research Foundation (1988).

[28] "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

[29] Feller, I., and P.E. Flanary, "Diffusion and Utilization of Scientific and Technological Knowledge Within State and Local Governments," National Aeronautics and Space Administration (January 1979).

[30] "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

[31] "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

[32] "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

[33] Prendergast, J., "A New Era in Transportation," Civil Engineering, American Society of Civil Engineers (New York, April 1992).

[34] "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

The fragmented responsibility for the public works infrastructure is compounded by the regulatory constraints affecting local governments. The administrative tools that local governments can use to procure innovation—funding mechanisms, procurement procedures, contracting, etc.—are controlled and regulated by the Federal and state governments.[35] Although controls are justifiable from many perspectives, they unintentionally inhibit the flexibility that local governments require to take advantage of innovation. OTA describes the distance that exists between Congress and public works entities regulated by its legislation, illustrated by the effort and time necessary to reverse adverse sections of 1986 tax legislation that limited the revenue-raising ability of local public works entities.

Some Government regulations, such as requirements of competitive bidding or the low-bid approach, impose constraints on innovation. While the low-bid approach for procurement at all Government levels has effectively helped to maintain fairness and discourage corruption, it can be an obstacle to procuring innovations from private suppliers.[36] As in the case of low-bid procurement, public agencies are also regulated in the selection of design professionals. This restricts the flexibility to apply innovative contractual approaches that have been successfully used in the private sector to address stringent project requirements.[37]

The increased complexity of governmental standards and regulations pertaining to the infrastructure itself can also hinder the ability to adopt innovation. This is a problem particularly when environmental standards and regulations are involved. The fragmentation of the regulatory responsibility sometimes is extreme, and even contradictory. For example, communities are often required to comply with the codes and standards of many overlapping jurisdictional authorities.[38] Another problem is the increasing rate at which regulations are challenged in court. For instance, about 80 percent of proposed U.S. Environmental Protection Agency (USEPA) standards go through litigation.[39]

The ability to innovate can be also affected by Government regulation of systems for which key technologies have been in steady use for a considerable time. These codes and regulations can easily become obsolete as the technology advances. Obsolete regulations may, in turn, interfere with the application of innovations if those regulations are not reviewed and revised on a timely basis.[40]

Another challenge hindering innovation in the public works infrastructure is the absence of a profit motive. Private entities have compelling financial reasons to continuously enhance their efficiency. Innovation is viewed as a tool for increasing profits through productivity improvements. Also, rewards for successful innovation in the private sector directly benefit the innovators as well as their employer, but the consequences of unsuccessful innovations are normally shared across all managerial levels. Neither public-sector agencies, nor their individual employees, historically have had a similar motivation to innovate. Public-sector agencies have not provided a risk-sharing atmosphere. In the public sector, successes tend to be shared with external players (e.g., elected officials, legislative bodies), but the consequences of unsuccessful decisions are localized to those who propose them. The result in governmental bodies is a disincentive to search for innovative techniques for maximizing efficiency.[41]

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35 "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

36 "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

37 Sweet, J., "Legal Aspects of Architecture, Engineering, and the Construction Process," West Publishing Company (1985).

38 "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

39 "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

40 "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

41 Feller, I., and P.E. Flanary, "Diffusion and Utilization of Scientific and Technological Knowledge Within State and Local Governments," National Aeronautics and Space Administration (January 1979).

Another problem is the constant migration of skilled workers from the public sector to the private sector in search of higher wages.[42] This is creating a serious shortage of public-sector personnel with the skill and knowledge to implement and manage innovation. Unlike common practice in the private sector, public works agencies provide little training for personnel to encourage recognition and successful use of innovations. This also creates difficulty in public works agencies to develop consensus on which innovative technologies offer the most potential benefit.[43]

Another barrier to innovation arises from the political nature of many public works administrative positions. The management of the public works infrastructure can be affected by the political agendas of elected officials. A consequence of this is an emphasis on short-term, high-visibility results.[44] This neglect of the long-term perspective is compounded by the lack of continuity within elective offices directly responsible for the public works infrastructure.[45] These conditions can inhibit investment in innovations that may have a relatively long payback period.

One way to address these problems suggested by OTA is to promote intergovernmental partnerships to coordinate infrastructure R&D.[46] An important goal of intergovernmental partnership should be to help State and local governments develop better fiscal and political tools for promoting innovation. It is especially important to allow local governments to develop innovative alternatives to obtain funding for public works projects.

Federal leadership is essential for the establishment of intergovernmental partnerships. As noted by Bernstein, there is no central national agency to focus R&D and transfer innovation into the field.[47] A study by CERF of Japan's success in incorporating innovations into construction practice found that a major factor is strong leadership in promoting and implementing innovation by government agencies such as the Ministry of Construction.[48] Key ingredients of Japan's government leadership role include the following:

1. Development of a bold vision for the future to address problems of serious national concern,
2. Identification of major research issues that must be addressed to reach the proposed vision,
3. Establishment of a partnership among government agencies, private business, and academia to develop and implement innovations contributing to fulfillment of the vision,
4. Clear definition of the government's role (e.g., financial, technical),
5. Coupling innovation and regulatory policy to reduce the potential liability of innovators,
6. Development of national strategies to transfer innovations into practice.

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42 "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

43 "Delivering the Goods: Public Works Technologies, Management, and Financing." Office of Technology Assessment (April 1991).

44 Feller, I., and Flanary, P. E., "Diffusion and Utilization of Scientific and Technological Knowledge Within State and Local Governments," National Aeronautics and Space Administration (January 1979).

45 Feller, I., and Flanary, P. E., "Diffusion and Utilization of Scientific and Technological Knowledge Within State and Local Governments," National Aeronautics and Space Administration (January 1979).

46 "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

47 Bernstein, H. M., "Is Innovative Engineering Becoming Extinct in the U.S.?," American Consulting Engineer (Vol 2, No. 4, 1991).

48 "Transferring Research into Practice: Lessons from Japan's Construction Industry," Civil Engineering Research Foundation, Japan International Research Task Force (November 1991).

The leadership role of the government in Japan is also very important in addressing national crises. For example, Japan's government acts as a catalyst to focus innovation and research on specific national emergencies, such as the energy crisis.

Leadership by Japan's central government is an essential part of that nation's success in innovation, but the process of innovation in Japan's public works infrastructure involves other important players. As shown in Figure 1, academia (through representation at the public works research center) and private industry are also essential to the process. This partnership reduces risk for all participants and offers incentives for private companies (e.g., tax incentives, low-interest loans). An important ingredient of Japan's national innovation transfer process is evaluation of R&D products by a neutral organization to ensure public safety and acceptance.[49]

Innovation at all Government levels can also be fostered by developing an organizational culture that encourages innovation. Personnel must be trained to understand, implement, and manage innovative ideas. A partnership between the State of Tennessee and its land grant university offers one example of how training can be effectively promoted.[50] Collins provides examples of innovation at the field level, promoted by an attitude that encourages developing imaginative solutions to everyday problems.[51] APWA has also documented the benefits of positive organizational attitudes toward innovation. Findings indicate that innovation is promoted in public works agencies where there is a recognition of the value of new technologies as problem solvers and as solutions to broad challenges.[52]

The fostering of a positive organizational attitude toward innovation must be accompanied by ensuring organizational *compatibility* with change. This requires effective communication channels, authority patterns, rules, and procedures that facilitate the adoption and use of new technologies. It is crucial to minimize potential conflicts arising from innovation (e.g., competitiveness between work groups) and to reward innovation at all organizational levels.[53] As previously noted, successful transfer of innovation often is driven by a champion of the innovation within the organization. The National Research Council recommends supporting these champions with funding, training, and awards.[54]

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[49] "Transferring Research into Practice: Lessons from Japan's Construction Industry," Civil Engineering Research Foundation, Japan International Research Task Force (November 1991).

[50] "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

[51] Collins, W. A., "Innovation: The Key to Local Roads Survival," Engineering 21st Century Highways, ASCE (1988).

[52] "Dynamic Technology Transfer and Utilization: The Key to Progressive Public Works Management," American Public Works Association, Editors: Cohn, M.M., and M.J. Manning (1974).

[53] Zaltman, G., and R. Duncan, "Strategies for Planned Change," John Wiley and Sons (1977).

[54] "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

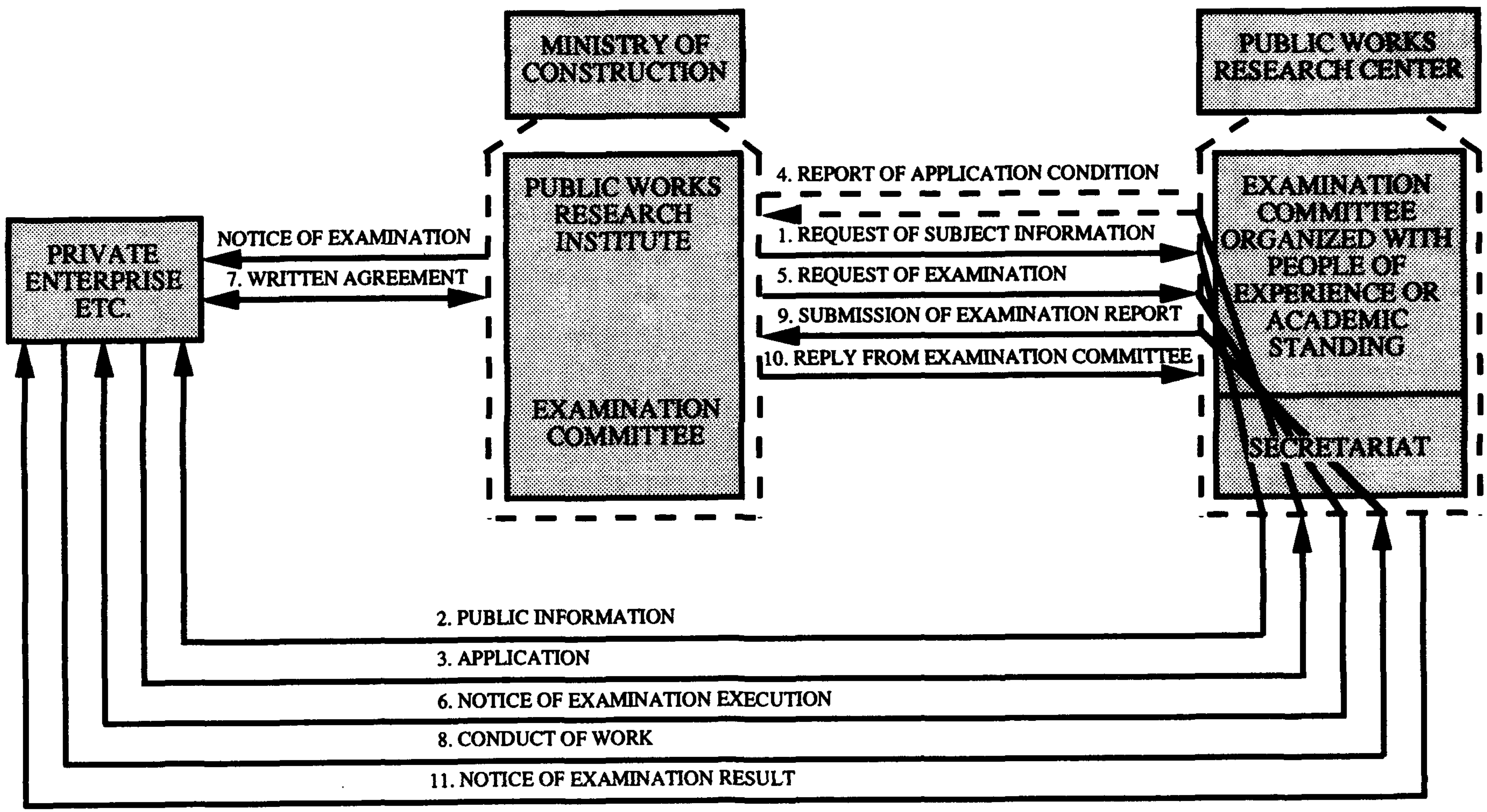

Figure 1. Japanese Process for Introducing R&D Technologies Into Practice for Public Works Projects.
(Source: CERF Japan International Research Task Force 1991. Used with permission.)

Other governmental barriers to innovation (e.g., the competitive-bid procurement process, inflexibility of standards and specifications) can be counterbalanced to some extent by promoting evolutionary changes in the way Government operates. Bernstein proposes the application of a life-cycle costing perspective in competitive bidding. This perspective can improve the transfer of innovations with sometimes higher initial costs, but offering long-term benefits by reducing operation and maintenance expenses. Bernstein also proposes the development of performance-based specifications that allow more innovation in the designed solutions.[55]

Local governments tend mainly to adopt innovations tried and proven by their peers. This tendency supports the concept of diffusion networks consisting of members with similar goals and interests, as described by Rogers. Organizations such as APWA are instrumental in communicating innovative technologies among public works agencies.

Risk and Liability

Risk and liability have become major obstacles to the adoption of innovations in the public works infrastructure. This is probably due to the trend in liability suit decisions in recent decades to compensate victims at the expense of public agencies.[56] Consequently, public works agencies tend to avoid projects that may include risk of damage to others. Such situations include the adoption of innovations which, if they fail, could cause harm to someone.

Risk and liability affect not only the creativity of public works agencies, but also the willingness to innovate by infrastructure designers, contractors, and financial institutions. Design of public works facilities is a fertile area for innovation, but fear of liability works as a disincentive for designers to innovate. This conservative attitude is compounded by the proliferation of codes and regulations that the designer has to follow.[57]

Liability concerns arise in part from the fragmented approach to facility acquisition. Acquisition of public works facilities is generally split into at least two major phases: the design phase, performed by a design professional (architect/engineer) and the construction phase, performed by a construction contractor. To reduce liability concerns, designers normally avoid new techniques that require unusual techniques or careful construction.[58] From the construction contractor's perspective, there is frequently a reluctance to be the first to apply a new technology. Although much more is learned from failures than from successes, it is unlikely that any construction contractor would be willing to be the first to experiment with unproven innovations on a live job.[59]

Another liability factor in procurement is funding; design and construction are normally funded with approaches that offer little flexibility for accommodating cost overruns related to application of innovative technologies. At the Federal and State levels a typical funding mechanism is legislative appropriations. At the local level, bonds are an important funding mechanism, and these require voter approval. Public agencies have a rigid and tightly controlled system to track and monitor project procurement costs.[60]

[55] Bernstein, H. M., "Tearing Down Road Blocks to Innovation," American Public Works Association Reporter (February 1992).

[56] Sweet, J., "Legal Aspects of Architecture, Engineering, and the Construction Process," West Publishing Company (1985).

[57] Sweet, J., "Legal Aspects of Architecture, Engineering, and the Construction Process," West Publishing Company (1985).

[58] "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

[59] "Transferring Research into Practice: Lessons from Japan's Construction Industry," Civil Engineering Research Foundation, Japan International Research Task Force (November 1991).

[60] Sweet, J., "Legal Aspects of Architecture, Engineering, and the Construction Process," West Publishing Company (1985).

It is clear that cost control systems are valuable to reduce cost overruns, but they may also discourage the adoption of innovations by failing to distinguish between overruns due to mismanagement and overruns resulting from the hidden costs or unforeseen complexities of applying an innovative technology.

Private-sector financial institutions play an important role in the funding of many public works projects. However, they are frequently reluctant to participate in projects that involve unusual risks. This is particularly true of environmental projects, where the continued evolution of regulations and technical knowledge make the accurate assessment of risk impossible.[61]

The reluctance to innovate is increased by each failure. With few exceptions, government agencies are more likely to penalize failures in innovation than to reward successes. This leads to a highly conservative public works infrastructure management approach, which resists innovation.[62] This is related to the fact that infrastructure failures are highly visible, while successes are taken for granted.

Undue aversion to risk further thwarts innovation because it makes it very difficult to set up demonstration projects to prove innovations in practice.[63] The failure to demonstrate innovations feeds a vicious cycle of resistance to innovation: potential users are reluctant to try innovative technologies that have no track record.

A very promising method of reducing the risk involved in implementing innovative technologies is to develop a formal infrastructure innovation demonstration program. This involves real-world projects where innovative techniques are carefully applied and monitored so (1) the effectiveness of the techniques is credibly proven and (2) the experience gained in the demonstration facilitates the implementation of these techniques in similar projects. Such demonstration projects have usually been structured to minimize risk to the innovators. The USEPA's Alternative and Innovative Technology Program, a relevant precedent for infrastructure projects, was operational until 1990. It consisted of an incentive for State and local governments to implement innovative techniques in the design and construction of environmental projects. The USEPA would absorb a major portion of the risk; in case of failure of the implemented innovations, the agency would provide up to 100 percent of the cost for repair or replacement.[64] Another formal program to demonstrate innovative technologies is incorporated into the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. This program provides $50 million to demonstrate new technologies for the construction or operation of high-speed rail systems.[65] Another benefit of demonstration projects is to enable the measurement of a new technology's potential costs and benefits.[66]

Bernstein goes further in proposing risk-reduction alternatives to promote innovation. He suggests the promotion of legislative measures to reduce the liability of innovators, including (1) caps on liability awards, (2) formal peer review to validate and endorse design innovations, and (3) alternative dispute-resolution mechanisms to reduce the cost of litigation. Bernstein also proposes the creation of test and evaluation centers whose mission would be to facilitate the demonstration of new technologies in the field.

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[61] "Paying for the Progress: Perspectives on Financing Environmental Protection," U.S. Environmental Protection Agency (Fall 1990).

[62] Feller, I., and P.E. Flanary, "Diffusion and Utilization of Scientific and Technological Knowledge Within State and Local Governments," National Aeronautics and Space Administration (January 1979).

[63] "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

[64] "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

[65] Prendergast, J., "A New Era in Transportation," Civil Engineering, American Society of Civil Engineers (New York, April 1992).

[66] "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

He also acknowledges the value of bringing the legal and insurance professions into discussions to identify improved mechanisms for risk reduction.[67,68]

As shown in Figure 1, in Japan's construction sector, innovations are tested and evaluated by neutral organizations to ensure public safety and acceptance. Only after this testing and certification process are they approved by Japan's government for practical use.

The National Council on Public Works Improvement (NCPWI) recommends risk-sharing arrangements as an encouragement for innovation.[69] Risk-analysis techniques can determine a balanced and fair distribution of risk for all participants—designer, public works agency, manufacturer, general contractor, etc. In Japan, together with the reduction in risk and liability for the development and testing of new technologies, there are incentives to make R&D attractive and profitable to the private sector.[70] These incentives include low-interest loans, tax incentives, and advantageous pricing on government contracts.

Gerwick describes a number of innovations in construction practice developed by a construction firm[71]. He concludes that innovations are always risky and that, quite often, the innovating firm does not benefit from them (although the construction industry as a whole tends to benefit from the new techniques). However, Gerwick clearly indicates that failure to innovate ultimately may cause a construction firm to go out of business. Innovation is important for survival in a competitive market. In Japan, R&D investment by contractors is considered essential for success. The construction sector in Japan is highly competitive, but most of the emphasis in competition is on the contractor's pre-qualifications and societal approval, not bid price. Contractor R&D efforts are very important both in Japan's pre-qualification process and for societal approval.[72]

Lack of Public and Private Partnerships

Solid partnership between Government and private industry is a necessary requisite for the development of demonstration projects as discussed in a previous section. CERF's study of Japan's success in construction innovations identifies a strong partnership among all sectors related to construction, including general contractors, consultants, government agencies, and academia. Government leadership, together with close cooperation between the public and private sectors, helps foster consensus about new technologies.

In the United States there are currently several good examples of cooperation between the public and private sectors on R&D with good potential to benefit the infrastructure. One is the Construction Productivity Advancement Research (CPAR) program in which the Federal Government (through the Army Corps of Engineers), academia, and the private sector work in partnership to develop innovations to

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[67] Bernstein, H. M., "Is Innovative Engineering Becoming Extinct in the U.S.?," American Consulting Engineer (Vol 2, No. 4, 1991).

[68] Bernstein, H. M., "Tearing Down Road Blocks to Innovation," American Public Works Association Reporter (February 1992).

[69] "Fragile Foundations," National Council on Public Works Improvement (February 1988).

[70] "Transferring Research into Practice: Lessons from Japan's Construction Industry," Civil Engineering Research Foundation, Japan International Research Task Force (November 1991).

[71] Gerwick, B., Jr., "Transferring Construction Innovation Into Practice: Lessons Learned," Excellence in the Constructed Project, Proceedings of the Construction Congress I (1989).

[72] "Transferring Research Into Practice: Lessons From Japan's Construction Industry," Civil Engineering Research Foundation, Japan International Research Task Force (November 1991).

enhance construction productivity.[73] This program is still small—about $5 million per year—but demonstrates both the feasibility and potential benefits of establishing public/private partnerships in R&D.

The manufacturing sector has also shown that partnerships can be effectively coordinated to promote R&D. The National Center for Manufacturing Sciences (NCMS) is a nonprofit organization funded by a group of U.S. tool manufacturers and suppliers to promote research and technology transfer. It is noteworthy that the partners in this effort are competitors. The success of NCMS is based on four factors: (1) addressing common goals, (2) responding to market pull, (3) identifying R&D areas suitable for cooperation among competitors, and (4) ensuring support by top management of the member firms by addressing their strategic goals.[74]

Another example of successful public/private R&D partnership, the Ben Franklin Partnership, has operated in Pennsylvania since the early 1980s. This partnership encompasses cooperative R&D efforts by the private sector and universities. It is funded by the State, with matching funds from the Federal Government and private sources. This partnership has been successful in developing profitable innovations.[75]

Funding

There are two major issues related to funding and innovation in the public works infrastructure. One is the actual level of funding for all of the steps in the innovation process, from R&D to diffusion and adoption. In comparison to other industrialized nations, the U.S. lags in its investment in innovation development for infrastructure, both in the public and private sectors. A recent OTA study concludes that Government spending for infrastructure R&D is inadequate.[76] The other funding issue related to innovation in the public works infrastructure is the potential role of innovative financing mechanisms. Innovative approaches are badly needed to overcome the financial hardships that commonly affect public works agencies.

As discussed previously, a large part of the U.S. public works infrastructure is administered and controlled by local governments. Local governments typically experience substantial budget difficulties, and do not have the fiscal power to generate the funding required to apply innovative methods and technologies.[77] Severe budget constraints are aggravated by the fact that public works programs are frequently targeted for budget cuts for the benefit of more visible programs.[78] Consequently, local governments typically have the resources to pursue only modest innovations that result in only marginal change.[79] They are often understaffed and lack the financial resources to implement innovations that

[73] "Construction Productivity Advancement Research (CPAR) Program," U.S. Army Corps of Engineers (January 1990).
[74] "Fragile Foundations," National Council on Public Works Improvement (February 1988).
[75] "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).
[76] "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).
[77] Feller, I., and Flanary, P. E., "Diffusion and Utilization of Scientific and Technological Knowledge Within State and Local Governments," National Aeronautics and Space Administration (January 1979).
[78] "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).
[79] Feller, I., and Flanary P. E., "Diffusion and Utilization of Scientific and Technological Knowledge within State and Local Governments," National Aeronautics and Space Administration (January 1979).

require major effort and expense up front. New technologies that require the scrapping of existing equipment and systems generally encounter high resistance at the local government level.[80]

The trend in public works funding continues to be a reduction in Federal spending creating an increase in State and local fiscal obligations. However, the ability of local governments to generate funding has not grown in proportion to this increase in obligations.[81] As Collins says, local governments are forced "to do more with less".[82] This trend of decreasing public works investment reduces the nation's overall productivity, undermining its international competitiveness.[83] The challenge is to reverse this trend and increase investment in the public works infrastructure.

Consequently, it is highly desirable to promote innovation in funding approaches, and examples of this type of innovation are documented in the literature. The APWA reports various successful innovations in the funding of public works projects.[84] Examples include the use of stormwater utility revenues to finance operation and maintenance of the stormwater system, and the use of waste as an energy source. A study performed for the National League of Cities identified a number of other innovative financing approaches including special financing districts (geographical partitions to raise money from owners for specific projects); exactions (required contribution to a public jurisdiction by developers or owners); independent public corporations to finance, construct, and operate public works facilities; and public/private partnerships.[85]

User fees are an important source of revenue to help finance the public works infrastructure. However, OTA notes that it is important to maintain a healthy balance of general revenue subsidies, taxes, and other community-wide fundraising alternatives without over-relying on user fees. This balance is influenced by factors such as the need to encourage economic development, the user's ability to pay, etc.[86]

Funding mechanisms that include private-sector participation are gaining interest. Several successful environment-related private/public partnerships that include major private-sector financial participation are documented by USEPA.[87] These successful cases have in common the achievement of the profit goals of the private partner, and of the cost and quality goals of the public partner.

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[80] "Dynamic Technology Transfer and Utilization: The Key to Progressive Public Works Management," American Public Works Association, Editors: Cohn, M.M., and Manning, M.J. (1974).

[81] Kane, A. R., "Financing Highways in the 21st Century," Engineering 21st Century Highways, ASCE (1988).

[82] Collins, W. A., "Innovation: The Key to Local Roads Survival," Engineering 21st Century Highways, ASCE (1988).

[83] "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

[84] "Good Practices in Public Works," American Public Works Association Research Foundation (1988).

[85] "Financing Infrastructure. Innovations at Local Level," Apooge Research, Inc., (National League of Cities, 1987).

[86] "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

[87] "Paying for the Progress: Perspectives on Financing Environmental Protection," US Environmental Protection Agency (Fall 1990).

Nine states are participating in an experiment to assess the effectiveness of toll-funded highways, as authorized by the 1987 Surface Transportation and Uniform Relocation Assistance Act.[88] Before this law was enacted, toll roads could not be funded by Federal money. Another alternative for funding highway construction and operation is privately built and operated toll roads. Although this option is not appropriate in every circumstance, it might be attractive for heavily congested traffic corridors.[89] ISTEA provides more flexibility for the funding of road construction. It also includes provisions to promote and fund research for innovative transportation alternatives.[90] Privatization may also be a viable alternative for funding innovative technologies in public works sectors other than transportation. In general, private firms can provide good service at a reasonable cost in stable or growing markets large enough to attract private capital.[91]

Size and Type of Infrastructure Projects

Many public infrastructure facilities are unique in terms of purpose, size, geographical location, life-cycle requirements, or other characteristics that make it difficult to successfully apply innovation. For instance, many miles of highways and waterways are located in areas of contrasting population densities and weather patterns. Technical solutions applicable in some areas may not be adequate in others. Another example of such facility characteristics is apparent in the case of large dams that are intended to have lifespans of 100 years or longer. Applying innovations to these types of projects is very costly and difficult.[92]

A typical obstacle to adopting innovations in the public works infrastructure is the absence of knowledge about expected costs and benefits.[93] This lack of knowledge results in large part from the uniqueness and complexity of most public works facilities.

Also, the public works infrastructure historically has been conceived and developed with relatively little attention to flexibility, expandability, and innovation. Although this attitude is changing, much of the public works infrastructure already in place suffers from this historical short-sightedness.[94]

The difficulty of quantifying the expected costs and benefits of innovation can be reduced through formal demonstration programs, as discussed previously. It is also important to improve the capability of predicting the costs and benefits that will result over time after innovations are implemented.

An entrepreneurial society looks at change as an opportunity for innovation and improvement. The United States is undergoing dramatic demographic changes that are reshaping population distribution both in urban and rural areas. Some of these changes, described by Scott,[95] include (1) continued population

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[88] "Transportation Infrastructure. Panelists' remarks at new directions in surface transportation seminar," United States General Accounting Office (December 1989).

[89] "Transportation Infrastructure. A Comparison of Federal and State Highway Laws," United States General Accounting Office (June 1990).

[90] Prendergast, J., "A New Era in Transportation," Civil Engineering, American Society of Civil Engineers (New York, April 1992).

[91] "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

[92] "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

[93] "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

[94] Feller, I., and Flanary, P. E., "Diffusion and Utilization of Scientific and Technological Knowledge Within State and Local Governments," National Aeronautics and Space Administration (January 1979).

[95] Scott, J. A., "America's Changing Demographics: Impacts on Transportation Requirements," Engineering 21st Century Highways, ASCE (1988).

growth, estimated to reach over 282 million in 2010, (2) an increased rate of redistribution with a slight decrease expected in the Midwest and a marked increase projected in the South (with California, Texas, and Florida possibly amounting for over 53 percent of the U.S. population by 2010), (3) continued growth of the suburbs, (4) a change in the ethnic mix, with substantial population gains by Hispanics, Americans, and Asian Americans, and (5) and an aging of the population, with a growth in the population 65 and older expected to reach 80 percent between 1985 and 2020. These dramatic changes are undoubtedly affecting the demands on the public works infrastructure, as well as the options available to secure adequate funding for operation and maintenance (O&M) and new construction. One example is illustrated by a projection of congestion increases of 300 to 400 percent by 2005.[96]

An expected implication of change for the public works infrastructure is new public demands that may not be satisfiable with existing systems and equipment. This challenge represents one of the most powerful reasons for implementing new technologies in the public works infrastructure.[97] In addition, there will be new demands created by changing regulations, particularly those addressing pollution control.[98]

The increasing complexity of the public works facilities represents challenge that promotes innovative solutions. Tatum identifies this increasing complexity as a motivation for innovation in the construction industry. He also cites foreign competition and greater owner requirements for cost effectiveness as important motivators for innovation by construction firms.[99] The solutions that Tatum proposes to meet these challenges through innovation are indicated in his model, which is reviewed in Chapter 3.

Education, Research, and Technology Transfer

Education and research systems are key elements in generating and adopting innovations in the public works infrastructure. Education is a key source of current information about innovations for public works managers and engineers. Furthermore, the education system is the primary source of future public works leaders. The research system is the provider of many important innovations–those that originate in the laboratory. Technology transfer is a necessary complement to research; it may be described as the process that motivates research and communicates and implements the developed solutions. A number of important challenges and opportunities are related to education and research systems, and technology transfer in the United States.

A major influence on infrastructure education and research is the field of civil engineering. Traditionally, civil engineering has focused on infrastructure design, but has not given enough attention to issues like implementation, operation, rehabilitation, and maintenance. This in effect limits the capability of the public sector to implement innovation in the rehabilitation and maintenance of the infrastructure.[100] In addition, civil engineering has lost attractiveness and status compared to other

[96] Statement of Eleanor Chemilsky, Assistant Comptroller General, before the U.S. House of Representatives, Committee on the Budget, "Traffic Congestion: The Need and Opportunity for Federal Involvement," United States General Accounting Office (May 1991).

[97] "Dynamic Technology Transfer and Utilization: The Key to Progressive Public Works Management," American Public Works Association, Editors: Cohn, M. M., and Manning, M. J. (1974).

[98] "Fragile Foundations," National Council on Public Works Improvement (February 1988).

[99] Tatum, C. B., "Construction Innovation: Demands, Successes and Lessons," American Society of Civil Engineers (New York, 1986).

[100] "Good Practices in Public Works," American Public Works Association Research Foundation (1988).

engineering disciplines which puts the profession at a disadvantage when competing for educational and research resources.[101]

As previously noted, the fragmented responsibility for the nation's public works infrastructure contributes to the fragmentation of R&D activities. The limited funding available for infrastructure R&D mainly originates at the Federal and State levels, but is scattered in many different directions. This causes underfunding of many relevant areas. There is absence of a national agenda for R&D activities to foster coordination and synergistic efforts.[102,103] Although much of the investment in public works infrastructure is ultimately handled at the local level, there are few incentives to focus much public or private R&D on local government support.[104]

University research is an important source of new technologies, but much of it historically has been basic research, which tends to have a long-term payoff. It is important to establish a good balance of university-based research activities supporting both well-structured, short-term infrastructure needs and long-term programs.[105] Such a balance would help close the gap between academic research centers and public works agencies identified by the APWA.[106] This gap also indicates a basic lack of attention to technology transfer. Few research institutions maintain dedicated resources to actively transfer their technologies into practice.

The contribution by research institutions to the public works infrastructure can be enhanced through the application of a two-point strategy. The first point in the strategy is to promote infrastructure R&D that addresses integrated, or cross-cutting issues. This approach looks at the various infrastructure modes as parts of an integrated whole.[107] In its recent report on the public works infrastructure, OTA recommends: (1) direct and immediate Federal action to identify the new technologies that offer best potential and (2) generating strategies to develop and implement those technologies. The OTA recommendation is very specific in singling out innovative techniques that have a cross-cutting approach: management information and condition-assessment systems, technologies to improve maintenance, and technologies to increase the capacity of existing facilities when new construction is impractical.[108] Efforts are underway to develop national consensus on critical research needs. The CERF recently coordinated a national forum that proposed an agenda for civil engineering research. A major thrust area of this agenda was revitalization of the public works infrastructure. The proposed areas for research correspond to the general approach suggested by OTA.[109,110]

The second point in this two-point strategy is to develop effective technology transfer mechanisms and commit the resources necessary to support them. Effective technology transfer requires consistent

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[101] "Infrastructure for the 21st Century," National Research Council (Washington, DC 1987).

[102] "Construction and Materials Research and Development for the Nation's Public Works" Office of Technology Assessment, (June 1987).

[103] "Delivering the Goods: Public Works Technologies, Management, and Financing" Office of Technology Assessment (April 1991).

[104] Feller, I., and Flanary, P. E., "Diffusion and Utilization of Scientific and Technological Knowledge Within State and Local Governments," National Aeronautics and Space Administration (January 1979).

[105] "Research Needs Related to the Nation's Infrastructure," American Society of Civil Engineers (New York 1984).

[106] "Dynamic Technology Transfer and Utilization: The Key to Progressive Public Works Management," American Public Works Association, Editors: Cohn, M.M., and M.J. Manning (1974).

[107] "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

[108] "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

[109] "Setting a National Research Agenda for the Civil Engineering Profession," Civil Engineering Research Foundation (Vols 1 and 2, August 1991).

[110] "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

efforts to communicate with potential users of research products through all stages of the innovation-development process. According to Walaszek,[111] this includes (1) a clear understanding of user needs and priorities when identifying research areas, (2) conducting of pilot tests during the development phase to ensure that the user needs are met, (3) adjustment of developed products if tests reveal that user needs are not being met satisfactorily, (4) development of effective communication techniques to disseminate the research product among the network of potential users, (5) field testing to demonstrate the product's benefits, (6) helping the user successfully adopt the product, and (7) evaluation of the product.

A key element in technology transfer is effective communication. Peer diffusion is a very effective way to communicate and convince potential users to adopt innovations.[112,113,114] In general, peer diffusion is effective when a homogeneous group of early adopters of an innovation communicate their success with the innovation to their peers. The contribution of professional associations such as APWA is noteworthy in this respect. APWA continuously works to facilitate peer diffusion of new technologies among public works managers.[115] The group consistently publicizes among its members innovative ideas used successfully by public works agencies. The innovations the group helps diffuse cover a wide spectrum of topical areas: management, rehabilitation, financing, upgrading of existing facilities, etc.

The APWA has also proposed the widespread use of information clearinghouses as another mechanism to diffuse innovation information.[116] It cites two successful examples: (1) the National Small Flows Clearinghouse, located at West Virginia University, established by the USEPA to disseminate information on innovative wastewater systems for rural communities, and (2) a technology transfer center at Oklahoma State University jointly sponsored by the state and the FHWA.

The leadership of the Federal Government is very important for increasing the benefit that can be obtained from the education and research systems. Increases in Federal funding for R&D in civil engineering and other areas directly related to the public works infrastructure could promote greater student interest and stronger university programs addressing infrastructure needs.[117]

Another technology transfer opportunity that could complement R&D activities is to purchase innovations from foreign countries and adapt them to U.S. needs.[118] Similarly, innovations could be adopted from other sectors (manufacturing, aerospace, etc.) into the design, construction, or operation of public works.[119]

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[111] Walaszek, J. A., "The Role of Communications Within Technology Transfer Activities of the U.S. Army Construction Engineering Research Laboratory," USACERL Technical Manuscript (July 1987).

[112] "Dynamic Technology Transfer and Utilization: The Key to Progressive Public Works Management," American Public Works Association, Editors: Cohn, M.M., and M.J. Manning (1974).

[113] Feller, I., and P.E. Flanary, "Diffusion and Utilization of Scientific and Technological Knowledge Within State and Local Governments," National Aeronautics and Space Administration (January 1979).

[114] "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

[115] "Good Practices in Public Works," American Public Works Association Research Foundation (1988).

[116] "Good Practices in Public Works," American Public Works Association Research Foundation (1988).

[117] "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

[118] "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

[119] Tatum, C. B., "Construction Innovation: Demands, Successes and Lessons," American Society of Civil Engineers (New York, 1986).

3 THE PROCESS OF INNOVATION DIFFUSION

This chapter summarizes the discussion in the literature about the processes of generating and adopting innovation in the public works infrastructure. Because those processes involve complex interactions among a diversity of elements (people, organizations, regulations, etc.), there are important variables that affect how innovation can be developed and applied in practice. The literature survey conducted for this study was not comprehensive because, as noted by Rogers, the number of publications addressing innovation diffusion has grown from a few hundred in the early 1960s to several thousand today.[120] The present survey concentrated on a representative balance of perspectives most pertinent to innovation in the public works infrastructure.

An important source of insight can be found in several models developed to explain the process of innovation. Although these models are not limited to the area of public works infrastructure, they provide useful perspectives on the factors that act as barriers or incentives for innovation diffusion. These models attempt to explain how innovative ideas migrate from creation to application. The following sections briefly describe some of the most recognized models found in the literature.

The Rogers Model

Rogers is considered a pioneer in researching the diffusion of innovations. He works from the perspective of the social sciences, studying innovation diffusion as a human and a social characteristic. He addresses the adoption of innovations both by individuals and organizations—in particular, innovations that are technological in nature (scientific and social technologies).[121]

Rogers decomposes the innovation diffusion mechanism into two processes: (1) the innovation-development process, by which new ideas are generated and applied and (2) the innovation-decision process, by which a potential user learns about new ideas and decides to adopt them. The Rogers model of innovation-development identifies six steps within an evolutionary process:

1. Recognition of a Need. Innovation is prompted by a need. When the need is recognized, the demand for research toward an answer is stimulated. Rogers notes that innovative ideas can exist without being applied—the need may stimulate the demand for an application of an unused innovation.

2. Basic and Applied Research. In the case of technological innovations, which are the subject of most innovation diffusion studies, fundamental scientific knowledge is initially developed through basic research, without a specific need in mind. Subsequently, applied research adapts that knowledge to solve a specific problem.

3. Development. Rogers defines this as the process of adjusting a new technology to the specific constraints of its intended users.

4. Commercialization. This is the stage at which the innovated technology is produced, packaged, marketed, and distributed. Rogers notes that innovations sometimes result not from R&D activities, but from an original idea applied to a problem by a practitioner in the field.

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[120]Rogers, E. M., "Diffusion of Innovation in Public Organizations," The Free Press (New York, 1983).
[121]Rogers, E. M., "Diffusion of Innovation in Public Organizations," The Free Press (New York, 1983).

5. Diffusion and Adoption. This is the process by which potential users are made aware of an innovation and decide to adopt it or reject it. Rogers discusses the role of the change agent (facilitator of innovation adoption, discussed below in more detail) and of technological gatekeeping (a mechanism for acquiring information about existing innovations and deciding which ones to adopt).

6. Consequences. This stage involves an assessment of how successful the adopted innovation was in solving the user's need.

Rogers also proposes a model for the innovation-decision process, by either an individual or a decisionmaker within an institution. In this case he takes the perspective of the potential user who learns about a new idea and applies it in practice. The major stages (or steps) in this model include:

1. Knowledge Stage. Information about an innovation becomes available to the individual or the decisionmaking agent.

2. Persuasion Stage. More information is considered, and the decisionmaker develops a positive or negative opinion about it.

3. Decision Stage. The innovation is either adopted or rejected. The change agent's effectiveness in demonstrating the usefulness of the new technology can heavily affect the decision.

4. Implementation Stage. The innovation is applied in practice. Rogers discusses a crucial stage in implementation called *reinvention*. Reinvention is the process of adapting an existing innovation to the specific needs and constraints of its new user.

5. Confirmation Stage. Depending on the results obtained first-hand, the availability of competing innovations, and information received from other users, the innovation may be confirmed or discontinued.

Another Rogers model describes a process of innovation adoption that applies specifically to organizations. This model includes five stages:

1. Agenda-Setting. Rogers defines this as a continuous process of seeking new technologies that might solve the organization's needs.

2. Matching. An identified need or performance gap is conceptually matched with an existing innovative solution.

3. Redefining/Restructuring. After an innovation is selected, it is reinvented to more exactly meet the organization's specific needs.

4. Clarifying. As the innovation is used, its applicability becomes clearer to the members of the organization and it begins to become part of the organization structure.

5. Routinizing. When the full innovation becomes part of the structure of the organization, it has successfully met the need it was adopted for, but loses its status as "innovative."

Rogers defines the first two steps of this process as the *initiation* phase. He defines the last three steps as the *implementation* phase. The *decision to adopt* an innovation is made between these two phases.

Although the models proposed by Rogers may appear to specify a rigid sequence of stages, he acknowledges that there are common variations. He asserts that his models represent a typical order of events, but some stages overlap. Furthermore, some stages may involve cycles of intermediate stages, and sometimes stages can be skipped altogether.

In addition to creating these three models, Rogers has also studied factors that affect the diffusion of innovations. One such factor is the perceived attributes of innovations which may positively or negatively affect their rate of adoption. These attributes include:

1. Relative Advantage. This attribute indicates the perception by potential user of how much better is the innovation as compared to the method or technology it would replace.

2. Compatibility. For an innovation to be adopted successfully, it has to be compatible with the adopter's existing values, constraints, needs, etc.

3. Complexity. Adoption of innovation is directly affected by the difficulty users have in understanding and using the innovation.

4. Trialability. This term refers to how difficult an innovation is to test without in effect adopting it.

5. Observability. Adoption will be affected by how readily a potential user can see results obtained by others with that innovation.

Another factor affecting adoption of innovation, according to Rogers, is the *degree of inclination* to adopt by potential users of innovations. This factor can range from very inclined to adopt (Rogers labels this group as the *innovators*) to skeptical and traditional (reluctant to innovate). Another important factor is the channel of communication used for the diffusion of innovations. One category of channels is *interpersonal communication*, which is affected by the homogeneity or heterogeneity of the diffusion network and the role of opinion leaders. The other category of communications channel is *mass media.*

Information diffusion systems may be centralized or decentralized. The initial acquisition of information about innovations may be hampered by a tight central system and promoted by a decentralized one. On the other hand, implementation of innovations may be promoted more effectively through a centrally controlled system but may be impaired by a decentralized system.

One other important factor identified by Rogers is the *change agent.* Change agents are individuals who bring an innovation to potential users with problems that might be solved by that innovation. Change agents are information sources that help the *potential user* adopt and implement the innovation.

The Shaffer Model

A model that focuses directly on technology transfer is the one developed by Shaffer[122,123] and refined by Walaszek.[124] For this model technology transfer is defined as the process by which R&D solutions are created and transferred to users to solve technological needs. The Shaffer technology transfer model was designed to fit the needs of the Army, but can be applied in other environments. The model is composed of seven major phases:

1. Problem Identification. A user community identifies problem areas and communicates them to an R&D organization. A variant of this phase is the joint identification of user needs by representatives of the user community and researchers. In either case, potential solutions are identified.

2. Survey Existing Technologies. Researchers identify any existing innovative technologies that may be wholly or partially adaptable to the user's needs. Subsequent steps in the technology transfer process apply whether an existing technology is to be adapted or the user's needs will be addressed through original research.

3. Research and Prototyping. This phase is an iterative process where research activities progress toward a pilot test of the solution concept. The outcome of the pilot test dictates what follows: either additional refinements are made to enhance usefulness, or the R&D project is canceled if the pilot test shows that the solution is unsatisfactory.

4. Test and Evaluation. The purpose of this phase is to demonstrate in the field how the developed solution can be used effectively. Information collected during this phase about such factors as cost savings, implementation hurdles, etc., is very valuable in the subsequent phases of technology transfer.

5. Development. This phase includes the refinement of the solution, plus all the packaging, commercialization, etc., required to deliver the R&D product to its potential users.

6. Authorization (Decision to Adopt). In the Army, the actual dissemination of a new technology to the field must be authorized through an official policy statement. In other organizations, innovations are normally adopted after the decision is made at the appropriate responsibility level. Additional packaging and distribution strategy issues sometimes must be addressed in this phase.

7. Application or Implementation. This phase involves the implementation and use of the new technologies in the field, including training and field support activities. This phase is also important in evaluating the performance of transferred technologies in everyday operation.

It is noteworthy that the Shaffer model specifies continuous communication with users (both actual and potential) from problem identification through the development and implementation of the solution.

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[122] Shaffer, L. R., "Product/System Development for Military Facilities," from the briefing on Technology Transfer Test Bed concept, U.S. Army Construction Engineering Research Laboratory (1985).

[123] Shaffer, L. R., "U.S. Army Corps of Engineers Technology Adoption Model Mechanisms," from the welcoming remarks at the "Workshop on Challenges and Opportunities for Innovation in the Public Works Infrastructure," U.S. Army Construction Engineering Research Laboratories (March 1992).

[124] Walaszek, J. A., "The Role of Communications Within Technology Transfer Activities of the U.S. Army Construction Engineering Research Laboratory," USACERL Technical Manuscript (July 1987).

By recognizing the necessity of responding effectively to user needs, Shaffer has modeled a demand-driven R&D process.

A study by Bisio and Gastwirt[125] also discusses the process of innovation from the perspective of a market-oriented entity developing an innovative solution to meet a market need. They split the innovation process into three major phases: (1) idea generation, when information about new technologies is matched with the market need; (2) problem solving or development, where operational goals are set and alternative solutions are designed to meet those goals; and (3) implementation and diffusion, which consists of the manufacturing, engineering, and market start-up to bring an innovation into use.

Bisio and Gastwirt studied the development of products that are marketed and sold in the form of many repetitive units, as in the manufacturing industry. It is noteworthy that they include the innovation process as an integral part of the development of each new product.

The Tatum Model

Tatum has performed influential research in the area of innovation in the construction industry.[126,127,128] In construction, the materials and processes used to build one facility are similar to those used to build others. However, as opposed to the manufacturing industry, there is typically only one unit of each product produced. With some exception, facilities are normally not mass-produced, and this is particularly true of public works infrastructure.

Tatum's model describes the major steps required to promote incorporation of innovations into a construction firm. More than a model to explain innovation in typical construction firms, Tatum's model is a proposal to enhance innovation within contracting firms. His model is the result of close study of innovative firms, and includes the following steps:

1. Recognize Forces and Opportunities for Innovation. Tatum asserts that innovation in construction can be shaped and motivated by a diverse array of factors internal and external to the innovating firm. These include (1) market competitive demands, such as project demands beyond the capability of traditional techniques, and competitive rivalry, (2) recognition of opportunity for improvement, (3) changing regulations, such as environmental, life-safety, etc., (4) availability of new technologies, and (5) management leadership in developing strategic focus in the incorporation of innovations. This last factor is also important in guiding all the other steps in Tatum's model.

2. Create Climate for Innovation. Tatum recognizes that the concern by construction firms for potential liability is an obstacle to innovation. However, this obstacle can be overcome through management leadership translated into the following actions: (1) development of a clear vision and commitment for improvement, (2) commitment of the resources needed to support innovation, (3) providing the organizational autonomy (time and freedom), and (4) tolerating failure.

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[125] Bisio, A., and L. Gastwirt, "Turning Research and Development into Profits," AMACOM (1979).

[126] Tatum, C. B., "What Prompts Construction Innovation?," Journal of Construction Engineering and Management (September 1984).

[127] Tatum, C. B., "Construction Innovation: Demands, Successes and Lessons," American Society of Civil Engineers (New York, 1986).

[128] Tatum, C. B., "Process of Innovation in Construction Firm," Journal of Construction Engineering and Management (December 1987).

3. Develop Necessary Capabilities. Construction involves a diverse number of disciplines. The firm's chances of successful innovation are enhanced by maintaining strong technical competence in its specialty areas, and other related areas. This effort can be enhanced by the involvement of a *technological gatekeeper*, a person within the firm who monitors innovations in the field.

4. Provide New Construction Technologies. The previous three steps are considered prerequisites to innovation. Tatum's fourth step addresses the adoption or creation of innovations: (1) direct adoption of innovative techniques, tools, etc., from specialty suppliers, (2) adaptation of technologies used in other fields, (3) incremental improvement of innovations, and (4) research and development. Tatum recognizes the historical lack of R&D by the construction industry, and argues that management must be committed to encouraging and trying new ideas.

5. Experiment and Refine. This step involves all the iterative testing and fine-tuning required to make a new technology operational.

6. Implement on Projects and in the Firm. This stage requires the commitment of resources. Key activities at this stage are developing and documenting experience with the innovation to demonstrate its value and promote acceptance. If successful, the firm will gain a competitive advantage in the market.

7. Feedback During Innovation. Tatum indicates that feedback is a key component of successful innovation adoption in construction firms.

Tatum also emphasizes the importance of individual *champions* of innovation within an institution. Champions are similar to the change agents described by Rogers in the sense that they lead and promote innovations, but they do it from within an organization.

The NASA Model

The National Aeronautics and Space Administration (NASA) at the Stennis Space Center in Mississippi has developed a model that addresses the transfer of innovative technology to the commercial market. This technology transfer process is a modification of the Shaffer model.

The NASA model divides the entire technology transfer process into six tasks:

1. Problem Identification, Classification, and Priority. Problems within the municipal public works community that might be addressed by the infusion of new technology are identified. Tools to accomplish this include a literature search and analysis, interviews, and questionnaires to public works practitioners. Once identified, the problems are placed into categories (e.g., transportation, buildings, water resources, solid waste, etc.) and priorities assigned.

2. Problem and Technology Matching. After the problem areas have been placed in order of priority, potential solutions in the form of programs, processes, or products are identified. The sources for infrastructure-related solutions could be Government, academia, or the private sector.

3. Market-Potential Evaluation. After high-priority problems are identified and matched with applicable technologies, the market potential of the possible solutions is evaluated. Public works practitioners and agencies play an important role in this step. This evaluation determines whether there is enough demand by municipal public works agencies to attract the private sector

into demonstrating and marketing the innovations. This evaluation could be supported by preliminary estimates of the market potential for the innovative technologies under consideration.

4. Technology Demonstration Partner Identification. Using the results of the first three tasks, companies willing to invest in marketing the innovation are identified. This step requires the partnership of Federal, State, and municipal agencies to cosponsor and demonstrate the new technologies.

5. Technology Demonstration Projects. When the demonstration cosponsors made their commitment, the new technologies are demonstrated.

6. Feedback. Lessons learned from the demonstration—both successes and problems—are made available for future demonstration projects and users.

Toward a Model for the Public Works Infrastructure

All of the models reviewed have provided insight into the basic steps required for an orderly process of innovation adoption, and indicates the types of mechanisms required to put it into practice. The models also illuminate the typical obstacles and opportunities that apply, more or less universally, to the problem of innovation adoption. In Chapter 5, concepts from all of the models reviewed are integrated into a model for innovation and technology transfer for the public works infrastructure. The model proposed in Chapter 5 also incorporates the expertise and insight provided by participants in the workshop on innovation in infrastructure hosted by USACERL.

4 PERSPECTIVES FROM WORKSHOP PARTICIPANTS

The literature survey identified the "state of the art" of published thought on innovation in the public works infrastructure (Chapter 2) and produced a number of models for innovation and technology transfer (Chapter 3). Evident from the literature, however, is that there are gaps in the understanding of how best to promote innovation in the public works infrastructure in the environment of global competition and scarce Government resources that will characterize the coming decades.

The objective of the workshop was to fill in some of the gaps in this understanding by presenting the observations of a select group of nationally recognized experts in the areas of civil engineering, construction, innovation, and technology transfer. While it must be noted that the workshop was not large or long enough to address every infrastructure-related topic of interest, the gathering at USACERL included a representative cross-section of Government, industry, and academic thought leaders.

The following paragraphs summarize the contributions of the workshop participants. The summaries are organized under the headings of the seven categories of barriers and opportunities for innovation discussed in Chapter 2. The corresponding papers are contained in full length in Volume 2 of this report.

Cultural Values and Social Perception of Innovation and Infrastructure

"Technological Advances and Public Works: A Synergistic or Antagonistic Relationship," by N. Hawkins

Hawkins looks at the cultural, educational, and social foundations as factors that can be used to promote or interfere with innovation. In his paper he parallels U.S. and Japanese innovative programs as a mechanism to determine the mentioned factors. He mentions the fragmentation of the U.S. construction industry as an obstacle for innovation. He describes the leadership role exerted by the Japanese Government through the Ministry of Construction, as well as the tight partnership between Government, academia, and industry to develop and implement innovations in practice.

"Barriers to Adoption of New Technologies," by P. Nowak

Nowak focuses on understanding the reasons that affect an individual's decision to adopt or reject an innovation. An individual can reject an innovation if he is unable or unwilling to adopt. Nowak indicates some causes of the inability to innovate are: lack of information, cost of information, complexity of innovation, limited support available, and inadequate managerial skill. An individual may be unwilling to adopt for reasons such as conflicting information, poor applicability, incompatibility, or risk.

Governmental Structure and Regulations

"Searching for the Infrastructure of Tomorrow: National Research Council Activities, Federal Interests, and Federal Roles," by A. Lemer

As the Director of the Building Research Board (BRB), Lemer describes BRB's active participation in the search for solutions to the infrastructure problem. Many of the facilities that are part of the public works infrastructure have a long life and are difficult to remove or retire. Also, in comparison with other sectors, the public works infrastructure has had few innovations in the last century (i.e., sewer systems, roads, and rails). He also mentions local distrust of the Government, which discourages investment and innovation.

A lot of potential exists for successful innovations which improve the condition and capacity of existing facilities. Also, it is important tc address cross-cutting research. The BRB is pursuing efforts to: encourage research, motivate changes in policy, and have better coordination of national and local efforts both private and public. There is also an ongoing effort to develop improved measurements of infrastructure performance.

"Identifying, Programming, Executing Infrastructure Research and Development," by C.O. Magnell

Magnell is the Director of Research for the Civil Engineering Research Foundation (CERF). He provides a very broad description of infrastructure as all the common structures and facilities enabling the society to function. He indicates that there is a shortage of R&D activities focused on the public works infrastructure. He also asserts that the major problem affecting the nation's infrastructure is the lack of vision of a desired end state for the public works infrastructure.

Magnell cautions about research activities that are an end in themselves. This approach cannot provide the badly needed solutions to infrastructure problems. He emphasizes the need for an adequate technology transfer process that, through user involvement, allows the generation of R&D products that are applicable and useful in field practice.

"How Demonstration Programs Improve Potential for Utilization," by R.H. Sullivan

Sullivan describes findings of the American Public Works Association (APWA), of which he is the Executive Director, on acceptance of innovations by public works organizations. The APWA found that, in general, public works officials are conservative, avoid risks, and (except for professional pride) are not motivated to innovate. Public works organizations are interested in demonstrations of innovative ideas, in peer evaluations of these innovations, and want to avoid "black boxes." The APWA also found that several factors impact the decision and ability to innovate (i.e., regulation by higher levels of government, jurisdictional limits, codes and standards, public support, risk, and employee training).

The APWA recommends the development of innovation demonstrations that are adequately monitored and recorded. It also recommends disseminating the findings of the demonstrations to all potential users.

"Advancing Innovation in Transportation Through Research," by C.M. Walton

As past president of the Transportation Research Board, Walton provides insightful guidelines to shape the transportation R&D efforts. This is especially critical now when there is growing interest and funding to sponsor transportation research. His proposed approach is to continue and expand on the success of the Strategic Highway Research Program (SHRP). Also, he recommends additional involvement from the private sector. He also recommends seizing opportunities that exist for transportation R&D. Among others, he cites: leveraging advanced technologies, multi-disciplinary teaming, public/private/academic partnering, facilitating risk taking by innovators, leadership at all levels, and others.

"How Effective is our Investment in Roads, Streets, and Highways?" by T. White

White focuses on the transportation infrastructure, which is a major component of the nation's infrastructure by several measures (i.e., contribution to GNP, number of jobs, etc.). However, the Federal R&D investment in transportation is very small (3.3 percent).

White provides several obstacles and opportunities for innovation in transportation. Among others, he proposes an integrated approach for R&D that covers the different modes of transportation and the establishment of long term policies for infrastructure development. He also notes a number of issues that interfere with the ability to innovate in transportation: technical issues being affected by political agendas, shortage of knowledgeable personnel, etc.

Risk and Liability

"Legal Problems with Innovation in Public Works," by C.F. Seemann

Seemann starts his paper by describing the historic trend in facility construction that moved the responsibility of construction from a single design-builder (master builder) to a team of participants contractually related to the owner. He also mentions the increase in social value for human life. These two factors have contributed to an added legal responsibility for contractors, designers, and owners.

Innovation in facility acquisition implies risk due to this legal responsibility and the probability of failure. Seemann argues that in spite of the risks involved, construction contractors can still derive profit from innovations. However, he asserts that designers are not motivated to innovate, due to lack of reward (low fees in competitive market), desire to stay in the mainstream to avoid liability in case of failure, and unwillingness by owners to motivate innovation.

He proposes a more active role by the Federal Government to promote innovation. This can be accomplished through the assumption of risk by the government in innovative projects and by developing flexible standards to accommodate design innovations.

Public and Private Partnership

"Implementation of Innovation Through Total Quality Management," by J.A. Broaddus

The ultimate goal of R&D activities is the transfer of technology. Broaddus describes the Construction Industry Institute (CII) and its total quality management (TQM) approach to overcoming the barriers that oppose technology transfer. TQM involves customer focus, emphasis on processes, continuous improvement of these processes through innovation, and people involvement.

CII is another example of successful partnership between private industry and academia. It also involves a few public entities. The emphasis is to have products delivered to the industry partners. To accomplish this, CII has used action teams conformed by industry participants to promote implementation of R&D products; educational programs that translate R&D results into course programs for training of construction personnel; and a consistent approach of making implementation "company-friendly."

"Innovation and Technology Transfer Opportunities: Industry/ University/ Government Partnerships," by W. Michalerya

Michalerya illustrates the potential for partnerships among industry, academia, and Government to develop R&D in the public works infrastructure. The Center for Advanced Technology for Large Structural Systems (ATLSS) at Lehigh University is supported by the National Science Foundation and industry partners. This industry partnership is valuable not only in the funding of projects but also in providing timely feedback from potential users of R&D products.

Funding

"Infrastructure Finance: the State and Local Perspectives," by B. Mays

Mays discusses the trend for the reduction in infrastructure spending by the Federal Government, which places increased burden on State and especially on local governments. There are several alternatives available for funding of public works projects, such as debt financing, own-source revenues, and public-private partnerships. However, there are also barriers that interfere with local government access to these alternatives. Mays discusses barriers like constitutional and regulatory constraints, political pressures, etc.

Size and Type of Infrastructure Projects and Facilities

"Performance Challenges to Infrastructure Design: Enhancing the Role of Innovation in Public Works," by J.P. Eberhard

Eberhard claims that the present infrastructure is the result of innovations developed more than a century ago (i.e., telephone, elevator, steel structural systems, indoor plumbing, sewers, automobile, etc.). He asserts that infrastructure innovations can be promoted by describing the functional performance demands for infrastructure systems. These new functional descriptions should be stated in language that is void of any specific solutions: (1) a means of movement for persons and goods, with horizontal and vertical components, (2) a means for communicating between persons and between organizations, (3) a "metabolic" process providing energy, materials, and disposal of wastes, and (4) a shelter for protection and for providing space.

Education, Research, and Technology Transfer

"Issues in Technology Transfer: Sharing Experience Between Manufacturing and Construction," by A. Baskin and S. Lu

Baskin and Lu share their experience in technology transfer for manufacturing support, applicable to construction of infrastructure facilities. They see as obstacles to innovation the fragmentation of the design-construct process, the presence of risk, and the lack of reward for innovators. One of the recommendations is to develop a more integrated approach for facility design and construction that eliminates the antagonistic relationship motivated by the present fragmented approach. They also indicate the potential value of innovative information systems to help in this integration, but caution about information systems that are incompatible with the user's way of doing things. They describe in detail their work in concurrent engineering to support integration of the design-manufacturing process.

"Technology Transfer as a Work-Practice Change Process," by J.M. De La Garza

De La Garza examines technology transfer as the procedure through which an organization adopts and implements innovations. Technology transfer implies change, and opposition to change is always to be expected (fear of change, reduced job performance during implementation, etc.). To promote the transfer and adoption of innovations within an organization, De La Garza recommends, based on his analysis and on his survey of relevant work by others: top management commitment; active change agents; active technology gatekeepers; and a technology transfer task force within the organization. De La Garza illustrates some of the key points with the transfer of computer-aided design and drafting (CADD) technology into the construction industry.

"Financing Capital Improvements Through Technology Transfer: Public-Private Collaboration in Research Commercialization," by M.B. Goldstein

Goldstein proposes strategies to perform technology transfer so research institutions can reduce their risks. He also proposes using the value of knowledge (in the form of innovations) as a possible source of revenue to help finance the solution of infrastructure needs. His premise is that through commercialization of innovations revenue can be raised by research institutions.

Goldstein lists three main alternatives for technology transfer of innovations into the marketplace: commercialization entities, start-up companies, and joint ventures (research institution/private company). He discusses the issue of risk associated with technology transfer. Risk originates by the possibility of occurrence of three major scenarios: economic loss, breach of contract, or harm by a defective innovative product. Goldstein suggests several avenues to control the risk associated with technology transfer based on risk analysis and minimization.

"Technology Transfer and Marketing: Army-Style," by J. Walaszek

Walaszek reviews some of the barriers to the adoption of innovations, categorized in three major classes: ineffective communications, human resistance to change, and organizational and industry constraints. He describes the solution to these barriers within the Army R&D and user community. The solution consists of a technology transfer process as described in Volume 1, Chapter 3. He emphasizes the importance of gathering user input and having user involvement throughout the different phases of the technology transfer process. This guarantees that the R&D products conveniently address the user needs, and that they fit within the operational constraints of the user's environment.

"An Example of Successful Innovation: Three-Dimensional Graphics on Construction Projects," by R. Zabilski

Zabilski describes the successful transfer and implementation of innovative computer-based graphical techniques for the planning and management of construction projects. The mentioned innovation allows engineers to visualize designed components, in place, long before actual construction. This makes for more effective planning and cost estimating of the facilities. The described tools also allow for improved construction control and delivery of as-built information to the owner/operator of the facility. From a general perspective, this paper restates the importance of innovative information systems as aids for the design, construction, operation, and management of facilities.

5 ANALYSIS AND RECOMMENDATIONS

Six Top Barriers to Innovation

The major barriers to innovation were identified in the literature search, then ranked in order of importance by a consensus of workshop participants. The barriers, along with possible methods of overcoming them, are listed in Table 2. The table serves as a concise summary of the findings of the literature search and the workshop. While the importance of the barriers are based largely on a consensus of workshop participants, the authors ultimately ranked them according to practicality as well as relevance. That is, any barrier that is practical to address *now* was considered of greater significance than an equally important barrier that cannot be practically addressed in the current environment. Nevertheless, some of these priorities do indeed require thinking beyond the political, social, and economic constraints of the 1990s. The authors believe such forward thinking is necessary if the public works infrastructure is to serve the nation reliably into the 21st century and beyond.

The text that follows summarizes key ideas offered by workshop participants. Readers interested in their contributions to this study can find the full text of their articles in Volume 2.

Create a Federal Focus Responsible for Defining National Infrastructure Policy and Vision

One of the most important and critical barriers is the lack of direction at the Federal level to guide the national strategy and vision for the U.S. public works infrastructure. Hawkins, Magnell, Walton, and White stress the need, either explicitly or implicitly, for a Federal vision and catalyst to lead and revitalize infrastructure R&D and technology transfer. With the creation of a Federal vision to guide the search for innovative infrastructure technologies and supporting policies, many other barriers will start to be addressed automatically. Therefore, it is considered a top priority that a Federal initiative be undertaken that will act as the national catalyst for innovation in the public works infrastructure. Although such an endeavor will not be simple, there are signs of a growing consensus for such an effort, including: (1) a similar recommendation by the Office of Technology Assessment, (2) supporting research and a workshop conducted by the National Science Foundation on civil infrastructure research, and (3) identification of revitalization of public works infrastructure as one of the top research thrusts at the National Civil Engineering Research Needs Forum, sponsored by CERF.

A Federal catalyst for innovation in the public works infrastructure would provide needed direction in R&D and help develop an integrated approach to design and construction that would help eliminate the antagonistic relationships promoted by the present fragmented approach. Such Federal involvement would be instrumental in fostering intergovernmental partnerships with state and local governments to develop better financial and political mechanisms for promoting innovation, promoting coherence in the currently fragmented approach to infrastructure R&D, and coordinating international R&D efforts for innovative infrastructure technologies.

Effective Technology Transfer Mechanisms

The barrier judged to be the second highest priority is the lack of an effective innovation and technology transfer mechanism. The inadequacy of current mechanisms inhibits public and private partnership in R&D and, as a consequence, a vicious cycle repeats: opposition to innovative technologies because businesses and public works agencies are reluctant to use innovations without a successful track record.

Table 2: Barriers to Innovation Transfer

Barrier	Methods to Overcome
Lack of a Federal initiative (focus) for defining the policy and vision for national infrastructure technology (R&D). Diverse and fragmented governmental structure and private sector organizations dealing with infrastructure; fragmented R&D efforts throughout the nation.	Create a comprehensive Federal initiative to establish a national infrastructure policy that will: (1) Act as a catalyst for innovation; (2) Keep abreast of international R&D for new technologies; (3) Foster intergovernmental partnerships between State and local governments to develop improved fiscal and political tools for promoting innovation.
Inadequate technology transfer mechanisms. Lack of public- and private-sector R&D cooperation; lack of R&D partnerships between the public and private sectors.	Develop adequate technology transfer mechanisms and commit necessary resources to support them; greater leadership from all levels of Government in support of R&D programs, and development of incentives to reward R&D investment by the private sector.
Lack of public awareness. Public opposition; discordance with widespread cultural values; "not invented here" syndrome; emphasis on short-term benefits, not long-term benefits to the nation.	Active partnership with community groups; building awareness and support groups; communicate with Congress; create mechanisms to resolve controversy; effective education related to key technologies and relevant research; communicate the importance of innovation in a national context.
Complexity of regulations. Governmental technical standards and regulations are complex and sometimes contradictory; increasing rate of legal challenges; obsolescence of regulations.	Developing flexible standards to accommodate technological and design innovation; regular review and appropriate revision of regulations affecting major technologies.
Reluctance to innovate for fear of legal liability. Conservative approaches intended to reduce potential risks; highly visible and publicized failures are penalized while successes go unrewarded; reluctance of financial institutions to fund infrastructure projects with unusual potential risks.	Risk-sharing to encourage innovation; peer evaluation of innovation; demonstrations of innovation, adequately monitored and documented; dissemination of the findings of the demonstrations to all potential users.
Inadequate organizational management for innovation adoption. Resistance to innovation that did not involve the user in defining the problem and specifying the solution; resistance to change; lack of flexibility in regulations; emphasis on short-term, high-visibility results; tendency to cut funding for "unglamorous" public works programs in favor of more visible programs.	Promote top management commitment; nurture active change agents; empower active technology gatekeepers and technology transfer task forces; comprehensive user training programs; promote Total Quality Management (TQM) of all the processes in innovation and technology transfer; innovative financing of public works projects.

Baskin and Lu, Broaddus, Hawkins, Lemer, Mays, Sullivan, Walton, and White offer numerous useful ideas for improving technology transfer mechanisms (see Volume 2). Their recommendations include (1) development of incentive programs to reward R&D investment by the private sector, (2) formal demonstration of innovation, effectively monitored and documented, (3) supporting technology transfer through peer diffusion, and (4) stronger leadership at all levels. Whatever specific recommendations are followed, it is clear that any adequate technology transfer mechanism will require a commitment of resources to support the mechanism through peer interchange of information and a dedicated information clearinghouse. (The author's recommendation for a national technology transfer mechanism follows discussion of the priorities.)

Creating Widespread Public Awareness

The public's lack of awareness of the impact of the public works infrastructure on the nation's economy and basic quality of life was considered the next most important barrier. This judgment is supported by the workshop presentations of Garza, Hawkins, Nowak, and Walaszek. Some of the successful innovations in public works projects have overcome this barrier through partnerships with community groups, awareness committees, and support groups. Also helpful in this connection would be the creation of formal mechanisms to resolve public controversy, such as expert panels and referees. Effective education in key technology areas, more targeted research through increased support of universities, and portraying the importance of innovation in a national context would also help break down the awareness barrier. It would be helpful to involve national groups such as the Rebuild America Coalition in any the national awareness campaign on the importance of the public works infrastructure. Current public awareness programs related to environmental issues could also tie in to this effort because many aspects of environment and infrastructure are virtually inseparable.

Simplifying Regulations

The complexity of regulations is considered a high-priority barrier. Increasingly stringent governmental technical standards and regulation result in complex—sometimes contradictory or obsolete—regulations, and inhibit steady use of innovative technology. This barrier, and methods for overcoming it, were addressed by Lemer, Magnell, Walton, and White. It is recommended that any national center of responsibility for innovation should consider the integrity of all relevant regulations and propose useful simplifications, assist regulating bodies in periodically revising regulations that affect major technologies, and explore the possibilities of developing flexible standards to accommodate design innovations.

Reducing Risk and Fear of Liability

The general consensus of workshop participants was that the reluctance to innovate due to fear of liability is a major problem, but difficult to attack. This barrier was discussed in many articles in the literature survey and from the workshop, especially in Seemann's presentation and Goldstein's article. Suggestions for overcoming this barrier included sharing risk to encourage innovation; more systematic peer evaluation of innovations; formal demonstration of innovations, effectively monitored and documented; and dissemination of demonstration findings to all potential users. Also, a national center for innovation in infrastructure could help overcome fear of liability by taking strong leadership in helping to revise laws and regulations into more integrated and simpler forms.

Organizational Management for Innovation Adoption

This sixth priority, inadequate organizational management for promotion and adoption of innovations, must be addressed locally or within organizations. Broaddus, Garza, Michalerya, Walton, Walaszek, and Nowak all stress the need for supportive organizational management as a key to effective innovation.

It is recommended that the commitment to innovation and technology transfer be actively promoted among top management within organizations. Also, technology transfer task forces within organizations, including active change agents or technology gatekeepers should be fostered. Comprehensive user training programs at the organization or agency level also should be promoted.

A National Technology Transfer Process

In addition to the lack of a national catalyst for infrastructure technology transfer, it is clear that many related obstacles impede a nationwide application of a technology transfer process. The current approach to infrastructure R&D is very fragmented in terms of regional or topical interests, is not driven by a common vision, and does not take advantage of useful developments in other disciplines. This fragmentation implies a very inefficient use of the R&D resources. There is lack of synergy and leverage among research efforts.

Several major recent reports recommend an extended role for innovation in the public works infrastructure.[129,130,131,132] In general, these reports focus on high-level legislative and executive policies. The authors propose that there are useful opportunities on a more modest scale that may be addressed without waiting for any major new policy initiatives. Specifically, the authors propose enhanced methods for promoting innovation that offer an incremental improvement over relevant technology transfer efforts that currently exist or are being planned. These efforts could be integrated to complement each other in promoting the development and transfer of innovation for the public works infrastructure. On a fundamental level, these recommendations correspond to the technology transfer model proposed by Shaffer and complemented by Walaszek.[133,134] As discussed in Chapter 3, many of the issues addressed in the Shaffer model are rooted in the Rogers model or discussed by Nowak. Figure 2 shows the major phases of technology transfer, as derived from these authors. The phases are:

1. *Identification of User Needs.* The origin of R&D activities in a technology-transfer-oriented environment is the need to satisfy user needs. Success at this requires effective communication between researchers and potential users of the developed solutions, and a clear understanding of the needs and priorities of the potential users.

2. *Research and Prototyping.* This phase involves the generation of solutions to the identified problems and needs. Existing technologies are surveyed to identify any existing innovations that may be adaptable to user needs. Whether the solution is an application of existing technology or a new R&D product, a laboratory-based test (or pilot test) is performed to verify that solutions meet user needs. If the result is not satisfactory, the R&D-produced concept is either adjusted or discarded.
3. *Test and Evaluation.* The proposed R&D solution is further refined and enhanced. The solution is then evaluated by means of a demonstration project performed under field conditions. As in Phase 2, the proposed solution is rejected or sent back to the drawing board if performance is

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[129] "Infrastructure for the 21st Century," National Research Council (Washington, DC, 1987).

[130] "Fragile Foundations," National Council on Public Works Improvement (February 1988).

[131] "Construction and Materials Research and Development for the Nation's Public Works" Office of Technology Assessment (June 1987).

[132] "Delivering the Goods: Public Works Technologies, Management, and Financing," Office of Technology Assessment (April 1991).

[133] Shaffer, L.R., "Product/System Development for Military Facilities," from the briefing on Technology Transfer Test Bed concept, U.S. Army Construction Engineering Research Laboratory, Champaign, IL (1985).

[134] Walaszek, J.A., "The Role of Communications Within Technology Transfer Activities of the U.S. Army Construction Engineering Research Laboratory," USACERL Technical Manuscript (July 1987).

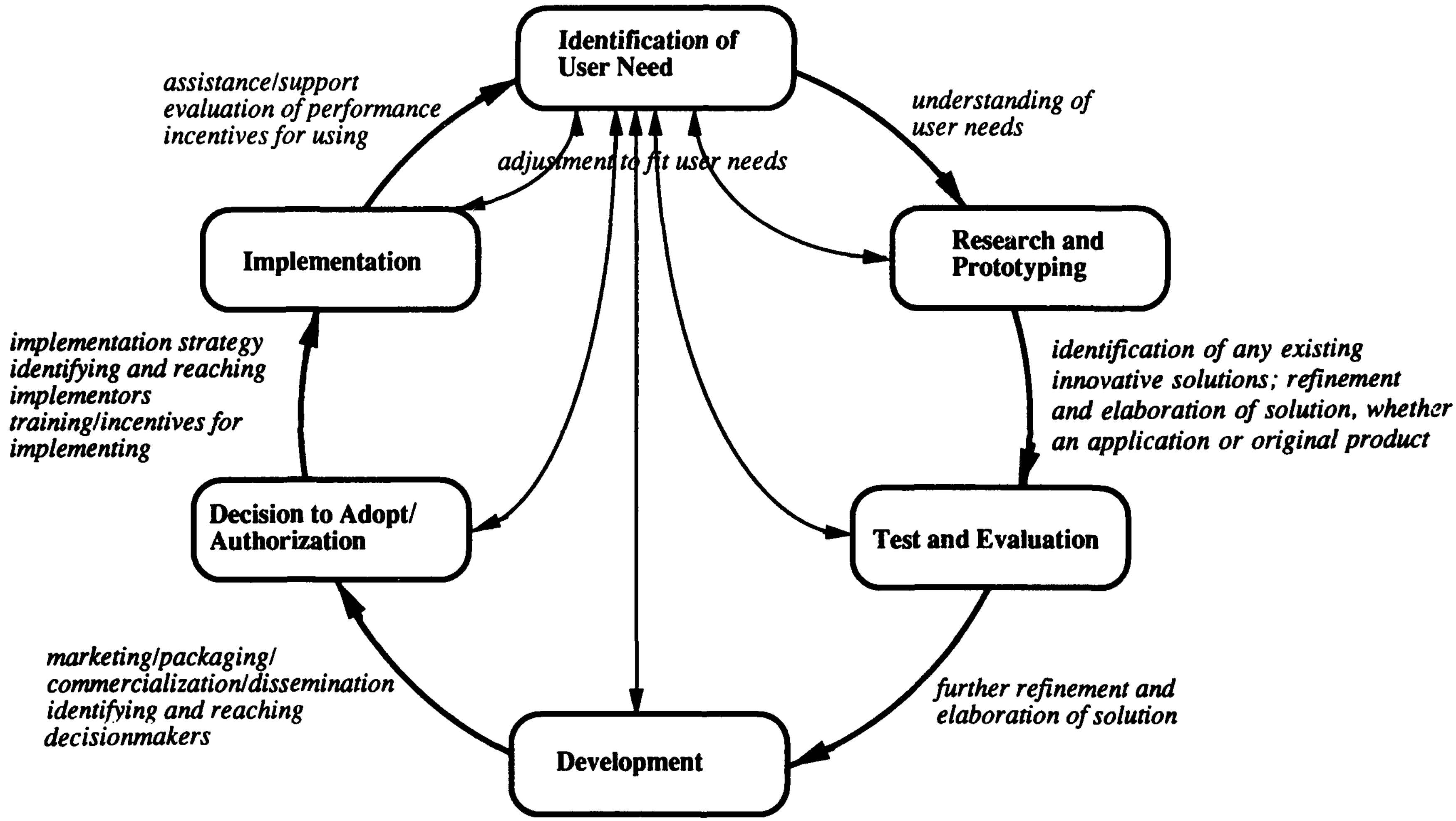

Figure 2. Technology Transfer Phases (adapted from Shaffer and Walaszek).

unsatisfactory. The results of the field demonstration are communicated to potential users.

4. *Development.* This phase includes additional refinement of the R&D solution for the targeted customer, and includes the packaging, marketing, commercialization, etc., required to produce a useful and deliverable product to potential users.

5. *Decision to Adopt or Authorization.* After a satisfactory field demonstration, the R&D product is packaged, marketed, commercialized, and distributed. Dedicated efforts are required to reach key decisionmakers within an organization of potential users.

6. *Implementation.* In this phase it is crucial to communicate with the people in the organization who implement new technologies. All necessary training must be provided. Incentives can be used to facilitate both the implementation and regular use of new technologies. After implementation, the developer of the technology must continue to provide the necessary technical support and assistance. Performance evaluation of the implemented innovation documents valuable information for future users.

This technology transfer model is based on continuous and consistent communication between the provider of new technologies and the potential and actual users. The goal of this communication is to ensure that the user's needs are truly addressed by the providers of R&D products.

Key elements of a technology transfer process based on the Shaffer model are (1) a coordinated effort among Government, academia, and industry to promote an integrated R&D effort, (2) an independent, formal testing and demonstration capability to promote greater confidence in innovative technologies, similar to the Japanese Public Works Research Center (as described by CERF[135]), and (3) a more coordinated and aggressive effort in disseminating new technologies. Figure 3 summarizes the recommendations for improving the development and transfer of new technologies. The following paragraphs describe these recommendations in detail.

Immediate action can be taken to more actively transfer innovations that are currently available, but unknown to many potential users. An inventory of newly developed technologies could be created and disseminated through technology information centers, as shown in Figure 3. An effective way of communicating about these new technologies would be through a computer-based information system accessible to public works entities, as suggested in the workshop discussions. Such an accessible on-line information resource could alleviate one of the barriers identified by Nowak—the scarcity or unavailability of information about innovations.

[135] "Transferring Research Into Practice: Lessons From Japan's Construction Industry," Civil Engineering Research Foundation, Japan International Research Task Force (November 1991).

Federal Initiative for Innovation in the Public Works Infrastructure

Longer-term actions should be directed towards constructing a Federal initiative that will have enough nationwide influence to lead R&D and technology transfer efforts for the public works infrastructure. As shown in Figure 3 this initiative should be responsible for coordinating and managing intermodal (cross-cutting) public works infrastructure R&D and technology transfer, and should assume a leading role in partnerships with university, industry, and Government laboratories. As recommended in the workshop discussions, this Federal catalyst for R&D **should not be a separate new bureaucracy, but should use existing processes, programs, and administrative structures** whenever possible.

This task can be accomplished by expanding the responsibilities of a number of existing Federal programs. Four options are proposed:

1. Existing institutions such as the Office of Science and Technology Policy (OSTP) could be utilized to manage a Federal infrastructure initiative, while the Federal Coordinating Council for Science, Engineering and Technology (FCCSET) could be used to coordinate it. The FCCSET is an efective planning tool for improving the coordination and efficient use of Federal R&D resources. Interagency research and education efforts brought together under FCCSET include the High Performance Computing and Communications, Advanced Materials and Processing, Biotechnology Research, Advanced Manufacturing R&D, and the U.S. Global Change Research Program. Although the FCCSET cannot manage the Federal R&D programs, the OSTP could be empowered to implement the infrastructure R&D policy and vision developed in coordination with the FCCSET. Because the OSTP and FCCSET are components of the Executive Branch, their effectiveness is limited by the lack of a comparable R&D review process within the Congress.[136] Therefore, if a complementary Congressional review process was introduced into the Office of Technology Assessment and the OSTP and the FCCSET were empowered to plan and coordinate Federal R&D programs, a proactive comprehensive infrastructure initiative could become a reality.

2. The existing framework of the Federal Laboratory Consortium could be used to identify regional R&D centers of expertise for the various infrastructure technologies within the Federal Laboratory community. These laboratories could then be empowered to identify and prioritize national R&D needs, and develop, evaluate, and demonstrate new infrastructure technologies.

3. A central agency could be assigned to organize and manage the overall initiative. Some Federal agencies have experience in managing infrastructure related R&D programs that involve partnerships among Government, academia, and industry. Three agencies with multi-discipline infrastructure experience are the National Institute of Standards and Technology (NIST), U.S. Army Corps of Engineers (USACE), and the National Science Foundation (NSF). The USACE has experience in directing the Construction Productivity Advancement Research program (CPAR), and two Corps laboratories, the Construction Engineering Research Laboratory (USACERL) and the Waterways Experiment Station (USAWES) have major R&D efforts in public works infrastructure. The NSF operates the Engineering Research Centers and is in the process of developing a major thrust area directly focused on infrastructure, as indicated by its recent workshop self study paper on the subject.[137]

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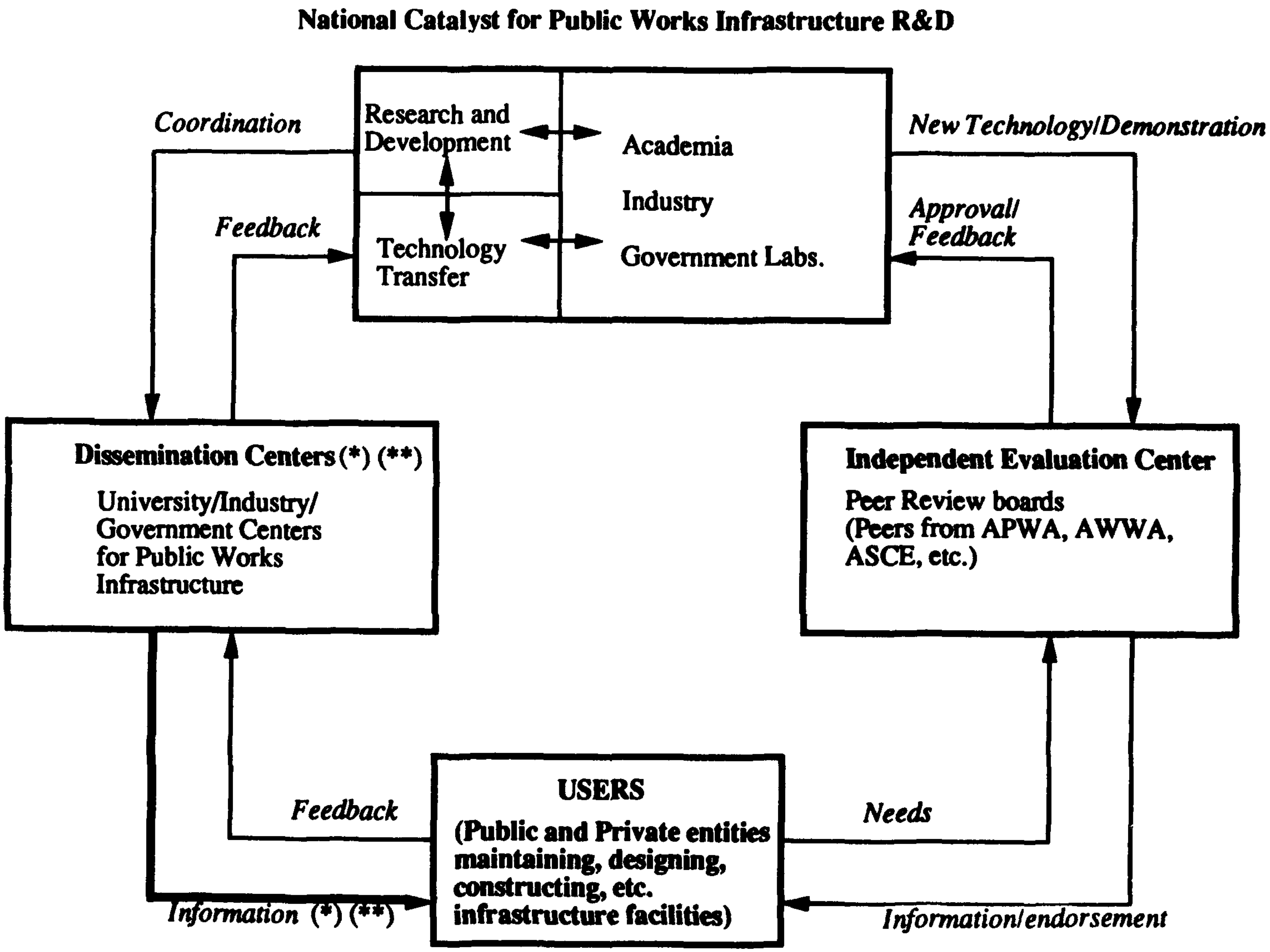
[136] "Improving the Coordination of Federal R&D Activities," Budget Baselines, Historical Data, and Alternatives for the Future, Office of Management and Budget, FY 1994 Bush Administration Budget Material Provided to Congress, 6 January 1993.

[137] "Civil Infrastructure Systems Research: A Self Study of the National Science Foundation Role," unpublished report prepared by NSF CIS Task Committee (March 1992).



(*) Recommended immediate action.
(**) In the long term these dissemination centers will become technology transfer centers, providing not only information on new technologies, but implementation assistance, support, and training.

Figure 3. Strategy for Public Works Infrastructure R&D and Technology Transfer (IRTT).

4. Another alternative could be a partnership between government bodies, academia, and industry. As proposed in the previous section, major technology transfer assistance could be provided by technology information dissemination centers. These dissemination centers could evolve from being information providers into active facilitators of technology transfer. Their role would be to assist and support the implementation of innovations, including training for the users of the innovative techniques. Currently, Columbia University, MIT, and other prominent research institutions have proposals to develop national infrastructure centers involving a partnership of universities with State and local government entities. These proposals could be the basis for establishing these and other organizations as national facilitators of technology transfer.

Independent Technology Evaluation Center

Many of the sources surveyed, as well as workshop discussions, indicate that the testing and demonstration of new technologies are key steps in a successful technology transfer process. In particular, tests and demonstrations help to mitigate risks for the potential user by proving innovative techniques in real-world situations. The evaluation of tests and demonstrations is most valuable and credible if performed by independent, universally respected parties. It is proposed that peer evaluation of new concepts and demonstration projects be performed by an independent evaluation center, possibly under the responsibility of the National Academy of Engineering. Participants in such a center should include technical and professional associations such as APWA, AWWA, ASCE, ASTM, and others. This proposal corresponds substantially to the Innovation, Test, and Evaluation Centers (ITEC) proposed by Bernstein.[138]

Key Tasks for National Coordination of Infrastructure R&D

Based on the authors' suggestions for a national strategy for innovation and technology transfer in the public works infrastructure, all the partners in the coordination of R&D and technology transfer will need to accomplish the following key tasks:

1. Identify public works needs that can be solved through R&D.
2. Coordinate efforts of public and private researchers to satisfy these user needs through R&D. This includes prioritizing needs, allocating funds, contracting, and supervising research efforts.
3. Develop a testing and demonstration program for new technologies to minimize risk and document relevant information for potential users.
4. Communicate R&D solutions to potential users through some form of information dissemination center, with assistance from an independent evaluation center that offers rigorous peer review of concepts and technologies.
5. Develop an implementation strategy in coordination with the potential users. This includes the packaging, promotion, distribution, funding, training, and user support of innovations to be transferred, with the ultimate goal of user self-sufficiency.
6. Evaluate performance of innovations in actual use to: add the performance information to the information package of every innovation; and to redesign/refine/fix the innovations as necessary.
7. Identify and secure the funds necessary for the operation of this technology transfer process. Possibilities include (1) creation of a public works infrastructure bank, funded by Federal and State grants, to finance the demonstration and implementation of innovations and (2) promoting greater participation by the private sector.

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[138] Bernstein, H.M., "Is Innovative Engineering Becoming Extinct in the U.S.?," American Consulting Engineer, Vol 2, No. 4 (1991).

There are also complementary actions recommended to help the user community (public works agencies and private entities that design, construct, and maintain infrastructure) close the technology transfer gap. Immediate actions that would make organizations more receptive to innovations include:

1. Supporting internal technology champions.
2. Developing mechanisms to reward innovators, minimize the impact of innovation failures, and increase the tolerance of failure in innovation.
3. Promoting an active technology gatekeeping function, which conducts a continuous and aggressive search for new technologies to solve current problems.

Longer-term actions that would promote the use of innovative technologies at the organization level include:

1. Development of training programs, mechanisms to prevent and address the failure of innovations, public support through community involvement in infrastructure technology issues.
2. Participation, in partnership with R&D entities, in the identification of problems and needs where R&D can contribute with solutions. Also, participation in the development of the solutions (throughout the technology transfer process).

Qualified technical and managerial personnel are an essential resource for continued improvement of the role of innovation in the public works infrastructure. As recognized by ASCE, OTA, and others, it is important to motivate young, talented people to pursue their careers in fields related to the design, construction, operation, and maintenance of the infrastructure.

Additionally, it is necessary to reduce risk for innovators. Seemann, Bernstein, and others recommend several risk-mitigating alternatives, including (1) peer review to validate and endorse innovative ideas before they are tried in the field, (2) field demonstrations to eliminate many risk-provoking uncertainties, (3) imposition of caps on liability suits, and (4) risk-sharing mechanisms involving all parties, including legal, insurance, and financial firms. Another important recommendation, emphasized in workshop papers and discussions, is the risk-mitigating role of the Federal Government. In cases such as demonstration projects, the application of innovations in the field is not possible unless the Federal Government assumes a considerable portion of the risk. Useful precedents exist, such as USEPA's Alternative and Innovative Technology Program, tried in the late 1980s, and the ISTEA's provisions for demonstration projects.

Systematic Transfer of Existing Technologies

While establishing a national catalyst for innovation and technology transfer is a top priority, success will not come quickly. However, many shorter-term efforts can be undertaken to "set the stage" for this change. An important example of such an effort is the transfer of currently available technology.

Several models for effective technology transfer, including those by Rogers, Shaffer, and NASA, were studied in depth and discussed in Chapter 3. A comparison of different phases of the three models is summarized in Table 3. These models are similar, but place varying emphasis on different phases of the technology transfer process. Rogers emphasizes the perspective of the organization that desires to adopt the technology. Shaffer's paradigm covers the entire process, from the inception of research ideas to the implementation. The NASA model addresses the transfer of existing technology to the commercial market.

From these three models the authors have derived a more detailed and expanded model called "Delivery of Currently Available Technology," or the DCAT model. This model is proposed to help develop a mechanism to more effectively deliver currently available technology to users. As the name suggests, this model emphasizes the delivery of technology, incorporating features of the Rogers, Shaffer, and NASA models. A schematic of the model is displayed in Figure 4.

The DCAT model is enhanced to include promotion of innovation and existing technology that is not used widely in the public works infrastructure. It attempts to provide detailed steps for integrating related efforts in ways that complement each other to promote the delivery of technologies that are not widely distributed or recognized.

- Step 1 of the proposed model for innovation and technology transfer is to identify, clarify, and prioritize the user's needs. This corresponds to the first step of both the Rogers and Shaffer models. Another element of step 1 is the matching of the need with existing technology. This step is missing from Shaffer's model, but may be considered implicit in the act of problem identification. However, the authors consider it important to include this step as a separate one to highlight the importance of exploiting existing innovation to avoid "reinventing the wheel," which represents a major waste of effort and resources.

- As noted above, Step 2 of this model is to adjust any existing innovative method or technology to meet the need clarified in Step 1. This is necessary when a perfectly applicable technology is not already available. This step may require minor changes to an existing technology. If it is necessary to make a major effort to modify the existing technology, the benefit will need to be measured against the cost of the required changes.

- Step 3 is to evaluate market potential. It may be advisable to perform this evaluation concurrently with Step 2, because it may not be worthwhile to continue working on adjustment of an existing technology if there is no market potential for doing so. In this context, lack of market potential means lack of potential users of the innovation. This is not to say that basic research is unnecessary, but for public works infrastructure the need to implement appropriately modified existing technologies is more urgent for improving the state of the declining national infrastructure.

- Step 4 is to conduct small-scale preliminary testing, either in the research setting or a small number of test sites. For this step, it would be ideal if the independent evaluation center described previously were established to provide independent evaluation and peer review. Assuming that establishment of an evaluation center will take some time, it will be necessary to rely on professional scientific, technical, and engineering societies or potential users for evaluation of innovative technologies.

- Step 5 is to identify demonstration partners willing to try to support use of the innovative method or technology. This partner will act as a champion of the new technology—a change agent within the user community.

Table 3: Comparison of Models for Generating and Disseminating Innovation

Categories of Comparison	Rogers Model	Shaffer Model	NASA Model
Identify Need	Seeking new technology for needs of the organization	Problem identification and its communication to research community	Identification, clarification, and prioritization of problems
Survey of Existing Technology	Matching the need with an existing technology	Identify any existing innovations that may be adaptable to user needs.	Matching problems to an existing technology
Basic and Applied R&D	Reinventing an innovation to adjust to the identified need	Research and prototyping	
Market Evaluation			Evaluation of market potential
Test and Evaluation		Test and evaluation	
Technology Demonstration Project Partner Identification			Identifying a demonstration partner
Conduct Technology Demonstration Project	Clarifying applicability to the members of organization		Establishing demonstration projects
Commercialization		Development and refinement	Feedback from demonstrations
Authorization	Use of innovation becomes routine within the organization	Authorization or decision to adopt	
Application		Implementation	

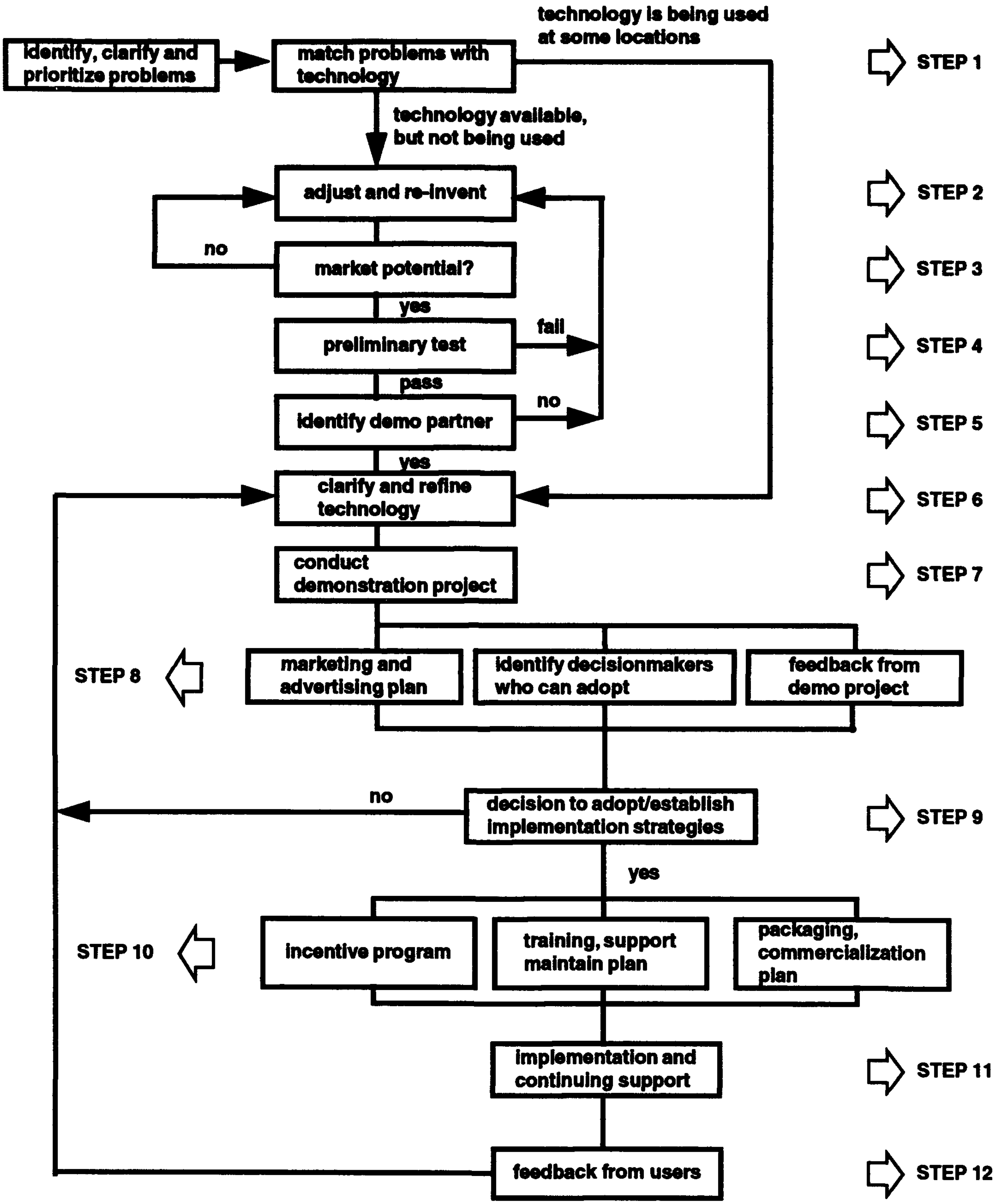

Figure 4. Proposed Mechanism for Delivery of Currently Available Technology (DCAT).

- Step 6 is to clarify and refine the innovation or technology to satisfy the needs of the potential user.

- Step 7 is to establish demonstration projects using information collected in Steps 5 and 6. The size of the demonstration will depend on the estimated benefits of the new technology. The greater the expected benefits, the larger the scale of the demonstration should be to credibly prove the technology, so it will be more widely distributed and accepted.

- Step 8 is to develop a marketing communications plan for the new technology once the demonstration projects are going well and have good support from the demonstration partners. To ensure successful delivery of the innovative technology, it is very important to communicate the availability of the product to potential users. Good commercial products can fail due to inadequate marketing communications. Another element of Step 8 is to develop plans to identify and communicate with key decisionmakers. This step can be considered part of the marketing process, but it was separated to highlight the importance of recognizing the impact of these decisionmakers on the adoption of new technology. These decisionmakers are often political appointees or elected officials who tend to value short-term, high-visibility results. To convince key decisionmakers to support a new technology, it is necessary to help make them aware of it or support changes in their current performance standards to put more importance on achieving long-term benefits. A third element of Step 8 is to collect feedback from users at demonstration sites to identify potential problems and develop suitable processes to transfer the technology.

- Step 9 involves adopting the technology and developing implementation strategies. Rogers called this step *routinizing*. To routinize, it is necessary to establish effective implementation strategies. Without this step, a new technology will not be used routinely.

- Step 10 is to develop incentives for using the technology. These incentives can be designed for use at various levels. For example, Federal, State and local governments could offer tax incentives and low-interest loans, while private companies could establish suitable programs to encourage employees to use the new technology. A second element of Step 10 is to develop a training, support, and maintenance plan for the new technology. A third element of Step 10 is to develop a packaging and commercialization plan, to enhance delivery to the user community at large.

- Step 11 is to implement and provide continuing support of the new technology.

- Step 12 is to improve the technology through periodic collection of feedback from users. This step will provide a measure of the ultimate success of the entire DCAT mechanism, and may also identify phases of the process that require enhancement in the future.

Application of this model as a mechanism to deliver currently available innovative methods and technologies for public works infrastructure will greatly facilitate technology transfer, and wider use of Government-sponsored R&D products. To support the DCAT mechanism, dissemination centers should be established for various infrastructure areas, such as: (1) highways and bridges, (2) mass transit, (3) aviation, (4) water supply, (5) water resources, (6) solid waste, (7) hazardous waste, (8) communications, (9) power and energy, and (10) public buildings. Each center could immediately start collecting updated information on user needs and potentially applicable technologies that already exist, then develop improved processes for delivering it to potential users. An effective way to communicate information on available technologies to appropriate potential users may be through development of computer-based information systems containing information on available technologies not currently in wide use by public works entities. Improved on-line access to this type of information could alleviate one of the barriers identified at the workshop by Nowak—the scarcity or unavailability of information about pertinent innovations. Each center could be located at universities, Government research centers, or private industry partners, but good coordination would be necessary to continuously collect all available information on innovative methods and technologies. Strong coordination will also be necessary for uniform adoption of the 12-step DCAT process as appropriate.

The authors are confident that technology dissemination centers, as described in this report, will be highly successful in delivering available technologies to potential users by following the 12 steps outlined in Figure 4.

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ABBREVIATIONS AND ACRONYMS

APWA	American Public Works Association
ARTBA	American Road and Transportation Builders Association
ASCE	American Society for Testing and Materials
AWWA	American Water Works Association
BRB	Building Research Board
CADD	computer-aided drafting and design
CERF	Civil Engineering Research Foundation
CII	Construction Industry Institute
CPAR	Construction Productivity Advancement Research
DCAT	Delivery of Currently Available Technology (model)
FCCSET	Federal Coordinating Council for Science, Engineering and Technology
FY	Fiscal Year
GFRC	Government Finance Research Center
GNP	Gross National Product
IDOT	Illinois Department of Transportation
IRTT	Public Works Infrastructure R&D and Technology Transfer
ISTEA	Intermodal Surface Transportation Efficiency Act
IWR	Institute for Water Resources
MIT	Massachusetts Institute of Technology
NASA	National Aeronautics and Space Administration
NCMS	National Center for Manufacturing Sciences
NCPWI	National Council on Public Works Improvement
NHWA	National Highway Association
NSF	National Science Foundation
NSPE	National Society of Professional Engineers
O&M	operations and maintenance
OSTP	Office of Science and Technology Policy
OTA	Office of Technology Assessment
PWIS	public works infrastructure
R&D	research and development
SHRP	Strategic Highway Research Program
TQM	Total Quality Management
TRB	Transportation Research Board
UIUC	University of Illinois at Urbana-Champaign
USACE	U.S. Army Corps of Engineers
USACERL	U.S. Army Construction Engineering Research Laboratories
USEPA	U.S. Environmental Protection Agency

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 1993

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
The Federal Infrastructure Strategy Program - Challenges and Opportunities for Innovation in Public Works Infrastructure - Volume I

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Construction Research Laboroatory
P.O. Box 4005
Champaign, ILinois 61820-1305

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Corps of Engineers
Water Resources Support Center
Institute for Water Resources
Casey Building
Ft. Belvoir, VA 22060-5586

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
IWR Report-93-FIS-2

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report provides the Federal Infrastructure Strategy Initiative with a "snap-shot" in time of Federal resources committed to intrastructure research and development (R&D). Resources are defined as levels of funding, and the number of Federal laboratories engages in infrastructure related R&D. This is the second in a series of interim reports prepared to support the Federal Intrastructure Strategy Initiative, a 3-year program to explore the development of an integrated multi-agency Federal infrastructure strategy.

14. SUBJECT TERMS
Infrastructure, engineering, innovation, public works, research and development, Federal funding

15. NUMBER OF PAGES
81

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std Z39-18
298-102