A STUDY TO RECOMMEND MEASURES OF THE BENEFITS OF INFRASTRUCTURE RD&T

FINAL REPORT

To

Turner-Fairbanks Highway Research Center
6300 Georgetown Pike
McLean, VA 22101

APRIL 29, 2003

Prepared by

Battelle
. . . Putting Technology To Work

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In association with

Civil Engineering Research Foundation
DeLapide and Associates
Wilbur Smith and Associates

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Disclaimer

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Executive Summary

The Federal Highway Administration's (FHWA) Research, Development and Technology (RD&T) Program directly supports the goals of the U.S. Department of Transportation (DOT) and the FHWA, to invest strategically in transportation infrastructure, to promote safe and secure transportation, to enhance our environment, and to create new alliances between the Nation's transportation and technology industries. The Office of Infrastructure R&D (HRDI) continually improves the nation's infrastructure by conducting high quality research with a national scope and focusing on national interest. Research needs are continuously identified through outreach processes by HRDI researchers with their state and local governments and industry counterparts. HRDI pursues advanced research initiatives, which are outside the realm of State highway agencies.

With HRDI's commitment to high quality research, there is the need to assess its programs to maximize resources and yield greater benefits. The assessment process involves not only identifying the benefits of research anecdotally, but also quantifiably. The establishment of a viable and meaningful system of performance measurements will enable HRDI research managers to take stock of where they currently stand and more accurately assess progress toward program objectives, and the goals of the agency and the Department. The primary objective of this project is to develop a framework for assessing the benefits of infrastructure research within the Office of Infrastructure R&D. A secondary objective will be to share these measures within the RD&T organization for the purpose of developing a comparable suite of measures quantifying the benefits of their own research. It is envisioned that the benefits assessment framework will be applicable to other research conducted by the Federal Highway Administration.

Benefits Assessment Framework

This report presents a description of the benefits assessment framework. The framework was developed by studying the selected research studies conducted by the Office of Infrastructure R&D of the Federal Highway Administration at the Turner Fairbanks Highway Research Center. The major parts of the framework, the performance measures, and surrogate measures are summarized in Table ES-1.

- Part A deals with research outputs and the metrics are quasi-quantitative.
- Part B deals with cost savings associated with implementation of research products and these metrics are quantitative.
- Part C assesses the environmental impacts of implementing the research products. The metrics are qualitative.
- Part D deals with customer satisfaction with the research products. The metrics are qualitative.

Table ES-1. List of Performance Measures

Part	Performance Measure	Type of Measure
A	**Research Output and Usage** • Achievement of research objectives • Types of Products from Research • Adoption for Implementation • Extent of Use/Number of Users of Research Product	Quasi-quantitative
B	**Cost Savings** • Agency costs (capital and operation) • User costs • Safety costs • Cost of research	Quantitative
C	**Environmental Impacts** • Air quality • Noise • Wetland and nature • Recycling • Aesthetics	Qualitative
D	**User Satisfaction** • Awareness • Access • Acceptability • Use • Value	Qualitative

The performance measures were selected based on results of the data analysis to cover a wide range of attributes so that benefits of HRDI research can be properly and adequately evaluated. The performance measures have been defined at a high level of detail so that the framework can be used to evaluate research projects as well as research programs.

In the framework, each performance measure has the following components.

- Definition of the performance measure or surrogate measures
- Research areas to which the measure is applicable
- Potential sources of data for performance measures
- Table for analyzing performance measures
- Notes and guidelines explaining the analysis.

The outline of the benefits assessment framework is shown in Figure ES-1.

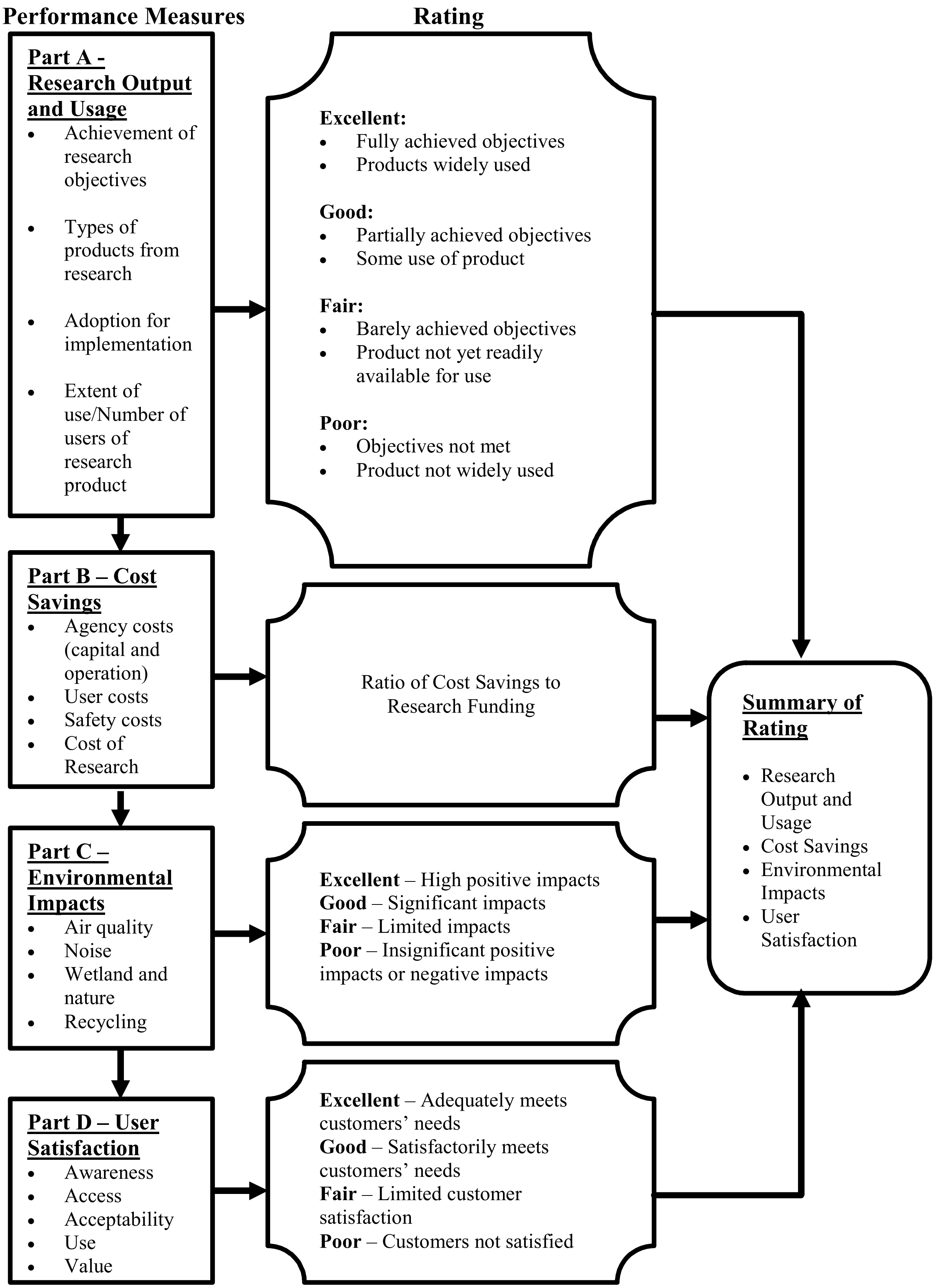

Figure ES-1. Outline of Benefits Assessment Framework

Conclusions and Recommendations

The guiding principle in the development of the performance measures and assessment framework was to ensure that the measures are relevant, that they capture all types of research activities, that they are objective enough to highlight the benefits and weaknesses of research programs and projects, and above all, simple enough to be easily understood and applied. To ensure that all research areas are covered, several surrogate measures were identified for the various measures. In applying the framework, several data sources were identified for each performance measure.

The final output of the benefits assessment framework is visualized as a report card where grades are assigned to the various components. Poor performance in one area does not necessarily lead to the conclusion that the program is a failure. The relative merits of the various components of the framework need to be considered in assessing the overall benefits of the program in any given year. In comparing any two research programs, it is also important to consider other external elements, such as strategic goals of each research program.

The core of the benefits assessment framework is data availability, especially on costs and customer satisfaction. In order to have access to relevant data, it is recommended that program managers maintain close links with users of their research products. In this regard, formal mechanisms for tracking and user feedback from state DOTs, AASHTO, and other customers should be established and maintained. It is recognized that depending on the research product, customer satisfaction may not be immediate and may occur several years after the product has been implemented. Periodic surveys or contacts with users (say 3-5 years depending on the product) may be helpful in assessing the usefulness of HRDI's research products.

In applying the framework to new and potential projects, it is recommended that assumptions and educated guesses of the data required be made and justified accordingly. It is recommended that results of the assessment be updated as new data becomes available.

It is recommended that the performance measures be reviewed periodically and the framework updated as needed to ensure consistency as the future directions of the research programs change. Additionally, it is recommended that this framework be converted into a decision support software tool that HRDI program and project managers can use in assessing benefits as well as in evaluating the success of their research programs.

1. Introduction

1.1 Background

The Federal Highway Administration's (FHWA) Research, Development and Technology (RD&T) Program directly supports the goals of the U.S. Department of Transportation (DOT) and the FHWA, to invest strategically in transportation infrastructure, to promote safe and secure transportation, to enhance our environment, and to create new alliances between the Nation's transportation and technology industries. The DOT's approach to research emphasizes cooperation, information-sharing, and the development of formal research agendas among agencies within DOT and across the entire Government. It promotes partnerships with State and local governments, academia, and the private sector, to cost-effectively accelerate the transformation of new technologies, concepts, and ideas into better transportation systems, processes, and services. The DOT Research and Development (R&D) Plan identifies key enabling elements that will transform our transportation services and help bring those improvements to pass.

The Office of Infrastructure R&D (HRDI) continually improves the nation's infrastructure by conducting high quality research with a national scope and focusing on national interest. Research needs are continuously identified through outreach processes by HRDI researchers with their state and local governments and industry counterparts. HRDI pursues advanced research initiatives, which are outside the realm of State highway agencies. HRDI operates 13 onsite experimental and analytical laboratories at the Turner Fairbanks Highway Research Center (TFHRC) supporting the testing of new research methodologies and innovations. Further, HRDI trains and houses technical experts consisting of research scientists and engineers to assist the FHWA Core Business Units, Resource Centers, and the worldwide transportation community.

Because of its commitment to high quality research, HRDI needs to assess its programs to maximize resources and yield greater benefits. The assessment process involves not only identifying the benefits of research anecdotally, but also quantifiably. The establishment of a viable and meaningful system of performance measurements will enable HRDI research managers to take stock of where they currently stand and more accurately assess progress toward program objectives, and the goals of the agency and the Department.

1.2 Project Objectives and Scope

The primary objective of this research project is to develop a framework of contextualized measures that may be used by researchers at HRDI to quantify the benefits of their research. A secondary objective will be to share these measures within the RD&T organization for the purpose of developing a comparable suite of measures quantifying the benefits of their own research.

The purpose of this project is to develop a framework for assessing the benefits of infrastructure research within the Office of Infrastructure R&D. The benefits assessment framework was developed using data from selected research projects that were completed over the past 20 years. These projects are grouped into the following research areas:

- New technology and innovation
- National design and data standards
- New and conventional materials.

The project requires that the methodology used to develop the benefits framework be documented, including guidelines for performance measures, data requirements, thresholds, ratings, and overall impacts.

2. Research Approach

2.1 Data Collection

The approach adopted in developing the framework involved several tasks, including data collection and analysis, identification of performance measures, and development of benefits assessment framework. In order to develop a benefits assessment framework, data on a subset of studies completed by HRDI in the last 20 years was gathered. The projects were selected in association with the HRDI program and project managers.

A total of 15 programs and projects were selected. The project list provides a good representation of the spectrum of HRDI research activities. The selected projects provided the data that was used in identifying relevant performance measures and developing a benefits assessment methodology. The following programs and projects were selected in each of the three research categories. It should be noted that some programs fall into more than one category. This is because individual research studies in these program areas could not fall into any of the three research areas. Summary descriptions of these projects and contact list are provided as appendices to this report.

- New Technology and Innovation
  - High Performance Steel Program
  - Hydrology and Hydraulics Program
  - Geotechnical Research Program
  - Ground Penetrating Radar for Pavements and Concrete Study
  - Epoxy Coated Rebars Study
  - Superpave Program
  - Impact Echo Study
  - Rapid Chloride Permeability Test Study

- National Design and Data Standards
  - High Performance Steel Program
  - Hydrology and Hydraulics Program
  - Geotechnical Research Program
  - Superpave Program
  - Timber Bridge Research Program
  - Temporary Works Program
  - Vessel Collision Design Specification Project
  - Epoxy Coated Rebars Study
  - Coefficient of Thermal Expansion Test
  - Guidelines for Use of Waste By-products in Pavements
  - Web NBI Project
  - Performance Related Specifications for Concrete

- New and Conventional Materials
  - High Performance Steel Program
  - Geotechnical Research Program
  - Superpave
  - Timber Bridge Research Program
  - Improved Marine Piling
  - Concrete Optimization Software Tool

The primary source of information leading to the development of a comprehensive knowledge base was through interviews with HRDI research program managers, other cooperators and/or partners, and a state DOT, representing the users. A template was developed for collecting information related to projects in each category. A copy of the template is included as an appendix to this report. Essential pieces of information gathered include study goals and objectives, duration of research, cost of conducting research, types of research outputs, target market and application, implementation, customers and users, impacts of adoption or implementation, and future research opportunities. Fifteen program and project managers were interviewed for this task.

A secondary source of information was a review of existing literature and retrieval of historical data. The literature review yielded information related to (i) success stories related to implementation and deployment of research outputs; (ii) measures for assessing the benefits, and (iii) identification of users who have directly applied research products. The literature review also provided information on approaches used by state DOTs in evaluating their research programs. Results of the literature review also include information on costs, and benefits, and evidences of application or adoption of research products.

It was expected that interviews with users and customers of research products would provide additional information to help assess the benefits (actual and perceived) expressed by these customers, and estimate the costs associated with implementation of research products. An interview guide was designed to gauge customer satisfaction with research results and the extent of use. The objective of the customer satisfaction analysis was to collect information in two forms, qualitative and quantitative, for the convergent purposes of identifying levels of satisfaction and identifying areas needing further research. The interviews also provide useful information for the benefits assessment framework particularly in identifying potential sources of data needed to apply the framework. The interviews were designed to obtain information that can be used to address questions such as:

- What conditions drive demand for the product and how it can, or has, helped provide "real world" benefits?
- Are research outputs readily available and accessible to all potential users?
- How well are the research results and data accepted and used by customers?
- Are customers satisfied with the outcomes from implementation of research results?
- What are the costs involved in implementing research results?
- What is the added value of the products or benefits or cost-savings resulting from the implementation of the research?

- What are the impacts of implementing research results (e.g., reduction in construction cost, enhancement in safety, reduction in congestion)?
- What are the constraints and problems associated with the implementation of HRDI research results?
- What are the future research needs?

Only one user was interviewed as part of the data collection exercise. This is because except for a few projects such as High Performance Steel and Timber Bridge Research Program, users of the research products could not be easily identified, even by the program managers. Most of the user type information were obtained from other cooperators and/or partners in HRDI research, and/or those whose roles involved delivery of the research products. Although there is a general understanding that state DOT pavement and bridge engineers are the probable users of the research products, no specifics as to which state DOTs use the research products were readily available. It is observed that for many HRDI research programs, tracking between HRDI research activities and product implementation and usage is virtually nonexistent. It is noted that a formal mechanism for tracking the research products and user feedback to the developers or researchers is essential and recommended in order to identify and quantify the benefits of research activities, identify shortcomings, problems and limitations of research products, and identify research gaps and future research opportunities.

2.2 Data Analysis

The analysis of the data collected during the interviews and literature review involved several steps. In the first step, the research information was synthesized and summarized.

In the second step, a number of performance measures were identified. The purpose of this step was to identify potential measures that could be used to assess the benefits of research products. It was important to identify those measures that are applicable to all research areas and those that are applicable only to specific research areas. These measures were used to assess the benefits of the research efforts. The performance measures were grouped into several categories.

The third step in the data analysis identified the sub-elements or surrogate measures of the performance measures and the weighting factors that would reflect the relative importance or significance of that measure in terms of the research benefits and cost savings. The weighting factors were used to express qualitative measures in quasi-quantitative terms.

The results of these analyses form the basis for the development of a framework for evaluating the research programs and projects. These are discussed in the following sections.

3. Benefits Assessment Framework

This section presents a brief discussion of the performance measures to serve as a prelude to description of the benefits assessment framework. The section begins with a summary of literature review on the subject of performance measures as it relates to RD&T programs.

3.1 Performance Measures

The term, performance measures, has been around for some time, but its popularity has increased with the passage in 1993 of the Government Performance and Results Act (GPRA). Although there are various traditional sources of definitions of additional terms related to performance measurement, no standard and commonly accepted definitions currently exist. Performance *measures* are assessment data or techniques that strongly, directly, or quantitatively reflect the degree to which results meet the needs and expectations of the customer [1]. These measures are often compared to goals or benchmark levels, such that remedial actions can be activated when benchmarks are not met. Performance *indicators*, on the other hand, are data or techniques that suggest general alignment of results with customer goals. They can typically be direct or surrogate measures for actual performance characteristics of interest, and they often are useful in identifying trends in overall performance, if not an actual comparison to a desired goal. In the simplest terms, performance measures are a stricter, quantitative benchmark of results compared to performance indicators.

Performance measures have become one component of public and internal perception of accountability – an issue that has recently grown in prominence within state DOTs [2]. Performance measures in RD&T programs can affect programs in a positive or negative manner. Having defensible performance measures, coupled with realistic goals, can provide, for example, instant credibility in the program and unquestioned accountability.

Generally, for management purposes, quantitative measures are preferred, because of their portability and understandability among various reviewers of information. However, there are cases for which quantitative measures are difficult or expensive to obtain, and qualitative measures provide reasonable guidance regarding a program's effectiveness or success.

A recent study [3] observed that program level benefits are important to research managers in justifying the existence of or investment in the RD&T unit. Accordingly, the need and desire for good methodologies and appropriate performance measures for program level benefits is compelling. Performance measures can be quantitative or qualitative. Qualitative measures are those that can be described in a meaningful way without any numerical or hierarchical relativity. Quantitative measures are those that can be assigned numerical or hierarchical relativity. Cost-benefit ratio is the most common quantitative performance measure in use because it is simple, attractive, and easily understood. The fundamental problem with this measure is the difficulty in establishing dollar values for the benefits or establishing benefits when they cannot be easily converted to a dollar basis (e.g., environmental impacts). Some of the reasons for the difficulty include the following:

- There is no widely used, commonly accepted methodology for assessing project or program benefits, making it difficult to use any values from previous similar projects in a state or values from another state.

- A basis for assigning dollar equivalents is not commonly accepted for areas such as enhanced safety or environmental improvement.

- Estimates provide quasi-quantitative data, yet are subjective.

It was also noted [3] that there appears to be agreement among RD&T units that cost-benefit ratio is generally a desirable performance measure; while at the same time there is recognition of the inherent difficulties in its application.

These difficulties were acknowledged and taken into consideration in developing the benefits assessment framework described in the following section.

3.2 Development of the Benefits Assessment Framework

As noted in the introduction, HRDI conducts a variety of studies related to highway infrastructure with a range of successful outcomes and impacts to a multitude of users. These outcomes range from new technologies and materials to specifications and guidelines.

The framework for benefits assessment includes the essential indicators of value for FHWA research customers in each of the three research categories: new technology and innovation, new design and data standards, and new and conventional materials. The goal is to develop the framework as a tool that can be used to evaluate the success of completed research as well as to select or prioritize future research. The following elements are the essential building blocks in developing the evaluation framework.

- Identification of performance measures for each category of projects or programs
- Definition of performance measures
- Identification of data sources on the performance measures
- Definition of benefit-cost analysis approach
- Interpretation of results

In developing the framework, the various components of the framework were first determined and defined. Then the performance measures and surrogate measures were developed for each component. The performance measures were selected based on the results of the data analysis to cover a wide range of attributes so that the benefits of HRDI research can be properly and adequately evaluated. This process went through several iterations to ensure that the performance measures reflect the research activities and all the potential benefit areas are identified and included. The performance measures have been defined at a high level of detail so that the framework can be used to evaluate research projects as well as research programs.

In defining the performance measures, it is recognized that some are qualitative while others are quantitative. In order to assign numeric values to the qualitative measures weighting factors were introduced to make them quasi-quantitative. The weighting factors are useful to reflect the level of importance or relevance of the various surrogate as well as primary performance measures.

Next, the performance measures are categorized into the following five major groups to serve as the key components of the framework as summarized in Table 1 and defined below. These components reflect the key areas to be used in assessing the benefits.

Table 1. List of Performance Measures

Part	Performance Measure	Type of Measure
A	**Research Output and Usage** • Achievement of Research Objectives • Types of Products from Research • Adoption for Implementation • Extent of Use/Number of Users of Research Product	Quasi-quantitative
B	**Cost Savings** • Agency Costs (capital and operation) • User costs • Safety costs • Cost of research	Quantitative
C	**Environmental Impacts** • Air quality • Noise • Wetland and Nature • Recycling • Aesthetics	Qualitative
D	**User Satisfaction** • Awareness • Access • Acceptability • Use • Value	Qualitative

1. Part A deals with the research outputs and the measures are quasi-quantitative.
2. Part B deals with cost savings associated with implementation of research products. These measures are quantitative.
3. Part C assesses the environmental impacts of implementing the research products. These measures are qualitative.
4. Part D deals with customer satisfaction with the research products. These measures are qualitative.

A number of performance measures and surrogates are defined for each part. The potential sources of data for these measures are also identified. This is followed by a detailed analysis of the benefits assessment. The performance measures, analytical framework as well as the interpretation of the results of the analysis are described in the following section. Figure 1 shows an outline of the benefits assessment framework.

3.3 Description of the Framework

This section presents a detailed description of the benefits assessment framework.

3.3.1 PART A – Research Output and Usage

The performance measures in this category address the relevance of HRDI research products in terms of quality or success of research effort and outputs. Five key measures are identified with several sub-elements or surrogate measures. These measures also address the extent of use and the acceptance by state DOTs, other state agencies, and other users. These are qualitative measures to which weighting factors are applied. The score of the measure is obtained as a weighted score of the surrogate measures expressed as a fraction of the total maximum possible score.

A.1 Achievement of Research Objectives

Before the benefits of any research can be assessed it is important to first assess the success and quality of the research effort. This measure primarily determines whether research objectives are achieved. The following surrogate measures are identified.

- Successful completion of the project,
- Publication of research reports,
- Generation of specifications or guidelines, if applicable,
- Publication of refereed papers in technical journals and conferences,
- Citations and awards received (if any).

The program and project managers are the primary data sources for this measure. These measures are applicable to all three research areas and projects. The primary measure of success is whether the research achieved its stated objectives. Consequently this measure is given the maximum weight. Recognizing that achievement cannot be binary, a scale from zero to three is provided with zero representing unmet objectives and three representing fully met objectives. The other measures of research success or quality are given a lower weight with a binary value representing if a measure was met or not.

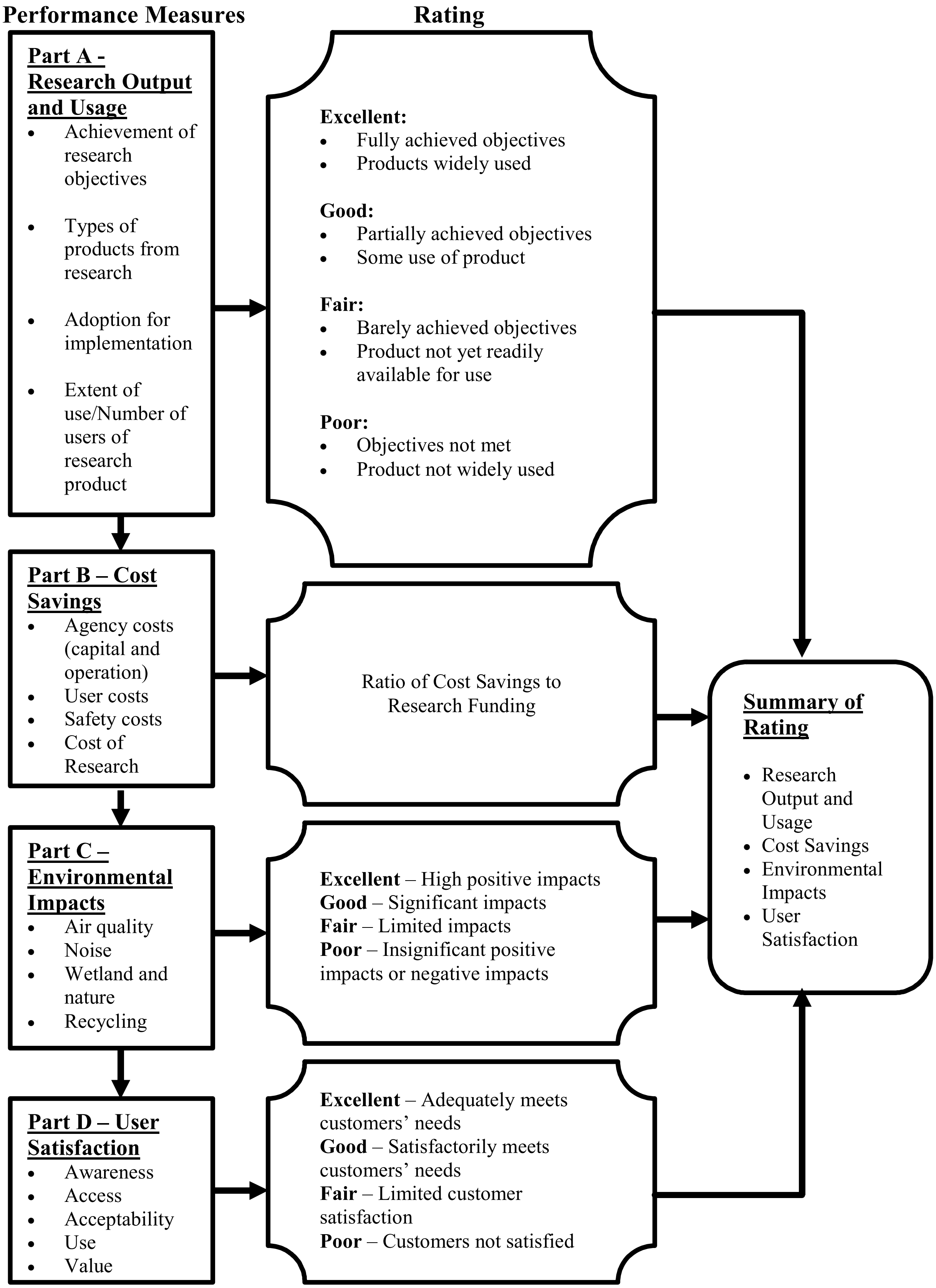

Figure 1. Summary of Framework

A.2 Types of Products from Research

This measure identifies the types of outputs or surrogate measures generated by the research effort, including:

- Specifications (new and revised)
- Guidelines and handbooks or educational material
- Improved conventional material and new innovative material
- New technology or equipment
- Software tools
- Advanced state-of-the-art procedures (e.g., methods and techniques)
- Exploratory research results
- Technology transfer tools

Project and program managers are the primary sources of data for these measures. These measures are applicable to all three research areas and projects. It should be noted that all projects do not produce all the possible research products. Relevant products are assigned a weight of 5 while non-applicable products are given a zero weight. The level of development represents the status of the product, with zero representing no development and three representing a completed product.

A.3 Adoption for Implementation

This measure addresses the level of implementation of research outputs (identified by the previous measure) by FHWA customers including national, international, state, and local highway and transportation agencies. A distinction is made between the two performance measures because implementation of a research project results by a national agency does not necessarily imply that it has been accepted and implemented by a large number of potential users; e.g., states. The weighting factors relate to the level of adoption or implementation of the product. Evidence of full usage or application of research product is weighted higher than partial adoption. In other words, a research product that is in the initial stages of being tested and implemented will carry less weight than one that has been implemented. A new product that has not been proven to perform its intended functions is weighted less than an old product that has been in use for sometime.

For projects whose primary outputs are specifications, adoption by organizations like AASHTO, ASCE, SAE or other standards agencies is critical. For projects whose output is new materials, commercial production of the material is a good indicator of success. Equipment and technology-based research are considered to be successful if transportation agencies use the resulting products. Projects with software tools as outputs are successful if their software is available as a completed product or in case of agency-specific software like Web NBI, is being used. The success of technology transfer tools is in their creation and use.

A.4 Extent of Use of Research Product

The previous measure was designed to assess the state of the product in terms of adoption and development at the national-level. This does not necessarily mean widespread acceptance and use at the state and local levels. This measure assesses the level of usage of the research products. This measure is considered one of the key measures of the benefits or quality of the research effort. This is because usage is a true reflection of the benefits associated with the research product. It is acknowledged that it might not be possible to obtain exact numbers for this measure. Thus, four major groupings were developed (expressed in terms of the number of states) as follows:

- None – no state and local agencies, institutions or other agencies use the research (0 points)
- Few – less than 20% of the states (10 states) have state and local agencies, institutions and others using the research (1 point)
- Several – 20% to 50% of the states (10-25 states) have state and local agencies, institutions and others using the research (2 points)
- Widespread – more than 50% of the states (more than 25 states) have state and local agencies, institutions and others using the research or if the product has been used by national and international agencies (3 points).

Overall Score for Part A

The overall score for the research output and usage performance measure is a weighted score combining the scores of the five measures with the weight of the measures. Table 2 shows the weighting factors applied to each category of performance measures. The relative measure weighting factor represents the relative significance of a performance measure in assessing the benefits of research program or product. Note that the extent of use or number of users of the research product is assigned the highest weighting factor. This is because this measure reflects the usefulness, relevance, and acceptance of the research product in addressing highway infrastructure problems, and therefore a benefit to the research program. This measure is assigned a higher weight than the adoption for implementation factor because adoption does not reflect actual usage of the product. The type of research product measure simply assesses the level of development of the research product, and was therefore assigned a lower weighting factor. Achievement of the research objectives is given an even lower weight because achieving the research objectives does not necessarily translate into a product that can be implemented, neither does it translate into a product that is widely accepted and implemented.

Table 2. Weighted Score for Part A

Performance Measure	Relative Measure Weight (w)	Measure Score (s)	Weighted Score (w*s)
A.1. Achievement of Research Objectives	10%		
A.2. Types of Products from Research	20%		
A.3. Adoption by FHWA Customers for Implementation	30%		
A.4. Extent of Use/Number of Users of Research Product	40%		
Total Score	100%		
RATING			

The rating scale below provides an overall rating of the research project or program for the research output and performance measure.

Part A – Rating Scale

Score > 75% –	Excellent: The research fully achieved its objectives, and has developed products that are readily available and adopted by national agencies. These products are widely used by states, local agencies, and other institutions.
60% < Score ≤ 75% –	Good: The research partially achieved its objectives, and has partially developed products that are available and adopted by national agencies. Several states, local agencies, and other institutions use these products.
45 < Score ≤ 60% –	Fair: The research barely achieved its objectives, and has developed products that are in the early stages of availability and adoption by national agencies. Few states, local agencies, and other institutions use these products.
Score < 45% –	Poor: The research did not quite achieve its intended objectives, and has not developed products that are available and adopted by national agencies. Few or no states, local agencies, or other institutions use these products.

3.3.2 PART B – Cost Savings

The second major part of the framework assesses the cost savings or benefits of implementing the research product. Cost saving is estimated as the difference in cost with and without the use of the research product. It is implicit that the set of measures is only applicable when the research products have been implemented. The cost savings include savings to the implementing agencies, road user costs, as well as safety costs. The agency cost savings can be further broken down into capital costs and operation costs (maintenance and rehabilitation). Cost savings resulting from the implementation of a research product can be classified into one or more of the following categories:

1 Reduced design and construction costs,
2 Extended service life of facilities,
3 Operational efficiencies,
4 Road user costs, and
5 Safety (crash) costs.

No distinction is made between the various areas of research. Instead, several sub-categories of costs are identified to include cost elements applicable to the different research areas. It is noted that cost savings may result from any combination of (i) the use of improved or new construction materials; (ii) advanced or innovative construction technologies and equipment; (iii) the use of new design and construction methods. In other words, implementation of any research product is likely to impact costs in at least one of the five cost components listed above. It is recognized that cost data on certain elements may be difficult to obtain. In such cases, it may be necessary to make assumptions based on domain knowledge or evidence from similar products. It is important that any such assumption is properly qualified and justified.

The cost savings can be expressed per unit or project or application depending on the nature of the research product. The implementation of some research products may result in an increase in the cost of one aspect but at the same time may also result in reduction in total life-cycle costs. For example, using epoxy coated rebars results in higher material costs, but the service life is extended.

The overall cost savings are annualized and calculated as the cumulative savings from agency, user, and safety costs. The following sections describe the guidelines for estimating cost savings.

B.1 Agency Cost Savings

Agency cost savings relate to the cost savings to the implementing agency (typically state DOTs and local agencies) that use HRDI research products. It is important to note that the cost elements listed are those that affect, in one way or the other, highway infrastructure construction and maintenance. Where cost savings occur in other relevant areas that are not included in the list, these should be specified in the "other" category.

Capital costs comprise:

- Design labor
- Construction materials
- Construction labor
- Construction Equipment
- Worker injury or death
- Other

Maintenance and rehabilitation cost elements include the following:

- Costs of inspection
- Maintenance labor costs
- Maintenance material costs
- Equipment costs
- Worker injury or death
- Other

The maintenance and rehabilitation cost savings result from improved maintenance activities either through the use of improved materials, construction techniques, or maintenance techniques and equipment. It also includes the cost savings from reduced injury and death to workers. The maintenance costs are spread over the lifecycle of the structure and must be converted to present worth values for purposes of comparison.

B.2 User Cost Savings

User cost savings include two elements: travel time and vehicle operation cost (VOC) savings. Travel time savings can be construction-related or incident-related. Both travel time and VOC savings can also result from the construction of new facilities, improvement of existing facilities, inspection, and maintenance of facilities. For the purpose of this benefit assessment framework, no distinction is made among the benefits due to these activities. The user cost savings are estimated as the differences in travel time multiplied by the unit costs with and without the implementation of the research product. User value-of-time is used to convert the travel time savings into monetary terms.

HRDI research can impact VOC in two main ways. First, VOC savings can be derived from using new and improved construction materials resulting in more durable highway infrastructure (e.g., high quality and durable pavements) that require less frequent maintenance and rehabilitation activities. VOC savings can be estimated by comparing the VOC under normal operating conditions with VOC from operating on pavements that need repair or improvements. Second, VOC savings can result from the use of new technologies and tools to reduce construction, inspection, and maintenance time. In this case, VOC savings can be estimated by comparing VOC under normal operating conditions with VOC in construction zones.

A recent study [4] concluded that driving on roads in need of repair or improvement costs American motorists an average of $222 annually each in extra VOC or $41.5 billion total. Another study [5] concluded that the use of durable construction materials reduces delays and saves extra VOC to motorists. Timing and quality of maintenance and rehabilitation of pavements is critical to the cost-effectiveness of operations.

B.3 Safety Cost Savings

Performance measures for assessing safety cost savings include the number and severity of crashes. Safety benefits are estimated as the number of potential crashes avoided due to the implementation of research products multiplied by average crash costs. It is noted that a lot of the safety products developed by HRDI are directed at reducing the number of fatalities and serious injuries. Therefore, safety benefits can also be expressed in terms of the reductions in the number by type of crash (fatal, serious injuries, property damage only). Sources of data on unit costs are identified in the assessment framework. The total safety cost savings are annualized.

Part B – Overall Cost Savings

The annual cost savings are the sum of agency, user cost, and safety savings. These are multiplied by the number of known or potential applications to obtain the total annual cost savings at the national level. This total is expressed as a ratio of the HRDI annual research budget for the program under consideration. This ratio represents the magnitude of benefits generated by the research program or project. In the real sense, this ratio is not a benefit cost ratio or return on investment because all the benefits and costs are not included in the calculation. No rating scale is suggested for cost savings because the ratio itself is a standard performance measure.

3.3.3 PART C – Environmental Impacts

Highway construction projects can have adverse impacts on the environment. For example, the construction of a highway can cause sediment and erosion problems and impact wetlands, and streams. Advances in environmental-friendly materials and their use in design is another way by which infrastructure research can impact the environment. While it is clear that TFHRC research impacts the environment, it is quite difficult to quantify in terms of dollars. Thus the measures in this area are qualitative or quasi-quantitative at best in nature, and are primarily determined by the project managers.

Part C – Rating Scale

Score > 75% –	Excellent: High positive environmental impacts
60% < Score ≤ 75% –	Good: Significant environmental impacts
45% < Score ≤ 60% –	Fair: Limited environmental impacts
Score < 45% –	Poor: Insignificant positive impacts or negative impacts

3.3.4 PART D – Customer Satisfaction

Part D of the framework assesses the level of satisfaction expressed by users of the research products. Users include FHWA Division personnel, state DOT staff and local agencies, bridge engineers, and pavement engineers and sometimes, international bodies, and ultimately the traveling public. The surrogate measures used are awareness, access, acceptance, use, and value that users place on the research product. The customer satisfaction results also indicate the effectiveness of the technology transfer methods used by HRDI in marketing their research products. Customer satisfaction measures assess extent to which HRDI's customers are satisfied by the choice of projects undertaken by the staff, timeliness and accuracy of research products, applicability of research to customer problems, responsiveness to requests for technical assistance, and quality of research products.

The measures are derived by user opinions gleaned by either interviews or customer surveys. These measures apply to all projects and typically are on a scale of 1 to 5 (1 being least and 5 most satisfied). These scale factors are intended to help gauge the strengths and weaknesses of the research program and technology transfer activities. All measures are equally important and therefore are weighted equally. The score for the customer satisfaction measure is obtained as a sum of the weighted scores of the surrogate measures expressed as a fraction of the total maximum possible score. The following rating scale is used for customer satisfaction analysis.

Part D – Rating Scale

Score > 75% –	Excellent: Meets customers' needs adequately
60% < Score ≤ 75% –	Good: Meets customers' needs satisfactorily
45% < Score ≤ 60% –	Fair: Limited customer satisfaction
Score ≤ 45% –	Poor: Customers not satisfied with research product.

3.3.5 Overall Benefits Assessment

The outputs from the various parts are summarized as shown in Table 3 below. The score of each component of the framework is recorded separately. This is visualized as a report card but with no aggregated or cumulative score for all the components.

Table 3. Summary of Benefits Assessment

Part	Performance Measure	Result	Remarks
A	Research Output and Usage		
B	Cost Savings		
C	Environmental Impacts		
D	Customer Satisfaction		

4. Summary of Results of Programs and Projects Studied

The benefits assessment framework is structured as a series of tables with guidelines and explanatory notes. One table is used for each performance measure. To facilitate its use, the framework is presented as a MS Excel workbook where each sheet in the workbook contains one table or performance measure. The sheets are linked together so that the weighted scores and ratings of the individual and all the measures are automatically calculated. In this way, the weighted scores are updated when changes are made to any cell. The benefits assessment framework is submitted as a separate document and also included as an appendix to this report.

The framework is easy to apply and flexible enough to allow program and project managers to add or revise surrogate measures where necessary.

The framework was applied to a few programs and projects and the summary results discussed in the following section. The detailed application of the framework for the examples is provided in Appendix B.

4.1 Discussion of Results

Seven projects and programs were analyzed using this framework. This section presents a summary of results of seven projects and programs that were analyzed using this framework. These programs and projects are:

- Epoxy Coated Rebars Project
- High Performance Steel Bridge Research Program
- Ground Penetrating Radar Project
- Web NBI Project
- Timber Bridge Research Program
- Temporary Works Research Program
- Geotechnical Research Program

The examples demonstrate the applicability of the model to different research areas as well as to both projects and programs. The results are summarized in the following table. These programs and projects were selected to illustrate the flexibility available to the manager in applying the framework. Appendix B of this document includes detailed worked out examples of these seven programs/projects.

The results clearly indicate that the programs and projects achieved their research objectives, have developed products that are readily available and are adopted by various agencies. Furthermore, the research products developed are widely used by states, local agencies, and other institutions.

It was observed that estimating cost savings is the most demanding part of the framework because of the data needs. For projects and programs for which sufficient data was available, it was noted that most of the project and programs have excellent rating. That is, the estimated cost savings at a national level is more than ten times the annual research funding. It is important to note that these cost savings include agency, road user, and safety cost savings.

Environmental impacts could not be quantified because these projects and programs were not primarily focused on addressing environmental concerns. This performance measure is qualitative in nature, and therefore, requires subjective assessment of the probable impacts of the projects on the environment measured by several factors. Program and project managers as well as users would be in a better position to assess the environmental impacts of their programs and projects.

Customer satisfaction assessment is subjective and was based on information gathered from the few users interviewed. It is noted that most of the projects and programs used in the illustrations are rated as excellent – i.e., the products, their delivery, and use meet the needs of the users adequately.

These examples illustrate the use of the framework in assessing the benefits of HRDI research. The detailed analyses of each project in the illustration are included in Appendix B.

Table 4. Summary Results of Studies

Performance Measure/ Program or Project	Result	Rating
A. Research Output and Usage		
Epoxy Coated Rebars Project	92%	*EXCELLENT*
High Performance Steel	79%	*EXCELLENT*
Ground Penetrating Radar	67%	*GOOD*
Web NBI	83%	*EXCELLENT*
Timber Bridge Research Program	83%	*EXCELLENT*
Temporary Works Program	93%	*EXCELLENT*
Geotechnical Research Program	89%	*EXCELLENT*
B. Cost Savings		
Epoxy Coated Rebars Project	Potential savings of $1,245 Million per year	Ratio of cost savings to research funding > 700
	Research funding of $1.75 Million	
High Performance Steel	A conservative estimate of $5.7 Million saved for 169 HPS bridges	Ratio of cost savings to research funding[1] = 2.5:1
	Research Funding of 2.3 Million	
Ground Penetrating Radar	Estimated $2.32 Million per year	Ratio of cost savings to research funding = 23.2:1
	Research funding of $2 million over 20 years; annual funding of $100,000	
Geotechnical Research Program	$76 million saved by using Geotechnical research by 10 northwestern states $70 million per year savings due to use of Durability of Geosynthetics Study $700 Million Annual savings with full implementation of earth reinforcement technologies	Ratio of cost savings to research funding[2]: > 1000
	Research Funding of $50 million total	

Performance Measure/ Program or Project	Result	Rating
Web NBI	*DATA NOT AVAILABLE*[3]	
Timber Bridge Research Program	*DATA NOT AVAILABLE*[4]	
Temporary Works Program	*DATA NOT AVAILABLE*[5]	
C. Environmental Impacts		
Epoxy Coated Rebars Project	*DATA NOT AVAILABLE*[6]	
High Performance Steel		
Ground Penetrating Radar		
Web NBI		
Temporary Works Program		
Geotechnical Research Program		
Timber Bridge Research Program	67%	*GOOD*
D. Customer Satisfaction		
Epoxy Coated Rebars Project	84%	*EXCELLENT*
High Performance Steel	76%	*EXCELLENT*
Ground Penetrating Radar	72%	*GOOD*
Web NBI	76%	*EXCELLENT*
Timber Bridge Research Program	64%	*GOOD*
Temporary Works Program	84%	*EXCELLENT*
Geotechnical Research Program	80%	*EXCELLENT*

Notes:

[1] *The savings are based on 169 applications of HPS for bridges. Each application results in an average cost savings of 10%. Consequently, as more bridges are built using HPS, the total cost savings are expected to increase.*

[2] *Geotechnical Research Program is one of the programs in TFHRC that received a high number of awards with its products and specifications. While detailed data about each of the products is unavailable, the publication "A quarter century of Geotechnical research" provides some data regarding cost savings.*

[3] *Web NBI results in the productivity savings to maintenance managers by providing a software and web-based query and download system which improves business projects and helps tracking of strategic performance measures. However, the data to calculate cost savings is not available. The software is currently being used by only the FHWA bridge engineers, and has not been released to the states.*

[4] *The cost savings of timber bridges are not clear as of date. There is a need for comparative lifecycle cost analysis and unit cost data for timber bridges as recognized by the document "Timber bridge economics", a Forest Products Laboratory and FHWA publication.*

[5] *Data on reduction in accidents due to temporary works collapses since the completion of the research is required to calculate the cost savings. While most states use the specifications, they do not have information on the number of accident before and after the research.*

[6] *Environmental impacts were not the primary focus of the research and there is no information on secondary impacts on the environment.*

5. Future Research Needs

This section outlines future research needs or research gaps. The following are the research needs identified during the interviews with program and project managers.

Epoxy Coated Rebars Study
- Multiple corrosion protection systems
- Steel clad coating cost reductions

Ground Penetration Radar (GPR) for Pavement and Concrete Study
- Portable GPR for pavement thickness
- Cart mounted GPR for dowel bar alignment
- Evaluations of GPR use and accuracy

High Performance Steel (HPS) Program
- HPS 100 research
- Continuous modifications to codes

Geotechnical Research Program
- Technical guidance for new technologies from foreign sources or other building disciplines

WebNBI Project
- Expand the capabilities of the WebNBI system

Timber Bridge Research Program
- Pedestrian trail bridge design standards and guidelines
- New engineered composites
- Portable bridges for emergencies
- Demonstration project

Information gathered during the interviews indicates that information on research needs can be obtained from recommendations for future research in research project reports and through feedback from users. It is therefore recommended that program managers keep track of their research products and keep in touch with the customers and users as a means of receiving feedback and inputs in identifying problems that can be researched.

6. Concluding Remarks and Recommendations

This project identifies performance measures and provides a framework to assess the benefits of research conducted by HRDI. The performance measures were developed based on data collected on selected projects completed by HRDI in the last 20 years. The guiding principle in the development of the performance measures and assessment framework was to ensure that the measures are relevant, that they capture all types of research activities, that they are objective enough to highlight the benefits and weaknesses of research programs and projects, and above all, simple enough to be easily understood and applied by HRDI program managers. To ensure that all research areas are covered, several surrogate measures were identified for the various measures. In applying the framework, several data sources were identified for each performance measure.

The final output of the benefits assessment framework is visualized as a report card where grades are assigned to the various components. Poor performance in one area does not necessarily lead to the conclusion that the program is a failure. The relative merits of the various components of the framework need to be considered in assessing the overall benefits of the program in any given year. In comparing any two research programs, it is also important to consider other external elements, such as strategic goals of each research program.

The core of the benefits assessment framework is data availability, especially on costs and customer satisfaction. In order to have access to relevant data, it is recommended that program managers maintain close links with users of their research products. In this regard, formal mechanisms for tracking and user feedback from state DOTs, AASHTO, and other customers should be established and maintained. For example, it is recommended that every product should contain a customer satisfaction form. It is recognized that depending on the research product, customer satisfaction may not be immediate and may occur several years after the product has been implemented. Periodic surveys or contacts with users (say 3-5 years depending on the product) may be helpful in assessing the usefulness of HRDI's research products.

In applying the framework to new and potential projects, it is recommended that assumptions and educated guesses of the data required be made and justified accordingly. It is also recommended that results of the assessment be updated as new data becomes available.

It is recommended that the performance measures be reviewed periodically and the framework updated as needed to ensure consistency as the future directions of the research programs change. Additionally, it is recommended that this framework be converted into a decision support software tool that HRDI program and project managers can use in assessing benefits as well as in evaluating the success of their research programs.

7. References

1. National Science and Technology Council, *Transportation Strategic Research Plan.* Office of Science and Technology Policy, Cambridge, MA. 1999.

2. Deen, T.B. and B.T. Harder, *NCHRP Synthesis of Highway Practice 280: Seven Keys to Building Robust Research Program*, Transportation Research Board, National Research Council, Washington DC. 2001.

3. Sabol, S.A. *NCHRP Synthesis of Highway Practice 300: Performance Measures for Research, Development, and Technology Programs*. Transportation Research Board, National Research Council, Washington DC. 2001.

4. The Road Information Program. *Extra Vehicle Operating Costs: What Motorist Pay to Drive on Roads in Need of Repair,* Washington DC, 2002 www.tripnet.org

5. Bureau of Transportation Statistics. "*Moving Ahead: The American Public Speaks on Roadways and Transportation in Communities*". FHWA, Washington DC. 2001

APPENDIX A

Benefits Assessment Framework

PART A – Research Output and Usage

Definition: The performance metrics in this category address the relevance of the HRDI research product in terms of the quality or success of the research effort and outputs. Five major measures are identified with several sub-elements or surrogate measures. These measures also address the extent of use and the acceptance by state DOTs and local agencies.
Data Source: Program and project managers
Research Areas: These metrics are applicable to any research area.

A.1. Achievement of Research Objectives (10%)

Definition: The following metrics address the relevance of the HRDI research product in terms of the quality/success of the research work including successful completion of the project and development of project report; generation of specifications or guidelines; publication of technical research papers; and awards received (if any). The project managers are the primary data sources.
Notes: The primary measure of success is if the research achieved its stated objectives. Consequently this measure is given the maximum weight. Recognizing that achievement cannot be binary, a scale from zero to three is provided with zero representing unmet objectives and three representing fully met objectives. Additional measures of research success include publishing of research reports by FHWA, refereed papers in technical journals and conferences, citations, and awards. These measures are given a lower weight with a binary value representing if a measure was met or not. Finally dividing the score by the maximum possible normalizes this metric.

Table A-1. Achievement of Research Objectives

Primary Performance Measure	**Weight** (5= critical, 2 = somewhat)	**Level of Achievement**				**Score** (level * weight)	**Maximum Score Possible** (max level * weight)
		0 = not	1 = barely	2 = partially	3 = fully		
Stated objective of program/project	5						15
Additional Measures		**Level of Achievement**					
		0 = No		1 = Yes		--	--
Research Reports published by FHWA	4						4
Papers published –in Peer reviewed Journals	3						3
Awards or Citations for Product	2						2
Total							24
Measure Score (total score / max score)							--

A.2. Types of Products from Research (20%)

Definition: This metric identifies the types of outputs or surrogate measures generated by the research effort, including:

- Specifications
- Guidelines and handbooks
- Innovative Material
- Technology/Equipment
- Software tools, etc.
- Technology Transfer Tools

Notes: All projects however do not produce all possible research products. In the analysis, the assessor would select products that are relevant to the research area under consideration. Relevant products are assigned a weight of 5 while non-applicable products are given a zero weight. The level of development represents the status of the product with zero representing no development while three represents a completed product. These metrics are normalized in a similar manner as Table A-1.

Table A-2. Types of Products from Research

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Level of Development				Score (level * weight)	Maximum Score Possible (max level * weight)
		0 = not developed	1 = initial stages	2 = partially developed	3 = fully developed		
Specifications (Design, construction, inspection, testing, maintenance, etc.)	5						15
	0						0
Guidelines/Handbooks (including tables, charts, monographs)	5						15
	0						0
Improved Conventional and New Innovative Materials (e.g., HPS, Rapid Setting Polymers, FRP)	5						15
	0						0
Advanced Technology and New Equipment (construction, inspection or testing)	5						15
	0						0
Software Tools (design, analysis, management, testing, inspection, etc.)	5						15
	0						0
Advanced state-of-the-art procedures (e.g., methods, techniques); Exploratory Research Results	5						15
	0						0
Technology Transfer (websites,, workshops, clearinghouses)	5						15
	0						0
Total							105
Measure Score (total score / max score)							--

A.3. Adoption for Implementation (30%)

Definition: This metric addresses the level of implementation of the research outputs identified by the previous metric.
Notes: For projects whose primary outputs are specifications, adoption by organizations like AASHTO, ASCE, SAE or other standards agencies is critical. For projects whose output is new or improved materials, commercial production of the material is a good indicator of success. Equipment and technology-based research are considered to be successful if transportation agencies use the product. Projects with software tools as outputs are successful if their software is available as a completed product or in case of agency specific software like WebNBI, are being used. The success of technology transfer tools is in their creation and use.

Table A-3. Adoption for Implementation

Performance Measure	Weight (5 = critical, 0 = Not Applicable)	Time Scale for Adoption				Score (level * weight)	Maximum Score Possible (max level * weight)
		4 = 0-5 yrs	3 = 5-10 yrs	2 = 10-15 yrs	1 = >15 yrs		
Time required/taken for research products to be adopted	5						20
	0						0
Performance Measures	**Weight** (5= critical, 0 = Not Applicable)	**Level of Adoption**				**Score** (level * weight)	**Maximum Score Possible** (max level * weight)
		0 = No	1 = Somewhat	2 = Fully			
Specifications (including Design, construction, inspection, testing, maintenance)	5	Have the specifications been adopted as National Specifications by AASHTO or appropriate standards Agencies?					10
	0						0
Guidelines/Handbooks (including tables, charts, monographs, etc.)		Do DOTs, FHWA, AASHTO, Colleges, or similar organizations and institutions adopt the guidelines/handbooks?					10
	0						0
Improved Conventional and New Innovative Materials (e.g., HPS, Rapid Setting Polymers, etc.)	5	Are the materials developed available commercially?					10
	0						
Advanced Technology and New Equipment (including construction, inspection or testing)	5	Are the technologies and equipment in regular use by transportation agencies (excluding pilot projects)?					10
	0						
Software Tools (for design, analysis, inspection, testing or management)	5	Is the software available for use by agencies? Has the software application been completely installed, tested and is currently used?					10
	0						
Technology Transfer Applications (including websites, clearinghouses, workshops, etc.)	5	Have technology transfer applications been created and implemented?					10
	0						
Total							80
Measure Score (total score / max score)							--

A.4. Extent of Use at the State-Level (40%)

Definition: The previous metric was designed to assess the state of the product in terms of adoption and development. This does not necessarily mean widespread acceptance and use at the state-level. This metric assesses the level of usage of the research products. This metric is considered one of the key measures of the benefits or quality of the research effort. This is because usage is a true reflection of the benefits associated of the research product.
Notes: It might not be possible to obtain exact numbers for this measure. Thus, four major groupings were developed (expressed in terms of the number states) as follows:

- **None** – no state and local agencies, institutions or other agencies use the research (0 points)
- **Few** – less than 20% of the States (10) have state and local agencies, institutions and others using the research (1 point)
- **Several** – 20% to 50% of the States (10-25) have state and local agencies, institutions and others using the research (2 points)
- **Widespread** – more than 50% of the States (more than 25) have state and local agencies, institutions and others using the research or if the product has been used by national and international agencies (3 points).

Table A-4. Extent of Use

Performance Measure	**Weight** (5 = critical, 0 = Not Applicable)	**Time Scale for Popular implementation**				**Score** (level * weight)	**Maximum Score Possible** (max level * weight)
		4 = 0-5 yrs	3 = 5-10 yrs	2 = 10-15 yrs	1 = >15 yrs		
Time required/taken for research products to be widely implemented	5						20
	0						0
Performance Measures	**Weight** (5= critical, 0 = Not Applicable)	**Extent of Use by Agencies, Institutions and Others within the States**				**Score** (level * weight)	**Maximum Score Possible** (max level * weight)
		0 = none	1 = few[1]	2 = several[2]	3 = widespread[3]		
Specifications (including Design, construction, inspection, testing, maintenance)	5	Number of states using the specifications					15
	0						0
Guidelines/Handbooks (including tables, charts, monographs)	5	Number of states that recommend or use the guidelines, handbooks, etc.					15
	0						0
Improved Conventional and New Innovative Materials (e.g., HPS, Rapid Setting Polymers, etc.)	5	Number of states with reported applications of the materials					15
	0						0
Advanced Technology and New Equipment (including construction, inspection or testing)	5	Number of states who have procured the equipment or the technology					15
	0						0
Software Tools (for design, analysis, inspection, testing or management)	5	Number of states with users of software					15
	0						0
Technology Transfer (including websites, clearinghouses, workshops, etc.)	5	Number of states which have requested additional information about technology or Number of states attending workshops or NHI courses					15
	0						0
Total							110
Measure Score (total score / max score)							

Overall Score for Research Output and Usage

Definition: The overall score for the research output and usage performance measure is a weighted score combining the scores of the five metrics with their weights. The relative weighting factor represents the relative significance of a performance measure in assessing the benefits of research program or product.

Table A-5. Overall Score for Research Output

Performance Measure	Relative Measure Weight (w)	Measure Score (s)	Weighted Score (w*s)
A.1. Achievement of research objectives	10%		
A.2. Types of Products from Research	20%		
A.3. Adoption for Implementation	30%		
A.4. Extent of Use/Number of Users of Research Product	40%		
TOTAL SCORE	100%		
RATING			

RATING SCALE – Part A

Score > 75% –	Excellent: The research fully achieved its objectives, has developed products that are readily available and adopted by national agencies. These products are widely used by states, local agencies, and other institutions.
60% < Score ≤ 75% –	Good: The research partially achieved its objectives, has partially developed products that are available and adopted by national agencies. Several states, local agencies, and other institutions use these products.
45 < Score ≤ 60% –	Fair: The research barely achieved its objectives, has developed products that are in the early stages of availability and adoption by national agencies. Few states, local agencies, and other institutions use these products.
Score < 45% –	Poor: The research did not achieve its intended objectives, has not developed product that are available and adopted by national agencies. Few or no states, local agencies, or other institutions use these products.

PART B – COST SAVINGS FRAMEWORK

Definition: This framework assesses the cost savings or benefits of implementing the research products. Cost saving is estimated as the difference in cost before and after the use of the research product. The cost savings include savings to the implementing agencies, road users, as well as safety. Several sub-categories of costs are identified to include cost elements applicable to the different research areas. It is recognized that cost data on certain elements may be difficult to obtain. In such cases it may be necessary to make assumptions based on domain knowledge or evidence from similar products. It is important that any such assumption be properly qualified and justified. The cost savings can be expressed per unit or project or application depending on the nature of the research product.
Data Source: Sources of cost data for the various elements are identified with the guidelines and explanatory notes.

B.1. Agency Cost Savings

Definition: This is the savings in cost to the implementing agency (typically state and local DOTs) for use of HRDI research product. Where cost savings occur in areas other than those identified below, these should be specified in the "other" category.
Notes: Implementation of some research products may result in higher cost in one area but a reduction in cost in other areas. For example, using epoxy coated reinforcing steel may result in an initial higher material cost but provide extended service life which would result in lower life-cycle cost. These cost increases should be listed and subtracted from the total cost savings.
Analysis: This first part of the table should be used to calculate capital costs incurred during the design and construction phases. The costs should be expressed as current dollars.

The second part of the table should be used to calculate the savings due to improved maintenance activities. The maintenance costs are spread over the lifecycle of the structure and must be converted to present worth values. The methods for calculating the cost savings are outlined in the next section.

Table B-1. Agency Cost Savings

<table>
<tr><td>Research Program/Project</td><td colspan="4"></td></tr>
<tr><td>Unit of measurement (Check appropriate unit)</td><td colspan="4">Per sq. foot _______
Per Lane-Mile _______
Per Bridge _______
Per Application _______
Other (Please Specify)
____________________</td></tr>
<tr><td>Definition of Typical Infrastructure (e.g., bridge: 150-ft span, 45-ft wide, 2 piers)</td><td colspan="4"></td></tr>
<tr><td>Existing or Potential Number of infrastructure elements on which research product has or could be applied (N) (i.e., Number of Applications)</td><td colspan="4"></td></tr>
<tr><td colspan="5">Capital Cost Savings of "activity" per Unit
(If project reduces capital costs)</td></tr>
<tr><td>Benefit Areas</td><td>Applicability (Yes = 1, 0 = No)</td><td>Cost With Use of Research Product</td><td>Cost Without Use of Research Product</td><td>Differential</td></tr>
<tr><td>– Design Labor Savings (expressed in $)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>– Construction Materials ($)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>– Construction Labor ($)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>– Worker Injury or Death ($)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>– Other ($)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Cost Per Unit (1)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Total Capital Costs (2) = (1)*(N)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Planned Service Life (in years) (S)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Total Capital Cost for enhanced service life = (3) = (2)*(S_{with}/$S_{without}$)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Total Annualized Capital Cost (AC) for enhanced service life (4)</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">AND/OR Operating Costs Savings Per Unit</td></tr>
<tr><td colspan="5">AND/OR Routine Maintenance Cost Savings
(If project reduces routine maintenance costs)</td></tr>
<tr><td>Cost per Inspection</td><td>Applicability (Yes = 1, 0 = No)</td><td>Cost With Use of Research Product</td><td>Cost Without Use of Research Product</td><td>Differential</td></tr>
<tr><td>Maintenance Frequency</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Average Maintenance Labor Costs ($)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Average Equipment Costs ($)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Maintenance Management Labor Costs</td><td></td><td></td><td></td><td></td></tr>
</table>

Maintenance Labor Injury or Death ($)				
Other				
Annual Cost per Unit (5)				
Total Annual Routine Maintenance Costs = AR (6) = (5)*(N)				
AND/OR Major Rehabilitation and Reconstruction (R&R) Cost Savings (If project reduces major R&R costs)				
Costs Per Major R&R	**Applicability (Yes = 1, 0 = No)**	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
Average Maintenance Labor Costs ($)				
Average Maintenance Material Costs ($)				
Average Equipment Costs ($)				
Maintenance Labor Injury or Death ($)				
Other ($)				
Cost of Major R&R (7)				
Total Cost of R&R (8) = (7)*(N)				
Service Life Enhancement (in years) (S)				
Total R&R Cost for enhanced service life = (9) = (8)*(S_{with}/$S_{without}$)				
Total Annualized Major R&R Cost (AM) for enhanced service life (10)				
Total Annual Operating Costs = (11) = *(6)+(10)*				
Total Annual Agency Costs = (12) = *(11)+(4)*				

Capital Costs - Definitions and Methods of Calculation

For purposes of this analysis, capital costs are defined as costs incurred in the deployment or implementation of the research product. Where cost data is available on more than one project or application of a research product, the average cost should be used. Guidelines for calculating capital cost savings are described below.

Design Time Savings: Research products such as specifications, guidelines, and software tools result in changes in the costs associated with the design phase of a project. While some research products reduce design time and labor costs involved, other products like LRFD specifications can actually increase the cost of the design phase. However, such specifications result in safer and longer lasting structures. Average hourly labor costs and estimated labor hours should be used in estimating design time savings.

The Bureau of Labor Statistics (www.bls.gov) can provide average labor cost information, if specific information cannot be found.

Design time savings can also be estimated by comparing average design bid estimates.

Construction Materials: Cost differences as a result of using new or improved versus conventional construction materials can be based on engineer's estimates if actual costs are not available. New materials may be more expensive than conventional materials, and in cases where the same quantity of new material is required, the total new material cost may be substantially higher than the conventional material being replaced. However, new and improved materials could extend the service life of the structure resulting in reduced life-cycle cost. Thus the construction material cost differences can be positive or negative.

Construction Labor: Labor cost savings are valid for research whose results reduce the labor cost associated with construction of the structure. The cost savings are calculated by multiplying the labor hours saved due to reduction in construction time, by the current average wage rates. A potential data source for average labor rates is the Bureau of Labor Statistics (www.bls.gov)

Labor Injury or Death: Worker safety enhancement due to the use of research products such as the new temporary works specifications and vehicle collision design specifications have the potential to reduce the number of accidents to the construction workers. The estimated number of such accidents from previous similar projects can be converted to cost using injury and fatality unit cost values from the National Safety Council and others.

Expected Service Life: The expected service life is needed to calculate the present worth and annualized costs.

Annualized Capital Cost: Capital cost savings are annualized for the expected service life of the infrastructure using the following equation:

$$AC = C_1 * \frac{i(1+i)^n}{\left[(1+i)^n - 1\right]} \qquad (1)$$

where
AC = Annualized Capital Costs
C_I = Initial Capital Costs
n = expected service Life
i = prevailing interest rate

Operating Cost - Definitions and Methods of Calculations

The cost savings in maintenance operations are classified into two major groups – Routine Maintenance and Major Rehabilitation and Reconstruction.

Routine Maintenance: Research products can help in reducing the frequency and duration of routine maintenance activities including inspections resulting in labor cost savings.

Frequency: The frequency of the routine maintenance activity (e.g., annual, bi-annual) should be noted in this section. This information is needed in calculating the life cycle costs.

Average Labor Cost Savings per Inspection: This is the change in labor cost to complete inspections for maintenance operations resulting from the implementation or adoption of the research product.

For example, while under current methods a 6-man crew (inspection plus traffic control) is required to inspect 1 or 2 bridge decks per day (4 hours/deck), the GPR method can complete 5 or more bridge decks per day (depending on their size and location) with a 2-man crew (1.5 hours/deck).

The average labor cost savings per deck can then be calculated as 4 (hours/deck)* 6 (persons involved) – 1.5 (hours/deck)* 2 (persons involved) = 21 hours* $10/hour (labor rate) = $210 per deck.

Average Equipment Cost Savings per Inspection: This is the change in equipment cost for inspections (e.g., bridges). Typically, the use of new equipment might result in additional costs.

Maintenance Management Labor Cost Savings per Inspection: Some research products such as WebNBI improve the productivity of the maintenance program by providing tools for the managers to make decisions regarding the infrastructure. The use of these tools result in labor time savings at the management level.

Maintenance Labor Injury or Death Cost Savings: Research products like GPR increase safety of workers by decreasing their exposure to traffic. The estimated number of such accidents from previous projects can be converted to cost using injury and fatality unit cost values from the National Safety Council and others.

Major R&R Cost Savings: These are actual costs expended during the reconstruction and rehabilitation of existing facilities. The primary impacts are due to products that help complete the R&R effort faster and cheaper while resulting in increased service life of the structure.

Annualized R&R Cost Savings: The R&R cost savings are annualized for the expected service life using the following equation:

$$AM = M_1 * \frac{i(1+i)^n}{\left[(1+i)^n - 1\right]} \quad (2)$$

where
AM = Annualized R&R Costs
M_1 = R&R Costs

n = Service Life
i = prevailing interest rate

Total Agency Costs: The total agency costs is the sum of the annualized capital costs, the annual routine maintenance costs and the annualized major R&R costs.

B.2. User and Safety Cost Savings

Definition: User cost savings include travel time savings and vehicle operation cost savings. These can further be broken down into savings resulting from the construction of new facilities, improving existing facilities, and inspection and maintenance of facilities. For the purposes of this benefit assessment framework, no distinction is made among these three categories.

Measures for assessing safety cost savings include the number and severity of crashes. While improvements in highway geometry and surfaces can be shown to improve safety, the number and severity of crashes can only be used as indicators of improvements rather than direct results of highway improvements. This is because other human and environmental factors contribute to highway crashes.

Table B-2. User and Safety Costs

User Cost Savings (If project produces user benefits)				
Savings Area	**Applicable** (0 = No; 1 = Yes)	**Annual Costs (Dollars)**		**Differential**
		Cost With Use of Research Product	**Cost Without Use of Research Product**	
Travel **Time** Cost				
Vehicle **Operating Cost**				
Property Damage				
Injury				
Loss of Life (Fatality)				
Annual User Costs (13)				
Total Annual User Costs (14) = (13)*(N)				

User Benefits – Notes and Guidelines

Travel Time Savings: Travel time savings can be converted to dollar values using the Value of Time (VOT) concept. The VOT varies by type of vehicle and type of trip. Typical values are in the range of $11-12 per hour for passenger cars. The average cost savings can be determined by the reductions in travel times multiplied by the VOT and annual average traffic volume. For example, a new bridge which reduced the travel time by 5 minutes for an AADT volume of 4000 vehicles would result in a savings of 5/60 (hours) * 4000/24 * 365 (traffic volume in a year) * $12 = $61,000.

A study by Memmott and Dudek's (1982) titled, "A Model to Calculate the Road User Costs at Work Zones," found that a one lane closure for an 8 hour workday on a four lane highway with 2000 vehicles per hour per lane costs motorists about $18,000.

Vehicle Operating Cost Savings: VOC savings can result from the use of (i) new and improved construction materials resulting in more lasting highway infrastructure (e.g., high quality and durable pavements) that require less frequent maintenance and rehabilitation activities; and or (ii) new technologies and tools to reduce construction, inspection, and maintenance time. VOC savings can be estimated by comparing the VOC under normal operating conditions with VOC from operating on pavements that need repair or improvements or with VOC in construction zones.

A recent study titled "Extra Vehicle Operating Costs: What Motorist Pay to Drive on Roads in Need of Repair" by The Road Information Program (2001) determined that driving on roads in need of repair or improvement costs American motorists an average of $222 annually each in extra VOC or a total cost of $41.5 billion annually for approximately 187 million American motorists.

Safety Benefits: Safety benefits are quantified by the reduction in number and severity of crashes. Crash costs can be obtained from the Federal Motor carrier Safety Administration (FMCSA), National Safety Council publications. Some useful reference include:

- FMCSA, Work Zone Traffic Crash Facts;
- FMCSA, "Analysis Brief: Cost of Large Truck – and Bus-Involved Crashes. Office of Research and Technology, U.S. Department of Transportation, Washington, D.C., 2000.
- National Safety Council. Estimating the Cost of Unintentional Injuries, 1998. http://www.nsc.org/lrs/statinfo/estcost8.htm .

Overall Cost Savings

The annual cost savings is the sum of agency, user, and safety savings per unit. The existing or potential magnitude of the infrastructure elements on which the research product has or could be applied is then used to extrapolate the savings to a national level. The annual research funding provides the basis for evaluating these cost savings. The ratio between the annual cost savings and the annual research funding is used to determine the rating for the project in terms of costs.

RATING SCALE – Part B

This ratio represents the magnitude of benefits generated by the research program or project. In the real sense, this ratio is not a benefit cost ratio or return on investment because all the benefits and costs are not included in the calculation. No rating scale is suggested for cost savings because the ratio in itself is a standard performance measure.

Table B-3. Overall Cost Savings

Ratio of Cost Savings to Research Funding Calculations		
	Cost With Use of Research Product	**Cost Without Use of Research Product**
ANNUAL AGENCY COSTS ***Table B-1 (12)***		
ANNUAL USER COSTS ***Table B-2 (14)***		
Total ANNUAL COSTS **(15) = *(12)+(14)***		
Total Cost Savings Per Year $CS = (15)_{with} - (15)_{without}$		
Total Annual Research Funding *(I)*		
Ratio of Total Cost Savings over Research Funding *(TCS/I)*		

PART C – ENVIRONMENTAL IMPACTS

Definition: Construction can have a great impact on the environment. For example, construction can cause sediment and erosion problems and impact wetlands, streams, etc. Research in construction procedures could potentially mitigate this problem. Advances in environmentally friendly materials and their use in design is another way by which infrastructure research can impact the environment. Development of less volatile paint systems and new materials to clean and repaint existing lead based paint systems can also have a positive impact on the environment. While it is clear that some research can impact the environment, it might be a difficult area to quantify in terms of dollars. Thus the metrics in this area are qualitative or quasi-quantitative in nature and are primarily determined by the project managers.
Data Source: Program and project managers, users
Research Area: All research areas and projects

Table C-1. Environmental Impacts

Environmental Impact	Weight (5 = critical, 0 = Not Applicable)	Level of Impact					Score (level * weight)	Max Score Possible = (max level *weight)
		-1 = negative impact	0 = none	1 = low	2 = medium	3 = high		
Improvement in Air Quality or Emissions Reduction	5							15
	0							0
Noise Abatement	5							15
	0							0
Wetland and nature preservation	5							15
	0							0
Recycling of Materials	5							15
	0							0
Aesthetics, etc.	5							15
	0							0
Others (please mention)	5							15
	0							0
Total								90
Measure Score (total score / max score)	--							
RATING								

RATING SCALE – Part C

Score > 75% –	Excellent: High positive environmental impacts
60% < Score ≤ 75% –	Good: Significant environmental impacts
45% < Score ≤ 60% –	Fair: Limited environmental impacts
Score < 45% –	Poor: Insignificant positive impacts or negative impacts

PART D – CUSTOMER SATISFACTION

Definition: The following performance measure directly addresses the customers' satisfaction with the research products. Users include states and local agencies and sometimes, international bodies, and ultimately the traveling public. The measures used are awareness, access, acceptance, use, and value that users place on the research product. Customer satisfaction metrics assess extent to which customers are satisfied by the choice of projects undertaken by the staff, timeliness and accuracy of research products, applicability of research to customer problems, responsiveness to requests for technical assistance, and quality of research products. A scale of 1 to 5 is used to indicate the level of satisfaction (1 being least and 5 being best). All measures are equally important and therefore are weighted equally.
Data Source: Customer surveys and interviews
Research Area: All research areas and projects

Table D-1. Customer Satisfaction

Primary Performance Measure	**Weight** (5 = critical, 0 = not applicable)	**Level of Satisfaction** 1 = low; 5 = high					**Score** (level * weight)	**Maximum Score Possible** (max level * weight)
		1	2	3	4	5		
Awareness of research product								
Access to research product								
Acceptance of research product								
Use of research product								
Value of research product								
Total								
Measure Score (total score / max score)								--
RATING								

RATING SCALE – Part D

Score > 75% – Excellent: Meets customers' needs adequately
60% < Score ≤ 75% – Good: Meets customers' needs satisfactorily
45% < Score ≤ 60% – Fair: Limited customers' satisfaction
Score < 45% – Poor: Customers not satisfied with research product.

OVERALL SCORECARD

The outputs from the various parts can be summarized as shown in the table below. The score or output from each component of the framework is recorded separately. This is visualized as a report card but with no aggregated or cumulative score for all the components. Converting all scores to a single number would tend to lose the essence of the assessment exercise.

Table E-1. Overall Scorecard

Part	Performance Measure	Result	Remarks
A	Research Output and Usage		
B	Cost Savings		
C	Environmental Impacts		
D	Customer Satisfaction		

APPENDIX B

Applications of Framework to Sample Programs and Projects

STUDY #1

EPOXY COATED REBARS PROJECT

Introduction – Since the early 1970s, the cost of maintaining, rehabilitating and reconstructing corrosion-damaged reinforced concrete structures has rapidly escalated, necessitating cost-effective corrosion protection systems. With this need, epoxy-coated reinforcement (ECR) has gained widespread acceptance as a means to extend the service life of parking garages, bridges, pavements and other reinforced concrete structures susceptible to corrosion.

Motivation and Objectives of the Project – To better manage the escalating maintenance costs of reinforced concrete structures and to assure maximum return on investment, many owners and specifiers are employing life cycle cost analyses to evaluate future expenditures and to justify the selection of corrosion protection strategies. To evaluate the life-cycle cost of any corrosion-protection strategy, a designer must determine the initial construction and material costs. The specific objective of the ECR research therefore was to determine a cost-effective corrosion protection system for the nation's bridge decks against chloride corrosion thereby reducing maintenance cost of concrete bridges and minimizing interruption to traffic that results from frequent maintenance activities.

Project History – Epoxy-coated reinforcement was first used in 1973. Since then, tens of thousands of structures have been constructed with this material. Many bridges — particularly those built in the 1970s and early 1980s — have now reached corrosive conditions in the concrete due to exposure to deicing salts, seawater, or harsh chemicals. However, field research has shown that the epoxy-coated reinforcement utilized in other structures is performing very well, and is significantly increasing the service life of the structures and, in turn, reducing life cycle costs.

Participating Agencies – The study was initiated by FHWA with heavy participation of the state DOTs. The Concrete Reinforcing Steel Institute conducts its own research in parallel with the government research.

Accomplishments and Outputs – Epoxy-coated reinforced concrete structures have proven their worth over the last 25+ years. Voluntary certification programs instituted by epoxy-coating plants produce a very high quality product. Research has shown that, by using epoxy coating, the structure's service life has exceeded the original projected service life. The increased service life of many structures has reduced life-cycle costs. The accomplishments of the ECR research are reflected in the following list of accolades:

- All standards in ASTM are based on this research
- Approx. 100,000 structures (including 48,970 bridge decks) contain epoxy-coated rebars
- Million to 5 million tons of epoxy-coated rebars have been used in the U.S.
- ECR is now the standard in the U.S. except in marine environments and Florida; Florida does not use salt in highways that would penetrate concrete and cause corrosion.

Numerous publications including:

- Summary report: "Corrosion Protection – Concrete Bridges" (FHWA-RD-98-088
- FHWA Technical Note: "Corrosion Protection Systems" – describes application process, performance experience, cost impacts and potential payoff.
- Field evaluation report: "Performance of Epoxy Coated Rebars in Bridge Decks" (FHWA-RD-96-092)
- Publication: "Materials and Methods for Corrosion Control of Reinforced and Prestressed Concrete Structures in New Construction" (FHWA-RD-00-081)
- Publication: "Corrosion Costs and Preventive Strategies in the United States" (FHWA-RD-01-156) and Tech Brief: ((FHWA-RD-01-157)

Implementation and Technology Transfer – Implementation of the ECR research and technology transfer programs took many forms including seminars and presentations, dissemination of technical publications (listed in the previous section), technical briefs that summarize the state-of-the-art.

Cost Implications – Excellent corrosion-protection performance coupled with a low initial cost has made epoxy-coated reinforcement a sound value for most reinforced concrete structures. When compared to alternative protection systems (or no corrosion protection at all), epoxy-coated reinforcement offers low life-cycle costs and thus a very cost-effective strategy.

Since its first use in the early 1970s, the cost of epoxy-coated reinforcement has dropped significantly. Early on, epoxy coating added 80% to 120% to the cost of uncoated reinforcement. As use and production grew, the cost decreased. Presently, the cost of epoxy coating typically adds about $0.10 to $0.20 per pound to the cost of steel reinforcement. For most structures, coating all reinforcing steel will usually only increase the total structural cost by 1% to 3%.

When use increased and production costs decreased, the low initial cost of epoxy coating proved to be even more cost effective. The investment in epoxy-coated reinforcing steel is often recouped in the first or second year of the service life extension, making this one of the most effective corrosion protection investments available and therefore an exceedingly good value.

Sources:

Paul Virmani, FHWA

http://www.crsi.org/ECR/economics.html

Epoxy Coated Rebars Project
PART A – Research Output and Usage

Table A-1. Achievement of Research Objectives (10%)

Primary Performance Measure	**Weight** (5 = critical, 2 = somewhat)	**Level of Achievement**				**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		0 = not met	1 = barely met	2 = partially met	3 = fully met		
Stated objective of program/project	5				3	15	15
Additional Measures	**Weight** (5 = critical, 2 = somewhat)	**Level of Achievement**					
		0 = No		1 = Yes		--	--
Research Reports published by FHWA	4			1		4	4
Papers published in Peer Reviewed Journals	3			1		3	3
Awards or Citations for Product	2			1		2	2
Total						24	24
Measure Score *(total score / max score)*							1.00

Table A-2. Types of Products from Research (20%)

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Level of Development				Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
		0 = not developed	1 = initial stage	2 = partially developed	3 = fully developed		
Specifications (including Design, construction, inspection, testing, maintenance)	5				3	15	15
	0						0
Guidelines/Handbooks (including tables, charts, monographs, etc.)	5				3	15	15
	0						0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5						15
	0						0
Advanced Technology and New Equipment (including construction, inspection or testing)	5				3	15	15
	0						0
Software Tools (design, analysis, management, testing, inspection, etc.)	5						15
	0						0
Advanced state-of-the-art procedures (e.g., methods, techniques); Exploratory Research Results	5						15
	0						0
Technology Transfer (including websites, clearinghouses, workshops, etc.)	5						15
	0						0
Total						45	45
Measure Score *(total score / max score)*							1.00

Table A-3. Adoption for Implementation (30%)

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Time Scale for Adoption: 4 = 0-5 yrs	3 = 5-10 yrs	2 = 10-15 yrs	1 = >15 yrs	Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
Time required/taken for research products to be adopted	5	4				20	20
	0						0

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Level of Adoption:) = No	1 = Somewhat	2 = Fully	Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
Specifications (including Design, construction, inspection, testing, maintenance)	5	Have the specifications been adopted as National Specifications by AASHTO or appropriate standards Agencies?			10	10
				2 (ATSM)		
	0					0
Guidelines/Handbooks (including tables, charts, monographs, etc.)	5	Do DOTs, FHWA, AASHTO, Colleges, or similar organizations and institutions adopt the guidelines/handbooks?			10	10
				2 (FHWA)		
	0					0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5	Are the materials developed available commercially?			10	10
				2		
	0					
Advanced Technology and New Equipment (including construction, inspection or testing)	5	Are the technologies and equipment in regular use by transportation agencies (excluding pilot projects)?			10	10
				2		
	0					
Software Tools (for design, analysis, inspection, testing or management)	5	Public Applications: Is the software available for use by agencies and public Specific Agency Applications: Has the software application been completely installed, tested and is currently used?				10
	0					
Technology Transfer Applications (including websites, clearinghouses, workshops, etc.)	5	Have technology transfer applications like websites, clearinghouses, workshops, etc. been created and implemented?				10
	0					
Total					60	60
Measure Score *(total score / max score)*						1.00

Table A-4. Extent of Use at the State-Level (40%)

Performance Measure	Weight (5 = critical, 0 = Not Applicable)	Time Scale for Popular implementation				Score (level * weight)	Maximum Score Possible (max level * weight)
		4 = 0-5 yrs	3 = 5-10 yrs	2 = 10-15 yrs	1 = >15 yrs		
Time required/taken for research products to be widely implemented	5		3			15	20
	0						0
Performance Measures	**Weight** (5 = critical, 0 = Not Applicable)	**Extent of Use by Agencies, Institutions and Others within the States**				**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		0 = none	1 = few[1]	2 = several[2]	3 = widespread[3]		
Specifications (including Design, construction, inspection, testing, maintenance)	5	Number of States using the specifications				15	15
					3		
	0					0	0
Guidelines/Handbooks (including tables, charts, monographs)	5	Number of States that recommended the use of the guidelines				10	15
				2			
	0					0	0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5	Number of States with reported applications of the materials				15	15
					3		
	0					0	0
Advanced Technology and New Equipment (including construction, inspection or testing)	5	Number of states who have procured the equipment or the technology				15	15
					3		
	0					0	0
Software Tools (for design, analysis, inspection, testing or management	5	Number of states with users of software					15
	0					0	0
Technology Transfer (including websites, clearinghouses, workshops, etc.)	5	Number of States which have requested additional information about technology or Number of states where NHI courses were conducted				5	15
			1				
	0					0	0
Total						75	95
Measure Score *(total score / max score)*							0.79

none – *no state and local agencies, institutions or other agencies use the research*

[1] **few** – *less than 20% of the States (10) have state and local agencies, institutions and others using the research*

[2] **several** – *20% to 50% of the States (25) have state and local agencies, institutions and others using the research*

[3] **widespread** – *more than 50% of the States (more than 25) have state and local agencies, institutions and others using the research or if the product has been used by national and international agencies.,*

Table A-5. Overall Score for Measurement of Research

Performance Measure	Relative Measure Weight (w)	Measure Score (s)	Weighted Score (w*s)
A.1. Achievement of research objectives	10%	1.00	0.10
A.2. Types of Products from Research	20%	1.00	0.20
A.3. Adoption for Implementation	30%	1.00	0.30
A.4. Extent of Use/Number of Users of Research Product	40%	0.79	0.32
TOTAL SCORE {∑ (W.S)}*100	100%		**92%**
RATING			**EXCELLENT**

Epoxy Coated Rebars Project
PART B – Cost Savings

B.1. Agency Cost Savings

Table B-1. Agency Cost Savings

Research Program/Project				
Unit of measurement (Check appropriate unit)	Per sq. foot __X__ (Bridge Deck Area) Per Lane-Mile ______ Per Bridge ______ Per Application ______ Other (Please Specify) ____________			
Definition of Typical Infrastructure	**e.g., bridge: 150-ft span, 45-ft wide, 2 piers**			
Existing or Potential Number of infrastructure elements on which research product has or could be applied (N) (i.e., Number of Applications)	**571 Million Square Feet (From WebNBI data)**			
Capital Cost Savings of "activity" per Unit (If project reduces capital costs)				
Benefit Areas	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
– Design Labor Savings (expressed in $)	0			
– Construction Materials ($)	1	$45.45	$45.00	1% Increase in Cost
– Construction Labor ($)	0			
– Worker Injury or Death ($)	0			
– Other ($)				
Cost Per Unit (1)	1	$45.45	$45.00	
Total Capital Costs (2) = (1)*(N)	1	$25,951.95 Million	$25,695 Million	
Planned Service Life (in years) (S)	1	20	10	
Total Capital Cost for enhanced service life = (3) = (2)*(S_{with}/$S_{without}$)		$25,951.95 Million	$51,390 Million	
Total Annualized Capital Cost (AC) for enhanced service life (4)		**2,082 Million**	**3,327 Million**	
AND/OR Operating Costs Savings Per Unit (NOT APPLICABLE)				

AND/OR Routine Maintenance Cost Savings (If project reduces routine maintenance costs)				
Cost of Inspection	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
Maintenance Frequency				
Average Maintenance Labor Costs ($)				
Average Equipment Costs ($)				
Maintenance Management Labor Costs				
Maintenance Labor Injury or Death ($)				
Other				
Annual Cost per Unit (5)				
Total Annual Routine Maintenance Costs = AR (6) = (5)*(N)	**NOT APPLICABLE**			
AND/OR Major Rehabilitation and Reconstruction (R&R) Cost Savings (If project reduces major R&R costs) (NOT APPLICABLE)				
Costs Per Major R&R	**Applicability (Yes = 1, 0 = No)**	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
Average Maintenance Labor Costs ($)				
Average Maintenance Material Costs ($)				
Average Equipment Costs ($)				
Maintenance Labor Injury or Death ($)				
Other ($)				
Cost of Major R&R (7)				
Total Cost of R&R (8) = (7)*(N)				
Service Life Enhancement (in years) (S)				
Total R&R Cost for enhanced service life = (9) = (8)*(S_{with}/$S_{without}$)				
Total Annualized Major R&R Cost (AM) for enhanced service life (10)	**NOT APPLICABLE**			
Total Annual Operating Costs = (11) = *(6)+(10)*				
Total Annual Agency Costs = (12) = *(11)+(4)*		**2,082 Million**	**3,327 Million**	

B.2. User and Safety Cost Savings

Table B-2. User and Safety Cost Savings

User Cost Savings (If project produces user benefits)				
Savings Area	**Applicable** (0 = No; 1 = Yes)	**Annual Costs (Dollars)**		**Differential**
		Cost With Use of Research Product	**Cost Without Use of Research Product**	
Travel **Time** Cost				
Vehicle **Operating Cost**				
Property Damage				
Injury				
Loss of Life (Fatality)				
Annual costs (13)				
Total Annual User Costs (14) = (13)*(N)	**NOT APPLICABLE**			

B-3 Overall Cost Savings

Table B-3. Overall Cost Savings

Ratio of Cost Savings to Research Funding Calculations		
	Cost With Use of Research Product	**Cost Without Use of Research Product**
ANNUAL AGENCY COSTS ***Table B-1 (12)***	$2,082 Million	$3,327 Million
ANNUAL USER COSTS ***Table B-2 (14)***	NOT APPLICABLE	NOT APPLICABLE
Total ANNUAL COSTS (15) = *(12)+(14)*	$2,082 Million	$3,327 Million
Total Cost Savings Per Year $CS = (15)_{with} - (15)_{without}$	**$1,245 Million per year**	
Total Annual Research Funding *(I)*	**$1.75 Million**	
Ratio of Total Cost Savings over Research Funding *(TCS/I)*	**711:1**	

Epoxy Coated Rebars Project
PART C – Environmental Impacts

Table C-1. Environmental Impacts

Environmental Impact	Weight (5 = critical, 0 = Not Applicable)	Level of Impact					Score (level * weight)	Max Score Possible = (max level *weight)
		-1 = negative impact	0 = none	1 = low	2 = medium	3 = high		
Improvement in Air Quality or Emissions Reduction	5							15
	0							0
Noise Abatement	5							15
	0							0
Wetland and nature preservation	5							15
	0							0
Recycling of Materials	5							15
	0							0
Aesthetics, etc.	5							15
	0							0
Others (please mention)	5							15
	0							0
Total								90
Measure Score (total score / max score)	--							
RATING								NOT APPLICABLE

Epoxy Coated Rebars Project
PART D – Customer Satisfaction

Table D-1. Customer Satisfaction

Primary Performance Measure	Weight (5 = critical, 2 = somewhat)	Level of Satisfaction 1 = low; 5 = high					Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
		1	2	3	4	5		
Awareness of Technology or Specifications	5					5	25	25
Ease of Implementation	5				4		20	25
Acceptance of Technology	5				4		20	25
Value and importance	5					5	25	25
Predicted impact on future technologies	5			3			15	25
Other								
Total							105	125
Measure Score *(total score / max score)*								**84%**
RATING								**EXCELLENT**

Epoxy Coated Rebars Project

Overall Scorecard

Table E-1. Overall Scorecard

PART	PERFORMANCE ELEMENT	RESULT
A	ACHIEVEMENT OF RESEARCH OBJECTIVES	**EXCELLENT (92%)**
B	COST SAVINGS	**Potential savings of $1,245 Million per year. Ratio of cost savings over research funding– 711:1**
C	ENVIRONMENTAL IMPACTS	**NOT APPLICABLE**
D	CUSTOMER SATISFACTION	**EXCELLENT (84%)**

STUDY #2

Ground Penetrating Radar Project

Introduction – Before the introduction of ground penetrating radar (GPR) technology, pavement thickness was determined by taking core samples, delaminations were measured by chain drag, and voids were monitored by taking core samples. These procedures were largely destructive to pavements. In contrast, the GPR systems use micro-power impulse radar, synthetic aperture techniques, and sophisticated signal processing and imaging algorithms to image a 2-meter wide width of a bridge deck at one time. Using frequency based diffusion tomography, the systems produce images of the internal structure of reinforced concrete bridge decks.

Motivation and Objectives of the Project – The motivation for this research was to advance the use of GPR in determining the thickness of pavements and pavement layers, locations and extent of delaminations in bridge decks, voids under pavements, and dowel bar alignment. The goal is to locate steel reinforcement, corrosion related delaminations, voids and debonds. The ultimate purpose for use of GPR and other non-destructive technologies is to provide information on the condition of the nation's bridges.

Project History – The GPR research project began in 1981. FHWA has had several research contracts to advance the use of radar in various applications. The initial FHWA contract looked at different technologies and assessed their potential applications in highways. Several promising technologies were investigated including radar and infrared. Radar had the best potential for highway applications and was thus pursued. Radar technology gained recognition on submarines during WWII. Potential highway applications include pavement thickness, debonding (delamination) detection in bridge decks (since early 1980s), dowel-bar misalignments (since early 1990s), strength of concrete, moisture content of concrete, small-depth (20ft to 100ft) geotechnical work to detect ground water tables, buried objects, etc., void detection (up to 20 inches) in pavements.

The GPR research project developed two engineering prototypes of a new generation ground-penetrating radar for bridge deck inspections. The PERES prototype was delivered to the FHWA in December 1997 and has been undergoing testing and evaluation. The HERMES prototype was delivered to the FHWA in October 1998. Both prototypes have been field tested with good results.

Participating Agencies – FHWA took the lead while SHRP and NCHRP followed in the development and adoption of the technology. The Federal Highway Administration and the Department of Energy’s Lawrence Livermore National Laboratory (LLNL) cooperated in the development of the prototypes of the new generation GPR for bridge deck inspections.

Accomplishments and Outputs – This research produced valuable publications including:
FHWA/RD-85/051 ~ “Rapid Non-Destructive Delamination Detection”
FHWA/RD-86/190 ~ “Evaluation of Ground-Probing Radar for Rapid Delamination Detection”
NCHRP Synthesis 255 ~ “GPR for Evaluating Subsurface conditions”

Most notably, the research led to the development of two important prototypes. The first system, named PERES (Precision Electromagnetic Roadway Evaluation System) utilizes a single micro-power radar element to scan reinforced concrete bridge decks. PERES positions the radar element at closely spaced intervals to interrogate the internal structure of concrete. Spatial resolution of less than 1 cm and depth resolution of less than 1 mm have been demonstrated with PERES. While PERES represents a very powerful new tool for the investigation and evaluation of the internal structure of reinforced concrete using radar, it is very slow. It has imaging rates of up to 2 meters per hour.

FHWA has also sponsored the development of HERMES (High-speed Electromagnetic Roadway Mapping and Evaluation System). HERMES overcomes the limitations of PERES by using an array of 64 closely spaced micro-power radar elements housed in a trailer. The array is towed over a bridge deck at speeds of up to 90 kilometers per hour (kph). The system can be applied at a range of speeds with variable spatial and depth resolution. At less than 30 kph, the system has a cross range spatial resolution of 3 cm and can penetrate 30 cm of concrete. At 90 kph, the cross range resolution is reduced to 6 cm and 15 cm of penetration.

Implementation and Technology Transfer – Both prototypes have been field tested with good results. The HERMES technology is available for commercial licensing through LLNL and was the recipient of a R&D 100 Award in 1998 by Research and Development Magazine as one of the year's most technologically significant inventions. Extensive laboratory and field testing as well as further development of data reduction and automated defect identification software are planned. A portable, single-element, hand-held, imaging system is also planned.

Unfortunately, data from HERMES and PERES did not provide the necessary range resolution to definitively image typical delamination cracks, but field testing showed that reinforcing steel and bridge deck details were typically rendered in images from both systems. Recommendations for design changes were made by FHWA, based on observed response characteristics from HERMES and PERES field-testing to improve system imaging of delaminations. After more than 20 states from across the country reviewed these recommendations through a planning meeting held at the Turner Fairbanks Highway Research Center (TFHRC), these design changes were incorporated into HERMES II. A controlled phenomenology study is currently being planned for the new HERMES II that will be conducted by FHWA through its Nondestructive Evaluation Validation Center (NDEVC). This phenomenology study will quantify the performance of the system over bridge deck features of interest before it is tested in the field. According to the FY 2002/2003 Performance Plan for the FHWA, research seems to be focused in the direction of PERES III instead of HERMES II.

Sources:

Peter Kopac, FHWA, http://www.tfhrc.gov/////structur/struc98/ch5.htm#ch5-2, http://www.tfhrc.gov///hnr20/nde/openingpage.htm

Ground Penetrating Radar
PART A – Research Output and Usage

Table A-1. Achievement of Research Objectives (10%)

Primary Performance Measure	**Weight** (5= critical, 2 = somewhat)	**Level of Achievement**				**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		0 = not met	1 = barely met	2 = partially met	3 = fully met		
Stated objective of program/project	5				3	15	15
Additional Measures	**Weight** (5= critical, 2 = somewhat)	**Level of Achievement**					
		0 = No		1 = Yes		--	--
Research Reports published by FHWA	4			1		4	4
Papers published in Peer Reviewed Journals	3			1		3	3
Awards or Citations for Product	2	0				0	2
Total						22	24
Measure Score *(total score / max score)*							0.92

Table A-2. Types of Products from Research (20%)

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Level of Development				Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
		0 = not developed	1 = initial stage	2 = partially developed	3 = fully developed		
Specifications (including Design, construction, inspection, testing, maintenance)	5						15
	0						0
Guidelines/Handbooks (including tables, charts, monographs, etc.)	5			2		10	15
	0						0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5						15
	0						0
Advanced Technology and New Equipment (including construction, inspection or testing)	5			2		10	15
	0						0
Software Tools (design, analysis, management, testing, inspection, etc.)	5			2		10	15
	0						0
Advanced state-of-the-art procedures (e.g., methods, techniques); Exploratory Research Results	5			2		10	15
	0						0
Technology Transfer (including websites, clearinghouses, workshops, etc.)	5			2		10	15
	0						0
Total						50	75
Measure Score *(total score / max score)*							0.67

Table A-3. Adoption for Implementation (30%)

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Time Scale for Adoption				Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
		4 = 0-5 yrs	3 = 5-10 yrs	2 = 10-15 yrs	1 = >15 yrs		
Time required/taken for research products to be adopted	5		3			15	20
	0						0
Performance Measures	**Weight** (5 = critical, 0 = Not Applicable)	**Level of Adoption**				**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		) = No	1 = Somewhat	2 = Fully			
Specifications (including Design, construction, inspection, testing, maintenance)	5	Have the specifications been adopted as National Specifications by AASHTO or appropriate standards Agencies?					10
	0						0
Guidelines/Handbooks (including tables, charts, monographs, etc.)	5	Do DOTs, FHWA, AASHTO, Colleges, or similar organizations and institutions adopt the guidelines/handbooks?				10	10
				2			
	0						0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5	Are the materials developed available commercially?					10
	0						
Advanced Technology and New Equipment (including construction, inspection or testing)	5	Are the technologies and equipment in regular use by transportation agencies (excluding pilot projects)?				5	10
			1				
	0						
Software Tools (for design, analysis, inspection, testing or management)	5	Public Applications: Is the software available for use by agencies and public Specific Agency Applications: Has the software application been completely installed, tested and is currently used?					10
	0						
Technology Transfer Applications (including websites, clearinghouses, workshops, etc.)	5	Have technology transfer applications like websites, clearinghouses, workshops, etc. been created and implemented?				5	10
			1				
	0						
Total						35	50
Measure Score *(total score / max score)*							0.70

Table A-4. Extent of Use at the State-Level (40%)

Performance Measure	Weight (5= critical, 0 = Not Applicable)	Time Scale for Popular implementation				Score (level * weight)	Maximum Score Possible (max level * weight)
		4 = 0-5 yrs	3 = 5-10 yrs	2 = 10-15 yrs	1 = >15 yrs		
Time required/taken for research products to be widely implemented	5			2		10	20
	0						0
Performance Measures	**Weight** (5 = critical, 0 = Not Applicable)	**Extent of Use by Agencies, Institutions and Others within the States**				**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		0 = none	1 = few[1]	2 = several[2]	3 = widespread[3]		
Specifications (including Design, construction, inspection, testing, maintenance)	5	Number of States using the specifications					15
	0					0	0
Guidelines/Handbooks (including tables, charts, monographs)	5	Number of States that recommended the use of the guidelines					15
	0					0	0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5	Number of States with reported applications of the materials					15
	0					0	0
Advanced Technology and New Equipment (including construction, inspection or testing)	5	Number of states who have procured the equipment or the technology				10	15
				2			
	0					0	0
Software Tools (for design, analysis, inspection, testing or management	5	Number of states with users of software					15
	0					0	0
Technology Transfer (including websites, clearinghouses, workshops, etc.)	5	Number of States which have requested additional information about technology or Number of states where NHI courses were conducted				10	15
				2			
	0					0	0
Total						30	50
Measure Score *(total score / max score)*							0.60

none – *no state and local agencies, institutions or other agencies use the research*

[1] **few** – *less than 20% of the States (10) have state and local agencies, institutions and others using the research*

[2] **several** – *20% to 50% of the States (25) have state and local agencies, institutions and others using the research*

[3] **widespread** – *more than 50% of the States (more than 25) have state and local agencies, institutions and others using the research or if the product has been used by national and international agencies.,*

Table A-5. Overall Score for Measurement of Research

Performance Measure	Relative Measure Weight (w)	Measure Score (s)	Weighted Score (w*s)
A.1. Achievement of research objectives	10%	0.92	0.09
A.2. Types of Products from Research	20%	0.67	0.13
A.3. Adoption for Implementation	30%	0.70	0.21
A.4. Extent of Use/Number of Users of Research Product	40%	0.60	0.24
TOTAL SCORE {∑ (W.S)}*100	100%		**67%**
RATING			**GOOD**

Ground Penetrating Radar
PART B – Cost Savings

B.1. Agency Cost Savings

Table B-1. Agency Cost Savings

Research Program/Project				
Unit of measurement (Check appropriate unit)	Per sq. foot ______ Per Lane-Mile ______ Per Bridge ___X__(Per Bridge Deck) Per Application ______ Other (Please Specify) ____________________			
Definition of Typical Infrastructure	**e.g., bridge: 150-ft span, 45-ft wide, 2 piers**			
Existing or Potential Number of infrastructure elements on which research product has or could be applied (N) (i.e., Number of Applications)	**Estimate: 2500 bridge decks or (50 per state) surveyed annually using GPR**			
Capital Cost Savings of "activity" per Unit (If project reduces capital costs) NOT APPLICABLE				
Benefit Areas	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
– Design Labor Savings (expressed in $)				
– Construction Materials ($)				
– Construction Labor ($)				
– Worker Injury or Death ($)				
– Other ($)				
Cost Per Unit (1)				
Total Capital Costs (2) = (1)*(N)				
Planned Service Life (in years) (S)				
Total Capital Cost for enhanced service life = (3) = (2)*(S_{with}/$S_{without}$)				
Total Annualized Capital Cost (AC) for enhanced service life (4)	**NOT APPLICABLE**			
AND/OR Operating Costs Savings Per Unit				

AND/OR Routine Maintenance Cost Savings (If project reduces routine maintenance costs)				
Cost of Inspection	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
Maintenance Frequency	0			
Average Maintenance Labor Costs ($)	1	$1000 (including equipment, labor and data interpretation costs	$528 (8 hours per deck, 6 man crew, $11/hour labor costs	
Average Equipment Costs ($)	1		$0	
Maintenance Management Labor Costs	0			
Maintenance Labor Injury or Death ($)	0			
Other	0			
Annual Cost per Unit (5)	1	**$1000**	**$528**	
Total Annual Routine Maintenance Costs = AR (6) = (5)*(N)	**1**	**$2,500,000**	**$1,320,000**	
AND/OR Major Rehabilitation and Reconstruction (R&R) Cost Savings (If project reduces major R&R costs) (NOT APPLICABLE)				
Costs Per Major R&R	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
Average Maintenance Labor Costs ($)				
Average Maintenance Material Costs ($)				
Average Equipment Costs ($)				
Maintenance Labor Injury or Death ($)				
Other ($)				
Cost of Major R&R (7)				
Total Cost of R&R (8) = (7)*(N)				
Service Life Enhancement (in years) (S)				
Total R&R Cost for enhanced service life = (9) = (8)*(S_{with}/$S_{without}$)				
Total Annualized Major R&R Cost (AM) for enhanced service life (10)	**NOT APPLICABLE**			
Total Annual Operating Costs = (11) = *(6)+(10)*	1	**$2,500,000**	**$1,320,000**	
Total Annual Agency Costs = (12) = *(11)+(4)*	1	**$2,500,000**	**$1,320,000**	

B.2. User and Safety Cost Savings

Table B-2. User and Safety Cost Savings

User Cost Savings (If project produces user benefits)				
Savings Area	**Applicable** (0 = No; 1 = Yes)	**Annual Costs (Dollars)**		**Differential**
		Cost With Use of Research Product	**Cost Without Use of Research Product**	
Travel **Time** Cost				
Vehicle **Operating Cost**				
Property Damage				
Injury				
Loss of Life (Fatality)				
Annual Road User Costs (13) ***Source: Techniques for manually estimating road user costs associated with construction projects, TTI***	**1**	**$0**	**$1400 (One lane closed, 4 lane rural interstate, 30,000 ADT)**	
Total Annual User Costs (14) = (13)*(N)	**1**	**$0**	**$3,500,000**	

B.3. Overall Cost Savings

Table B-3. Overall Cost Savings

Ratio of Cost Savings to Research Funding Calculations		
	Cost With Use of Research Product	**Cost Without Use of Research Product**
ANNUAL AGENCY COSTS ***Table B-1 (12)***	$2,500,000	$1,320,000
ANNUAL USER COSTS ***Table B-2 (14)***	$0	$3,500,000
Total ANNUAL COSTS (15) = ***(12)+(14)***	$2,500,000	$4,820,000
Total Cost Savings Per Year $CS = (15)_{with} - (15)_{without}$	**$2.32 Million per year**	
Total Annual Research Funding ***(I)***	**$100,000 ($2 million over 20 years)**	
Ratio of Total Cost Savings over Research Funding ***(TCS/I)***	**23.2**	

Ground Penetrating Radar
PART C – Environmental Impacts

Table C-1. Environmental Impacts

Environmental Impact	**Weight** (5 = critical, 0 = Not Applicable)	**Level of Impact**					**Score** (level * weight)	**Max Score Possible** = (max level *weight)
		-1 = negative impact	0 = none	1 = low	2 = medium	3 = high		
Improvement in Air Quality or Emissions Reduction	5							15
	0							0
Noise Abatement	5							15
	0							0
Wetland and nature preservation	5							15
	0							0
Recycling of Materials	5							15
	0							0
Aesthetics, etc.	5							15
	0							0
Others (please mention)	5							15
	0							0
Total								90
Measure Score (total score / max score)	--							
RATING								NOT APPLICABLE

Ground Penetrating Radar
PART D – Customer Satisfaction

Table D-1. Customer Satisfaction

Primary Performance Measure	**Weight** (5 = critical, 2 = somewhat)	**Level of Satisfaction** 1 = low; 5 = high					**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		1	2	3	4	5		
Awareness of Technology or Specifications	5				4		20	25
Ease of Implementation	5			3			15	25
Acceptance of Technology	5			3			15	25
Value and importance	5				4		20	25
Predicted impact on future technologies	5				4		20	25
Other								
Total							90	125
Measure Score *(total score / max score)*								**72%**
RATING								**GOOD**

Ground Penetrating Radar
Overall Scorecard

Table E-1. Overall Scorecard

PART	PERFORMANCE MEASURE	RESULT
A	ACHIEVEMENT OF RESEARCH OBJECTIVES	**GOOD (67%)**
B	COST SAVINGS	**Potential savings of $2.3 Million per year. Ratio of cost savings to research funding – 23.2: 1**
C	ENVIRONMENTAL IMPACTS	**NOT APPLICABLE**
D	CUSTOMER SATISFACTION	**GOOD (72%)**

STUDY #3
High Performance Steel Research Program

Introduction – Prior to the High Performance Steel (HPS) Program, the steel industry did its own research just to sell products. Higher strength steel existed but was brittle and hard to weld. The U.S. Navy, a major consumer of steel, developed specifications in collaboration with industry for its direct consumption. The construction always went to low bidders. Previously, the steel construction industry benefited from the "Buy-America" clause and thus had no incentive for R&D. Now HPS has spurred modernization of steel in the USA.

Motivation and Objectives of the Program – The drive behind the HPS program has been to develop high performance steel grades that would improve bridge construction practice. The primary measure of performance is higher strength, but it must also be tough and easy to weld.

Program History – Since inception of the High Performance Steel Program in 1992, it has worked to develop high performance steel grades. In 1997, the Civil engineering Research Foundation (CERF) gave an award to the HPS program for: "most significant innovation in the construction industry", and cited it for: "going from fundamental research to actual implementation within 3 years." The Research is ongoing through FY 2003 with continuous update of codes. Higher grade steel: HPS-100 is under research and is expected to be ready for field-testing in about 1 year.

Participating Agencies – The HPS program is a cooperative one between the FHWA, the U.S. Navy, and the American Iron and Steel Institute (AISI). The FHWA has an inter-agency agreement with the U.S. Navy to use the latter's resources. The Navy in turn has set up a cooperative research agreement with the American Iron and Steel Institute.

Accomplishments and Outputs – As a result of this program, higher grades of steel have been developed notably the HPS-70W. Design specifications have been revised in AASHTO codes and in welding codes, and several reports and flyers have been published. Benefits of the program include the following:

a. Ability to use less steel in construction when HPS is substituted
b. Although HPS costs more, much less steel is needed and there are additional savings from ancillary construction work (earth, roads, piers, etc.)
c. The first cost of bridge construction is reduced by 10% from use of HPS
d. Ability to use much longer single spans without as many piers as traditionally needed.

Implementation and Technology Transfer – Since development of HPS, U.S. now produces better steel products than Japan, which used to be the leader. HPS developers went through a lot of R&D and product testing to convince agencies to make code changes to HPS. An effective technological transfer tool was the offer to the States to get higher contributions of Federal construction funds if they adopted HPS. This program represents one focus area of a larger steel bridge program at the TFHRC.

Sources: Bill Wright, FHWA, Steel products website: www.steel.org

High Performance Steel Research Program
PART A – Research Output and Usage

Table A-1. Achievement of Research Objectives (10%)

Primary Performance Measure	Weight (5 = critical, 2 = somewhat)	Level of Achievement				Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
		0 = not met	1 = barely met	2 = partially met	3 = fully met		
Stated objective of program/project	5				3	15	15
Additional Measures	**Weight** (5 = critical, 2 = somewhat)	**Level of Achievement**					
		0 = No		1 = Yes		--	--
Research Reports published by FHWA	4			1		4	4
Papers published in Peer Reviewed Journals	3			1		3	3
Awards or Citations for Product	2			1		2	2
Total						24	24
Measure Score *(total score / max score)*							1.00

Table A-2. Types of Products from Research (20%)

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Level of Development				Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
		0 = not developed	1 = initial stage	2 = partially developed	3 = fully developed		
Specifications (including Design, construction, inspection, testing, maintenance)	5				3	15	15
	0						0
Guidelines/Handbooks (including tables, charts, monographs, etc.)	5				3	15	15
	0						0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5				3	15	15
	0						0
Advanced Technology and New Equipment (including construction, inspection or testing)							15
	0						0
Software Tools (design, analysis, management, testing, inspection, etc.)							15
	0						0
Advanced state-of-the-art procedures (e.g., methods, techniques); Exploratory Research Results							15
	0						0
Technology Transfer (including websites, clearinghouses, workshops, etc.)	5			2		10	15
	0						0
Total						55	60
Measure Score *(total score / max score)*							0.92

Table A-3. Adoption for Implementation (30%)

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Time Scale for Adoption				Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
		4 = 0-5 yrs	3 = 5-10 yrs	2 = 10-15 yrs	1 = >15 yrs		
Time required/taken for research products to be adopted	5		3			15	20
	0						0
Performance Measures	**Weight** (5 = critical, 0 = Not Applicable)	**Level of Adoption**				**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		) = No	1 = Somewhat	2 = Fully			
Specifications (including Design, construction, inspection, testing, maintenance)	5	Have the specifications been adopted as National Specifications by AASHTO or appropriate standards Agencies?				10	10
				2			
	0						0
Guidelines/Handbooks (including tables, charts, monographs, etc.)	5	Do DOTs, FHWA, AASHTO, Colleges, or similar organizations and institutions adopt the guidelines/handbooks?				5	10
			1				
	0						0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5	Are the materials developed available commercially?				10	10
				2			
	0						
Advanced Technology and New Equipment (including construction, inspection or testing)	5	Are the technologies and equipment in regular use by transportation agencies (excluding pilot projects)?					10
	0						
Software Tools (for design, analysis, inspection, testing or management)	5	Public Applications: Is the software available for use by agencies and public Specific Agency Applications: Has the software application been completely installed, tested and is currently used?					10
	0						
Technology Transfer Applications (including websites, clearinghouses, workshops, etc.)	5	Have technology transfer applications like websites, clearinghouses, workshops, etc. been created and implemented?				5	10
			1				
	0						
Total						45	60
Measure Score *(total score / max score)*							0.75

Table A-4. Extent of Use at the State-Level (40%)

Performance Measure	**Weight** (5 = critical, 0 = Not Applicable)	**Time Scale for Popular implementation**				**Score** (level * weight)	**Maximum Score Possible** (max level * weight)
		4 = 0-5 yrs	3 = 5-10 yrs	2 = 10-15 yrs	1 = >15 yrs		
Time required/taken for research products to be widely implemented	5		3			15	20
	0						0
Performance Measures	**Weight** (5 = critical, 0 = Not Applicable)	**Extent of Use by Agencies, Institutions and Others within the States**				**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		0 = none	1 = few[1]	2 = several[2]	3 = widespread[3]		
Specifications (including Design, construction, inspection, testing, maintenance)	5	Number of States using the specifications				10	15
				2			
	0					0	0
Guidelines/Handbooks (including tables, charts, monographs)	5	Number of States that recommended the use of the guidelines				10	15
				2			
	0					0	0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5	Number of States with reported applications of the materials				15	15
					3		
	0					0	0
Advanced Technology and New Equipment (including construction, inspection or testing)	5	Number of states who have procured the equipment or the technology					15
	0					0	0
Software Tools (for design, analysis, inspection, testing or management	5	Number of states with users of software					15
	0					0	0
Technology Transfer (including websites, clearinghouses, workshops, etc.)	5	Number of States which have requested additional information about technology or Number of states where NHI courses were conducted				5	15
			1				
	0					0	0
Total						55	80
Measure Score *(total score / max score)*							0.69

none – *no state and local agencies, institutions or other agencies use the research*

[1] **few** – *less than 20% of the States (10) have state and local agencies, institutions and others using the research*

[2] **several** – *20% to 50% of the States (25) have state and local agencies, institutions and others using the research*

[3] **widespread** – *more than 50% of the States (more than 25) have state and local agencies, institutions and others using the research or if the product has been used by national and international agencies.*

Table A-5. Overall Score for Measurement of Research

Performance Measure	Relative Measure Weight (w)	Measure Score (s)	Weighted Score (w*s)
A.1. Achievement of research objectives	10%	1.00	0.10
A.2. Types of Products from Research	20%	0.92	0.18
A.3. Adoption for Implementation	30%	0.75	0.23
A.4. Extent of Use/Number of Users of Research Product	40%	0.69	0.28
TOTAL SCORE {∑ (W.S)}*100	100%		**79%**
RATING			**EXCELLENT**

High Performance Steel Research Program
PART B – Cost Savings

B.1 Agency Cost Savings

Table B-1. Agency Cost Savings

Research Program/Project				
Unit of measurement (Check appropriate unit)	Per sq. foot ______ Per Lane-Mile ______ Per Bridge __X___ Per Application ______ Other (Please Specify) ____________________			
Definition of Typical Infrastructure	**e.g., bridge: 150-ft span, 45-ft wide, 2 piers**			
Existing or Potential Number of infrastructure elements on which research product has or could be applied (N) (i.e., Number of Applications)	**169 Bridges being fabricated, planned or in service**			
Capital Cost Savings of "activity" per Unit (If project reduces capital costs) NOT APPLICABLE				
Benefit Areas	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
– Design Labor Savings (expressed in $)	0			
– Construction Materials ($)	1	$303,300	$337,000(150 ft X 45 ft, 50 lbs/sq. ft, $1.00/lb in place costs	10% differential
– Construction Labor ($)	0			
– Worker Injury or Death ($)	0			
– Other ($)	0			
Cost Per Unit (1)	1	**$303,300**	**$337,000**	
Total Capital Costs (2) = (1)*(N)	1	**$51,257,700**	**$56,953,00**	
Planned Service Life (in years) (S)	0			
Total Capital Cost for enhanced service life = (3) = (2)*(S_{with}/$S_{without}$)	0			
Total Annualized Capital Cost (AC) for enhanced service life (4)	0			
AND/OR Operating Costs Savings Per Unit				
AND/OR Routine Maintenance Cost Savings				

(If project reduces routine maintenance costs) NOT APPLICABLE				
Cost of Inspection	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
Maintenance Frequency				
Average Maintenance Labor Costs ($)				
Average Equipment Costs ($)				
Maintenance Management Labor Costs				
Maintenance Labor Injury or Death ($)				
Other				
Annual Cost per Unit (5)				
Total Annual Routine Maintenance Costs = AR (6) = (5)*(N)	**NOT APPLICABLE**			
AND/OR Major Rehabilitation and Reconstruction (R&R) Cost Savings (If project reduces major R&R costs) (NOT APPLICABLE)				
Costs Per Major R&R	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
Average Maintenance Labor Costs ($)				
Average Maintenance Material Costs ($)				
Average Equipment Costs ($)				
Maintenance Labor Injury or Death ($)				
Other ($)				
Cost of Major R&R (7)				
Total Cost of R&R (8) = (7)*(N)				
Service Life Enhancement (in years) (S)				
Total R&R Cost for enhanced service life = (9) = (8)*(S_{with}/$S_{without}$)				
Total Annualized Major R&R Cost (AM) for enhanced service life (10)	**NOT APPLICABLE**			
Total Annual Operating Costs = (11) = *(6)+(10)*	**NOT APPLICABLE**			
Total Annual Agency Costs = (12) = *(11)+(4)*	**1**	**$51,257,700**	**$56,953,00**	

B.2. User and Safety Cost Savings

Table B-2. User and Safety Cost Savings

User Cost Savings (If project produces user benefits)				
Savings Area	**Applicable** (0 = No; 1 = Yes)	**Annual Costs (Dollars)**		**Differential**
		Cost With Use of Research Product	**Cost Without Use of Research Product**	
Travel **Time** Cost				
Vehicle **Operating Cost**				
Property Damage				
Injury				
Loss of Life (Fatality)				
Annual Costs (13)				
Total Annual User Costs (14) = (13)*(N)	**NOT APPLICABLE**			

B-3 Overall Cost Savings

Table B-3. Overall Cost Savings

Ratio of Cost Savings to Research Funding Calculations		
	Cost With Use of Research Product	**Cost Without Use of Research Product**
AGENCY COSTS *Table B-1 (12)*	**$51,257,700**	**$56,953,00**
USER COSTS *Table B-2 (14)*	NOT APPLICABLE	NOT APPLICABLE
Total COSTS (15) = *(12)+(14)*	**$51,257,700**	**$56,953,00**
Total Cost Savings Per Year *$CS = (15)_{with} - (15)_{without}$*	**$5.7 Million (Estimated total savings for 169 bridges constructed using HPS. Since a sample bridge was assumed for material cost calculations, the actual cost savings may be significantly higher than shown**	
Total Annual Research Funding *(I)*	**$2.3 Million**	
Ratio of Total Cost Savings over Research Funding *(TCS/I)*	**2.5:1 (Additional implementations will increase cost savings)**	

High Performance Steel Research Program
PART C – Environmental Impacts

Table C-1. Environmental Impacts

Environmental Impact	Weight (5 = critical, 0 = Not Applicable)	Level of Impact: -1 = negative impact	0 = none	1 = low	2 = medium	3 = high	Score (level * weight)	Max Score Possible = (max level *weight)
Improvement in Air Quality or Emissions Reduction	5							15
	0							0
Noise Abatement	5							15
	0							0
Wetland and nature preservation	5							15
	0							0
Recycling of Materials	5							15
	0							0
Aesthetics, etc.	5							15
	0							0
Others (please mention)	5							15
	0							0
Total								90
Measure Score (total score / max score)	--							
RATING								NOT APPLICABLE

High Performance Steel Research Program
PART D – Customer Satisfaction

Table D-1. Customer Satisfaction

Primary Performance Measure	**Weight** (5 = critical, 2 = somewhat)	**Level of Satisfaction** 1 = low; 5 = high					**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		1	2	3	4	5		
Awareness of Technology or Specifications	5				4		20	25
Ease of Implementation	5				4		20	25
Acceptance of Technology	5				4		20	25
Value and importance	5				4		20	25
Predicted impact on future technologies	5			3			15	25
Other								
Total							95	125
Measure Score *(total score / max score)*								**76%**
RATING								**EXCELLENT**

High Performance Steel Research Program
Overall Scorecard

Table E-1. Overall Scorecard

PART	**PERFORMANCE MEASURE**	**RESULT**
A	ACHIEVEMENT OF RESEARCH OBJECTIVES	**GOOD (79%)**
B	COST SAVINGS	**$5.7 Million saved for 169 HPS bridges. Ratio of cost savings over research funding: 2.5:1**
C	ENVIRONMENTAL IMPACTS	**NOT APPLICABLE**
D	CUSTOMER SATISFACTION	**EXCELLENT (76%)**

STUDY #4
Geotechnical Research Program

Introduction – A series of FHWA studies in the 1970's determined that various segments within the field of highway geotechnology needed significant improvement in design and construction applications. This was especially important considering that bridge foundations, retaining wall systems, embankments, and cut-slope operations account for well over 50 percent of the total cost of most highway projects. The assessment studies found that pile design was more guesswork than it was scientific, especially for group behavior of piles. Other foundation systems such as drilled shafts and spread footings were starting to replace piles in a few cases, but piles were usually selected in the vast majority of projects, although in some cases they may not have been the best choice. Reasons most often cited were the lack of adequate performance records for the alternative choices and/or the need for better design and construction guidelines.

Motivation and Objectives of the Program – Design techniques suffered from a lack of precise definitions and a very imperfect understanding of fundamental behavior mechanisms that govern geotechnical structures. In addition, defining soil and rock behavior under foundation loads was difficult and expensive. It was therefore imperative that accurate and rational guidelines be developed for geotechnical-related design and construction applications to ensure safe and efficient highway structures. Research objectives aimed at developing improved predictive techniques for foundation design and soil behavior; improved design and construction guidelines for ground improvement techniques, such as reinforced soil, stone columns, dynamic compaction, soil nailing, tieback anchors; and prefabricated vertical drains. Future (ongoing) research aims to develop new and/or improved support systems for bridge foundations and deep excavations for highway construction projects.

Program History – Since program inception in 1975, there has been a significant influx of innovative geotechnical methods to retain earth masses and/or improve ground materials to withstand heavy loads. As a result of these discoveries, FHWA expanded the Geotechnical Research Program to address many of these needs. The program was divided into three main projects: Soil Behavior, Foundations, and Ground Improvement. During the 1990's, the soil behavior project was completed, and the other two were revised to reflect the accomplishments in each project plus the objectives still to be achieved.

Participating Agencies – The FHWA program in geotechnical research is supported through staff research and contract research. The FHWA maintains a Geotechnical Laboratory Complex on site, which consists of soil mechanics, soil behavior, and foundations testing facilities.

Accomplishments and Outputs – Ground improvement technologies were imported from foreign countries where it was less important to understand how the improvement mechanism worked. The research has been targeted at making improvements to AASHTO specifications, and has made a positive impact on the methodology, devices and specifications used in the nation.

Implementation and Technology Transfer – Implementation and technology transfer of the Geotechnical Research Program were accomplished through demonstration programs, experimental projects, workshops and seminars, operations surveillance and National Highway Institute training courses. The program and its various activities are documented in the publication, "A Quarter Century of Geotechnical Research", FHWA-RD-98-139.

Sources:

Albert DiMillio, FHWA
TFHRC website: Chapter One, "Introduction," of "A Quarter Century of Geotechnical Research", Accessed at: http://www.tfhrc.gov/structur/gtr/century/index.htm

Geotechnical Research Program
PART A – Research Output and Usage

Table A-1. Achievement of Research Objectives (10%)

Primary Performance Measure	**Weight** (5 = critical, 2 = somewhat)	**Level of Achievement**				**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		0 = not met	1 = barely met	2 = partially met	3 = fully met		
Stated objective of program/project	5				3	15	15
Additional Measures	**Weight** (5 = critical, 2 = somewhat)	**Level of Achievement**					
		0 = No		1 = Yes		--	--
Research Reports published by FHWA	4			1		4	4
Papers published in Peer Reviewed Journals	3			1		3	3
Awards or Citations for Product	2			1		2	2
Total						24	24
Measure Score *(total score / max score)*							1.00

Table A-2. Types of Products from Research (20%)

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Level of Development				Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
		0 = not developed	1 = initial stage	2 = partially developed	3 = fully developed		
Specifications (including Design, construction, inspection, testing, maintenance)	5				3	15	15
	0						0
Guidelines/Handbooks (including tables, charts, monographs, etc.)	5				3	15	15
	0						0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5				3	15	15
	0						0
Advanced Technology and New Equipment (including construction, inspection or testing)	5				3	15	15
	0						0
Software Tools (design, analysis, management, testing, inspection, etc.)	5				3	15	15
	0						0
Advanced state-of-the-art procedures (e.g., methods, techniques); Exploratory Research Results	5				3	15	15
	0						0
Technology Transfer (including websites, clearinghouses, workshops, etc.)	5				3	15	15
	0						0
Total						105	105
Measure Score *(total score / max score)*							1.00

Table A-3. Adoption for Implementation (30%)

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Time Scale for Adoption				Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
		4 = 0-5 yrs	3 = 5-10 yrs	2 = 10-15 yrs	1 = >15 yrs		
Time required/taken for research products to be adopted	5		3			15	20
	0						0
Performance Measures	**Weight** (5 = critical, 0 = Not Applicable)	**Level of Adoption**				**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		0 = No	1 = Somewhat	2 = Fully			
Specifications (including Design, construction, inspection, testing, maintenance)	5	Have the specifications been adopted as National Specifications by AASHTO or appropriate standards Agencies?				10	10
				2			
	0						0
Guidelines/Handbooks (including tables, charts, monographs, etc.)	5	Do DOTs, FHWA, AASHTO, Colleges, or similar organizations and institutions adopt the guidelines/handbooks?				10	10
				2			
	0						0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5	Are the materials developed available commercially?				5	10
			1				
	0						
Advanced Technology and New Equipment (including construction, inspection or testing)	5	Are the technologies and equipment in regular use by transportation agencies (excluding pilot projects)?				5	10
			1				
	0						
Software Tools (for design, analysis, inspection, testing or management)	5	Public Applications: Is the software available for use by agencies and public Specific Agency Applications: Has the software application been completely installed, tested and is currently used?				5	10
			1				
	0						
Technology Transfer Applications (including websites, clearinghouses, workshops, etc.)	5	Have technology transfer applications like websites, clearinghouses, workshops, etc. been created and implemented?				10	10
				2			
	0						
Total						60	80
Measure Score *(total score / max score)*							0.75

Table A-4. Extent of Use at the State-Level (40%)

Performance Measure	Weight (5 = critical, 0 = Not Applicable)	Time Scale for Popular implementation				Score (level * weight)	Maximum Score Possible (max level * weight)
		4 = 0-5 yrs	3 = 5-10 yrs	2 = 10-15 yrs	1 = >15 yrs		
Time required/taken for research products to be widely implemented	5		3			15	20
	0						0
Performance Measures	**Weight** (5 = critical, 0 = Not Applicable)	**Extent of Use by Agencies, Institutions and Others within the States**				**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		0 = none	1 = few[1]	2 = several[2]	3 = widespread[3]		
Specifications (including Design, construction, inspection, testing, maintenance)	5	Number of States using the specifications				15	15
					3		
	0					0	0
Guidelines/Handbooks (including tables, charts, monographs)	5	Number of States that recommended the use of the guidelines				15	15
					3		
	0					0	0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5	Number of States with reported applications of the materials				15	15
					3		
	0					0	0
Advanced Technology and New Equipment (including construction, inspection or testing)	5	Number of states who have procured the equipment or the technology				15	15
					3		
	0					0	0
Software Tools (for design, analysis, inspection, testing or management	5	Number of states with users of software					15
	0					0	0
Technology Transfer (including websites, clearinghouses, workshops, etc.)	5	Number of States which have requested additional information about technology or Number of states where NHI courses were conducted				10	15
				2			
	0					0	0
Total						85	95
Measure Score *(total score / max score)*							0.89

none – *no state and local agencies, institutions or other agencies use the research*

[1] **few** – *less than 20% of the States (10) have state and local agencies, institutions and others using the research*

[2] **several** – *20% to 50% of the States (25) have state and local agencies, institutions and others using the research*

[3] **widespread** – *more than 50% of the States (more than 25) have state and local agencies, institutions and others using the research or if the product has been used by national international agencies.*

Table A-5. Overall Score for Measurement of Research

Performance Measure	Relative Measure Weight (w)	Measure Score (s)	Weighted Score (w*s)
A.1. Achievement of research objectives	10%	1.00	0.10
A.2. Types of Products from Research	20%	1.00	0.20
A.3. Adoption for Implementation	30%	0.75	0.23
A.4. Extent of Use/Number of Users of Research Product	40%	0.89	0.36
TOTAL SCORE {∑ (W.S)}*100	100%		**89%**
RATING			**EXCELLENT**

Geotechnical Research Program
PART B – Cost Savings

B.1. Agency Cost Savings

Table B-1. Agency Cost Savings

Research Program/Project				
Unit of measurement (Check appropriate unit)	Per sq. foot ______ Per Lane-Mile ______ Per Bridge ______ Per Application ______ Other (Please Specify) ____________________			
Definition of Typical Infrastructure	**e.g., bridge: 150-ft span, 45-ft wide, 2 piers**			
Existing or Potential Number of infrastructure elements on which research product has or could be applied (N) (i.e., Number of Applications)				
Capital Cost Savings of "activity" per Unit (If project reduces capital costs)				
Benefit Areas	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
– Design Labor Savings (expressed in $)				
– Construction Materials ($)				
– Construction Labor ($)				
– Worker Injury or Death ($)				
– Other ($)				
Cost Per Unit (1)				
Total Capital Costs (2) = (1)*(N)				
Planned Service Life (in years) (S)				
Total Capital Cost for enhanced service life = (3) = (2)*(S_{with}/$S_{without}$)				
Total Annualized Capital Cost (AC) for enhanced service life (4)				
AND/OR Operating Costs Savings Per Unit				

AND/OR Routine Maintenance Cost Savings (If project reduces routine maintenance costs)				
Cost of Inspection	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
Maintenance Frequency				
Average Maintenance Labor Costs ($)				
Average Equipment Costs ($)				
Maintenance Management Labor Costs				
Maintenance Labor Injury or Death ($)				
Other				
Annual Cost per Unit (5)				
Total Annual Routine Maintenance Costs = AR (6) = (5)*(N)				
AND/OR Major Rehabilitation and Reconstruction (R&R) Cost Savings (If project reduces major R&R costs)				
Costs Per Major R&R	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
Average Maintenance Labor Costs ($)				
Average Maintenance Material Costs ($)				
Average Equipment Costs ($)				
Maintenance Labor Injury or Death ($)				
Other ($)				
Cost of Major R&R (7)				
Total Cost of R&R (8) = (7)*(N)				
Service Life Enhancement (in years) (S)				
Total R&R Cost for enhanced service life = (9) = (8)*(S_{with}/$S_{without}$)				
Total Annualized Major R&R Cost (AM) for enhanced service life (10)				
Total Annual Operating Costs = (11) = *(6)+(10)*				
Total Annual Agency Costs = (12) = *(11)+(4)*				

B.2. User and Safety Cost Savings

Table B-2. User and Safety Cost Savings

User Cost Savings (If project produces user benefits)				
Savings Area	**Applicable** (0 = No; 1 = Yes)	**Annual Costs (Dollars)**		**Differential**
		Cost With Use of Research Product	**Cost Without Use of Research Product**	
Travel **Time** Cost				
Vehicle **Operating Cost**				
Property Damage				
Injury				
Loss of Life (Fatality)				
Annual costs (13)				
Total Annual User Costs (14) = (13)*(N)				

B.3. Overall Cost Savings

The Geotechnical research program has been one of the most awarded and successful programs at TFHRC. This program has resulted in many specifications, materials and technologies, which are widely used through out the country. While individual project cost savings are very difficult to obtain, the TFHRC publication "A quarter century of Geotechnical research" provides some idea of the nature of the cost savings due to the program. These are listed in the table below.

Table B-3. Overall Cost Savings

Ratio of Cost Savings to Research Funding Calculations		
	Cost With Use of Research Product	**Cost Without Use of Research Product**
ANNUAL AGENCY COSTS *Table B-1 (12)*		
ANNUAL USER COSTS *Table B-2 (14)*		
Total ANNUAL COSTS (15) = *(12)+(14)*		
Total Cost Savings Per Year *CS = (15)$_{with}$ –(15)$_{without}$*	*$76 million saved by using geotechnical research by 10 northwestern states $70 million per year savings due to use of Durability of Geosynthetics Study $700 Million Annually with full implementation of earth reinforcement technologies.*	
Total Annual Research Funding *(I)*	**$ 50 Million**	
Ratio of Total Cost Savings over Research Funding *(TCS/I)*	**>1000**	

Geotechnical Research Program
PART C – Environmental Impacts

Table C-1. Environmental Impacts

Environmental Impact	**Weight** (5 = critical, 0 = Not Applicable)	**Level of Impact**					**Score** (level * weight)	**Max Score Possible** = (max level *weight)
		-1 = negative impact	0 = none	1 = low	2 = medium	3 = high		
Improvement in Air Quality or Emissions Reduction	5							15
	0							0
Noise Abatement	5							15
	0							0
Wetland and nature preservation	5							15
	0							0
Recycling of Materials	5							15
	0							0
Aesthetics, etc.	5							15
	0							0
Others (please mention)	5							15
	0							0
Total								90
Measure Score (total score / max score)	--							
RATING								NOT APPLICABLE

Geotechnical Research Program
PART D – Customer Satisfaction

Table D-1. Customer Satisfaction

Primary Performance Measure	**Weight** (5 = critical, 2 = somewhat)	**Level of Satisfaction** 1 = low; 5 = high					**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		1	2	3	4	5		
Awareness of Technology or Specifications	5					5	25	25
Ease of Implementation	5				4		20	25
Acceptance of Technology	5			3			15	25
Value and importance	5				4		20	25
Predicted impact on future technologies	5				4		20	25
Other								
Total							100	125
Measure Score *(total score / max score)*								**80%**
RATING								**EXCELLENT**

Geotechnical Research Program Overall Scorecard

Table E-1. Overall Scorecard

PART	**PERFORMANCE MEASURE**	**RESULT**
A	ACHIEVEMENT OF RESEARCH OBJECTIVES	**EXCELLENT (89%)**
B	COST SAVINGS	**Ratio of cost savings over research funding - > 1000:1**
C	ENVIRONMENTAL IMPACTS	**NOT APPLICABLE**
D	CUSTOMER SATISFACTION	**EXCELLENT (80%)**

STUDY #5
Web NBI Project

Introduction – This project is an example of a research project to explore how the Internet and web-based technology could be used to develop an application to provide query and analysis capabilities to bridge engineers. It is being tested and evaluated by FHWA bridge engineers and will be delivered to FHWA Office of Bridge Technology for use once the development is completed. This is the product of the Bridge Management Inventory Project. Bridge Management involves (a) making information decisions and (b) understanding performance. The Bridge Management Inventory Project enables (a) the development of deterioration models and (b) the development of decision information systems.

The WebNBI is thus one project out of a larger Information Systems related to bridges. It can link the bridge database with other databases using GIS. The product will enable users to accomplish the following:

a. Disseminate information
b. Perform queries
c. Perform Statistical Analyses
d. Produce Maps and Charts of queries and analyses
e. Download information from analyses performed online
f. Download databases by State
g. Download the national database through FHWA

The success of the Bridge Information Systems can spur interest in the development of other information systems, such as Roads Information Systems, National Highway Planning Information Systems, and National Pavement Management Systems.

Motivation and Objectives of the Project – The initial objective of this project was to investigate and develop a system to provide ad-hoc query capability for the National Bridge Inventory Database. Future objectives have expanded to include (a) adding a Mapping Interface, (b) adding Time Series Analysis, and (c) looking at element level data fields.

Project History – The National Bridge Inventory (NBI) Database was established by the FHWA in 1972. Every bridge longer than 20 feet is to be included in the inventory. Currently, NBI is the National Standard for bridge inventories. Element level data is not applied uniformly at the national level. (FHWA is considering taking the initiative to study and develop standards for element level data.)

The WebNBI project was initiated in June 2000. Previously, special requests were forwarded to the Office of Bridge Technology for special analyses. The procedure was cumbersome and slow and the existing report generator was unreliable and inconvenient.

Participating Agencies – The study is sponsored by FHWA and is undertaken at the Bridge Management Information Lab at TFHRC.

Accomplishments and Outputs – The project has so far resulted in the following:

1. Development of software and a web-based query and download system
2. Greatly improved business process
3. Supports tracking of strategic performance measures

The FHWA Project Managers developing the WebNBI have won a Performance Award from the Office of Bridge Technology.

Implementation and Technology Transfer – The application is used over the Internet. Due to concerns for misinterpretation, the client will ultimately determine who has access to the WebNBI. Currently only FHWA bridge engineers have access to it.

Sources:

Steve Chase, FHWA
John Hooks, FHWA
Chris Nutakor, FHWA

Web NBI
PART A – Research Output and Usage

Table A-1. Achievement of Research Objectives (10%)

Primary Performance Measure	Weight (5 = critical, 2 = somewhat)	Level of Achievement				Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
		0 = not met	1 = barely met	2 = partially met	3 = fully met		
Stated objective of program/project	5				3	15	15
Additional Measures	**Weight** (5 = critical, 2 = somewhat)	**Level of Achievement**					
		0 = No		1 = Yes		--	--
Research Reports published by FHWA	4	0				0	4
Papers published in Peer Reviewed Journals	3	0				0	3
Awards or Citations for Product	2			1		2	2
Total						17	24
Measure Score *(total score / max score)*							0.71

Table A-2. Types of Products from Research (20%)

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Level of Development				Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
		0 = not developed	1 = initial stage	2 = partially developed	3 = fully developed		
Specifications (including Design, construction, inspection, testing, maintenance)	5						15
	0						0
Guidelines/Handbooks (including tables, charts, monographs, etc.)	5						15
	0						0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5						15
	0						0
Advanced Technology and New Equipment (including construction, inspection or testing)	5						15
	0						0
Software Tools (design, analysis, management, testing, inspection, etc.)	5				3	15	15
	0						0
Advanced state-of-the-art procedures (e.g., methods, techniques); Exploratory Research Results							15
	0						0
Technology Transfer (including websites, clearinghouses, workshops, etc.)							15
	0						0
Total						15	15
Measure Score *(total score / max score)*							1.00

Table A-3. Adoption for Implementation (30%)

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Time Scale for Adoption: 4 = 0-5 yrs	3 = 5-10 yrs	2 = 10-15 yrs	1 = >15 yrs	Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
Time required/taken for research products to be adopted							20
	0						0

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Level of Adoption:) = No	1 = Somewhat	2 = Fully	Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
Specifications (including Design, construction, inspection, testing, maintenance)	5	Have the specifications been adopted as National Specifications by AASHTO or appropriate standards Agencies?				10
	0					0
Guidelines/Handbooks (including tables, charts, monographs, etc.)	5	Do DOTs, FHWA, AASHTO, Colleges, or similar organizations and institutions adopt the guidelines/handbooks?				10
	0					0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5	Are the materials developed available commercially?				10
	0					
Advanced Technology and New Equipment (including construction, inspection or testing)	5	Are the technologies and equipment in regular use by transportation agencies (excluding pilot projects)?				10
	0					
Software Tools (for design, analysis, inspection, testing or management)	5	Public Applications: Is the software available for use by agencies and public Specific Agency Applications: Has the software application been completely installed, tested and is currently used?			10	10
				2		
	0					
Technology Transfer Applications (including websites, clearinghouses, workshops, etc.)		Have technology transfer applications like websites, clearinghouses, workshops, etc. been created and implemented?				10
	0					
Total					10	10
Measure Score *(total score / max score)*						1.00

Table A-4. Extent of Use at the State-Level (40%)

Performance Measure	Weight (5 = critical, 0 = Not Applicable)	Time Scale for Popular implementation				Score (level * weight)	Maximum Score Possible (max level * weight)
		4 = 0-5 yrs	3 = 5-10 yrs	2 = 10-15 yrs	1 = >15 yrs		
Time required/taken for research products to be widely implemented	5						20
	0						0
Performance Measures	**Weight** (5 = critical, 0 = Not Applicable)	**Extent of Use by Agencies, Institutions and Others within the States**				**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		0 = none	1 = few[1]	2 = several[2]	3 = widespread[3]		
Specifications (including Design, construction, inspection, testing, maintenance)	5	Number of States using the specifications					15
	0					0	0
Guidelines/Handbooks (including tables, charts, monographs)	5	Number of States that recommended the use of the guidelines					15
	0					0	0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5	Number of States with reported applications of the materials					15
	0					0	0
Advanced Technology and New Equipment (including construction, inspection or testing)	5	Number of states who have procured the equipment or the technology					15
	0					0	0
Software Tools (for design, analysis, inspection, testing or management	5	Number of states with users of software[4]				10	15
				2			
	0					0	0
Technology Transfer (including websites, clearinghouses, workshops, etc.)	5	Number of States which have requested additional information about technology or Number of states where NHI courses were conducted					15
	0					0	0
Total						10	15
Measure Score *(total score / max score)*							0.67

none – *no state and local agencies, institutions or other agencies use the research*

[1] **few** – *less than 20% of the States (10) have state and local agencies, institutions and others using the research*

[2] **several** – *20% to 50% of the States (25) have state and local agencies, institutions and others using the research*

[3] **widespread** – *more than 50% of the States (more than 25) have state and local agencies, institutions and others using the research or if the product has been used by national international agencies.*

[4] *Due to concerns for misinterpretation, the client has not decided on providing access to the Web NBI tools to all the interested parties. However, all FHWA bridge engineers have access.*

Table A-5. Overall Score for Measurement of Research

Performance Measure	Relative Measure Weight (w)	Measure Score (s)	Weighted Score (w*s)
A.1. Achievement of research objectives	10%	0.71	0.07
A.2. Types of Products from Research	20%	1.00	0.20
A.3. Adoption for Implementation	30%	1.00	0.30
A.4. Extent of Use/Number of Users of Research Product	40%	0.67	0.27
TOTAL SCORE {∑ (W.S)}*100	100%		**83%**
RATING			**EXCELLENT**

Web NBI
PART B – Cost Savings

B.1. Agency Cost Savings

Table B-1. Agency Cost Savings

Research Program/Project				
Unit of measurement (Check appropriate unit)	Per sq. foot ______ Per Lane-Mile ______ Per Bridge ______ Per Application ______ Other (Please Specify) ____________________			
Definition of Typical Infrastructure	**e.g., bridge: 150-ft span, 45-ft wide, 2 piers**			
Existing or Potential Number of infrastructure elements on which research product has or could be applied (N) (i.e., Number of Applications)				
Capital Cost Savings of "activity" per Unit (If project reduces capital costs) NOT AVAILABLE				
Benefit Areas	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
– Design Labor Savings (expressed in $)				
– Construction Materials ($)				
– Construction Labor ($)				
– Worker Injury or Death ($)				
– Other ($)				
Cost Per Unit (1)				
Total Capital Costs (2) = (1)*(N)				
Planned Service Life (in years) (S)				
Total Capital Cost for enhanced service life = (3) = (2)*(S_{with}/$S_{without}$)				
Total Annualized Capital Cost (AC) for enhanced service life (4)	NOT AVAILABLE			
AND/OR Operating Costs Savings Per Unit				

AND/OR Routine Maintenance Cost Savings (If project reduces routine maintenance costs) NOT AVAILABLE				
Cost of Inspection	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
Maintenance Frequency				
Average Maintenance Labor Costs ($)				
Average Equipment Costs ($)				
Maintenance Management Labor Costs				
Maintenance Labor Injury or Death ($)				
Other				
Annual Cost per Unit (5)				
Total Annual Routine Maintenance Costs = AR (6) = (5)*(N)	**NOT AVAILABLE**			
AND/OR Major Rehabilitation and Reconstruction (R&R) Cost Savings (If project reduces major R&R costs)				
Costs Per Major R&R	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
Average Maintenance Labor Costs ($)				
Average Maintenance Material Costs ($)				
Average Equipment Costs ($)				
Maintenance Labor Injury or Death ($)				
Other ($)				
Cost of Major R&R (7)				
Total Cost of R&R (8) = (7)*(N)				
Service Life Enhancement (in years) (S)				
Total R&R Cost for enhanced service life = (9) = (8)*(S_{with}/$S_{without}$)				
Total Annualized Major R&R Cost (AM) for enhanced service life (10)				
Total Annual Operating Costs = (11) = *(6)+(10)*				
Total Annual Agency Costs = (12) = *(11)+(4)*	NOT AVAILABLE			

B.2. User and Safety Cost Savings

Table B-2. User and Safety Cost Savings

User Cost Savings (If project produces user benefits)				
Savings Area	**Applicable** (0 = No; 1 = Yes)	**Annual Costs (Dollars)**		**Differential**
		Cost With Use of Research Product	**Cost Without Use of Research Product**	
Travel **Time** Cost				
Vehicle **Operating Cost**				
Property Damage				
Injury				
Loss of Life (Fatality)				
Annual costs (13)				
Total Annual User Costs (14) = (13)*(N)	**NOT APPLICABLE**			

B.3. Overall Cost Savings

Table B-3. Overall Cost Savings

Ratio of Cost Savings to Research Funding Calculations		
	Cost With Use of Research Product	**Cost Without Use of Research Product**
ANNUAL AGENCY COSTS ***Table B-1 (12)***	DATA NOT AVAILABLE	
ANNUAL USER COSTS ***Table B-2 (14)***	NOT APPICABLE	
Total ANNUAL COSTS (15) = *(12)+(14)*	DATA NOT AVAILABLE	
Total Cost Savings Per Year $CS = (15)_{with} - (15)_{without}$	DATA NOT AVAILABLE	
Total Annual Research Funding *(I)*	**$250,000**	
Ratio of Total Cost Savings over Research Funding *(TCS/I)*	**UNKNOWN**	

Web NBI
PART C – Environmental Impacts

Table C-1. Environmental Impacts

Environmental Impact	**Weight** (5 = critical, 0 = Not Applicable)	**Level of Impact**					**Score** (level * weight)	**Max Score Possible** = (max level *weight)
		-1 = negative impact	0 = none	1 = low	2 = medium	3 = high		
Improvement in Air Quality or Emissions Reduction	5							15
	0							0
Noise Abatement	5							15
	0							0
Wetland and nature preservation	5							15
	0							0
Recycling of Materials	5							15
	0							0
Aesthetics, etc	5							15
	0							0
Others (please mention)	5							15
	0							0
Total								90
Measure Score (total score / max score)	--							
RATING								NOT APPLICABLE

Web NBI
PART D – Customer Satisfaction

Table D-1. Customer Satisfaction

Primary Performance Measure	Weight (5 = critical, 2 = somewhat)	Level of Satisfaction 1 = low; 5 = high					Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
		1	2	3	4	5		
Awareness of Technology or Specifications	5					5	25	25
Ease of Implementation	5				4		20	25
Acceptance of Technology	5				4		20	25
Value and importance	5			3			15	25
Predicted impact on future technologies	5			3			15	25
Other								
Total							95	125
Measure Score *(total score / max score)*								**76%**
RATING								**EXCELLENT**

Web NBI

Table E-1. Overall Scorecard

PART	PERFORMANCE MEASURE	RESULT
A	ACHIEVEMENT OF RESEARCH OBJECTIVES	**EXCELLENT (83%)**
B	COST SAVINGS	**UNKNOWN (Data not available)**
C	ENVIRONMENTAL IMPACTS	**NOT APPLICABLE**
D	CUSTOMER SATISFACTION	**EXCELLENT (76%)**

STUDY #6
Timber Bridge Research Program

Introduction – Wood has been used for building bridges for hundreds of years. Since the turn of the century with the development of steel and of reinforced and prestressed concrete, however, wood has slowly been replaced as the preferred bridge building material for vehicular bridges. With this decline in the use of timber bridges, the incentive to conduct research to advance wood technology for vehicular bridges has not kept up with that of other materials.

Motivation and Objectives of the Program – The drive behind the timber bridge program has been to revitalize local economies by finding means and methodologies for developing wood, especially the abundant supply of under-utilized wood species, species native to a particular region, and smaller sizes and grades of lumber for highway applications.

Program History – In the late 1980's there was renewed interest in developing wood for vehicular bridge applications. The Timber Bridge Initiative (TBI) was established in 1988. Renamed the Wood in Transportation (WIT) Program and administered by the USDA Forest Service, the TBI continues today and includes research, technology transfer and demonstration bridge programs. Alongside the WIT program, the Federal Highway Administration in 1990 initiated its timber bridge program. The FHWA program grew substantially after passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. The ISTEA authorized significant funding from 1992 to 1997 for timber bridge research, technology transfer, and demonstration bridges. Today, although smaller in scope, the FHWA continues to advance timber bridge technology by conducting research into advanced wood composites through the combination of wood and fiber reinforced polymer composites.

Participating Agencies – The Forest Service (FS) and the FHWA have been coordinating, leveraging resources, and jointly conducting its timber bridge programs. As a result, much has been done through research and technology transfer to advance the state of the knowledge.

Accomplishments and Outputs – A large number of research projects have been completed, and a number of demonstration bridges built. The programs have been instrumental in developing new highway timber bridge systems; engineering design criteria for characterizing lumber design properties; research into preservative systems which are environmentally sound with respect to application, use, and disposal of treated timber; development of bridge railings for timber bridges and wood sound barriers; and measures which demonstrate effective, safe, and reliable methods for inspection and rehabilitation of existing highway timber structures.

Implementation and Technology Transfer – Implementation of the timber bridge research and technology transfer programs has always involved our partners, and our customers. The programs are based on a national needs-assessment report titled, "Development of a Six-Year Research Needs Assessment for Timber Transportation Structures", prepared for the FS/FHWA by the Iowa State University. This effort involved a nationwide survey of Federal, State and local bridge engineers, academics, timber industry organizations, private consultants, and resource utilization personnel to identify research projects and priorities. The FS National Wood in Transportation Information Center (NWITIC) provides a major portion of the technology transfer program, including assistance and state-of-the-art information on timber bridges. NWITC also continues to provide matching funds on a competitive basis to local governments to demonstrate timber bridge technology through the construction of innovative bridges.

Sources:

Sheila Duwadi, FHWA
http://www.fpl.fs.fed.us/wit/

Timber Bridge Research Program
PART A – Research Output and Usage

Table A-1. Achievement of Research Objectives (10%)

Primary Performance Measure	Weight (5 = critical, 2 = somewhat)	Level of Achievement				Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
		0 = not met	1 = barely met	2 = partially met	3 = fully met		
Stated objective of program/project	5				3	15	15
Additional Measures	**Weight** (5 = critical, 2 = somewhat)	**Level of Achievement**					
		0 = No		1 = Yes		--	--
Research Reports published by FHWA	4			1		4	4
Papers published in Peer Reviewed Journals	3			1		3	3
Awards or Citations for Product	2	0				0	2
Total						22	24
Measure Score *(total score / max score)*							0.92

Table A-2. Types of Products from Research (20%)

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Level of Development				Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
		0 = not developed	1 = initial stage	2 = partially developed	3 = fully developed		
Specifications (including Design, construction, inspection, testing, maintenance)	5				3	15	15
	0						0
Guidelines/Handbooks (including tables, charts, monographs, etc.)	5				3	15	15
	0						0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5				3	15	15
	0						0
Advanced Technology and New Equipment (including construction, inspection or testing)	5			2		10	15
	0						0
Software Tools (design, analysis, management, testing, inspection, etc.)	5				3	15	15
	0						0
Advanced state-of-the-art procedures (e.g., methods, techniques); Exploratory Research Results	5				3	15	15
	0						0
Technology Transfer (including websites, clearinghouses, workshops, etc.)	5				3	15	15
	0						0
Total						100	105
Measure Score *(total score / max score)*							0.95

Table A-3. Adoption for Implementation (30%)

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Time Scale for Adoption: 4 = 0-5 yrs	3 = 5-10 yrs	2 = 10-15 yrs	1 = >15 yrs	Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
Time required/taken for research products to be adopted	5		3			15	20
	0						0

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Level of Adoption:) = No	1 = Somewhat	2 = Fully	Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
Specifications (including Design, construction, inspection, testing, maintenance)	5	Have the specifications been adopted as National Specifications by AASHTO or appropriate standards Agencies?			5	10
			1			
	0					0
Guidelines/Handbooks (including tables, charts, monographs, etc.)	5	Do DOTs, FHWA, AASHTO, Colleges, or similar organizations and institutions adopt the guidelines/handbooks?			10	10
				2		
	0					0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5	Are the materials developed available commercially?			5	10
			1			
	0					
Advanced Technology and New Equipment (including construction, inspection or testing)	5	Are the technologies and equipment in regular use by transportation agencies (excluding pilot projects)?			0	10
		0				
	0					
Software Tools (for design, analysis, inspection, testing or management)	5	Public Applications: Is the software available for use by agencies and public Specific Agency Applications: Has the software application been completely installed, tested and is currently used?			5	10
			1			
	0					
Technology Transfer Applications (including websites, clearinghouses, workshops, etc.)	5	Have technology transfer applications like websites, clearinghouses, workshops, etc. been created and implemented?			10	10
				2		
	0					
Total					50	80
Measure Score *(total score / max score)*						0.63

Table A-4. Extent of Use at the State-Level (40%)

Performance Measure	Weight (5 = critical, 0 = Not Applicable)	Time Scale for Popular Implementation				Score (level * weight)	Maximum Score Possible (max level * weight)
		4 = 0-5 yrs	3 = 5-10 yrs	2 = 10-15 yrs	1 = >15 yrs		
Time required/taken for research products to be widely implemented	5		3			15	20
	0						0
Performance Measures	**Weight** (5 = critical, 0 = Not Applicable)	**Extent of Use by Agencies, Institutions and Others within the States**				**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		0 = none	1 = few[1]	2 = several[2]	3 = widespread[3]		
Specifications (including Design, construction, inspection, testing, maintenance)	5	Number of States using the specifications				15	15
					3		
	0					0	0
Guidelines/Handbooks (including tables, charts, monographs)	5	Number of States that recommended the use of the guidelines				15	15
					3		
	0					0	0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5	Number of States with reported applications of the materials				15	15
					3		
	0					0	0
Advanced Technology and New Equipment (including construction, inspection or testing)	5	Number of states who have procured the equipment or the technology				0	15
		0					
	0					0	0
Software Tools (for design, analysis, inspection, testing or management	5	Number of states with users of software				5	15
			1				
	0					0	0
Technology Transfer (including websites, clearinghouses, workshops, etc.)	5	Number of States which have requested additional information about technology or Number of states where NHI courses were conducted				15	15
					3		
	0					0	0
Total						80	110
Measure Score*(total score / max score)*							0.73

none – *no state and local agencies, institutions or other agencies use the research*

[1] **few** – *less than 20% of the States (10) have state and local agencies, institutions and others using the research*

[2] **several** – *20% to 50% of the States (25) have state and local agencies, institutions and others using the research*

[3] **widespread** – *more than 50% of the States (more than 25) have state and local agencies, institutions and others using the research or if the product has been used by national international agencies.*

Table A-5. Overall Score for Measurement of Research

Performance Measure	Relative Measure Weight (w)	Measure Score (s)	Weighted Score (w*s)
A.1. Achievement of research objectives	10%	0.92	0.09
A.2. Types of Products from Research	20%	0.95	0.19
A.3. Adoption for Implementation	30%	0.63	0.19
A.4. Extent of Use/Number of Users of Research Product	40%	0.73	0.29
TOTAL SCORE {∑ (W.S)}*100	100%		**76%**
RATING			**EXCELLENT**

Timber Bridge Research Program
PART B – Cost Savings

B.1. Agency Cost Savings

Table B-1. Agency Cost Savings

Research Program/Project				
Unit of measurement (Check appropriate unit)	Per sq. foot ______ Per Lane-Mile ______ Per Bridge __X__ Per Application ______ Other (Please Specify) ____________________			
Definition of Typical Infrastructure	**e.g., bridge: 150-ft span, 45-ft wide, 2 piers**			
Existing or Potential Number of infrastructure elements on which research product has or could be applied (N) (i.e., Number of Applications)	**Approximately 50,000 all timber or timber deck bridges (source: NBI)**			
Capital Cost Savings of "activity" per Unit (If project reduces capital costs) NOT AVAILABLE				
Benefit Areas	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
– Design Labor Savings (expressed in $)				
– Construction Materials ($)				
– Construction Labor ($)				
– Worker Injury or Death ($)				
– Other ($)				
Cost Per Unit (1)				
Total Capital Costs (2) = (1)*(N)				
Planned Service Life (in years) (S)				
Total Capital Cost for enhanced service life = (3) = (2)*(S_{with}/$S_{without}$)				
Total Annualized Capital Cost (AC) for enhanced service life (4)	NOT AVAILABLE			
AND/OR Operating Costs Savings Per Unit				

AND/OR Routine Maintenance Cost Savings (If project reduces routine maintenance costs) NOT AVAILABLE				
Cost of Inspection	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
Maintenance Frequency				
Average Maintenance Labor Costs ($)				
Average Equipment Costs ($)				
Maintenance Management Labor Costs				
Maintenance Labor Injury or Death ($)				
Other				
Annual Cost per Unit (5)				
Total Annual Routine Maintenance Costs = AR (6) = (5)*(N)	**NOT AVAILABLE**			
AND/OR Major Rehabilitation and Reconstruction (R&R) Cost Savings (If project reduces major R&R costs)				
Costs Per Major R&R	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
Average Maintenance Labor Costs ($)				
Average Maintenance Material Costs ($)				
Average Equipment Costs ($)				
Maintenance Labor Injury or Death ($)				
Other ($)				
Cost of Major R&R (7)				
Total Cost of R&R (8) = (7)*(N)				
Service Life Enhancement (in years) (S)				
Total R&R Cost for enhanced service life = (9) = (8)*(S_{with}/$S_{without}$)				
Total Annualized Major R&R Cost (AM) for enhanced service life (10)				
Total Annual Operating Costs = (11) = *(6)+(10)*				
Total Annual Agency Costs = (12) = *(11)+(4)*	NOT AVAILABLE			

B.2. User and Safety Cost Savings

Table B-2. User and Safety Cost Savings

User Cost Savings (If project produces user benefits)				
Savings Area	**Applicable** (0 = No; 1 = Yes)	**Annual Costs (Dollars)**		**Differential**
		Cost With Use of Research Product	**Cost Without Use of Research Product**	
Travel **Time** Cost				
Vehicle **Operating Cost**				
Property Damage				
Injury				
Loss of Life (Fatality)				
Annual costs (13)				
Total Annual User Costs (14) = (13)*(N)	**NOT APPLICABLE**			

B.3. Overall Cost Savings

Table B-3. Overall Cost Savings

Ratio of Cost Savings to Research Funding Calculations		
	Cost With Use of Research Product	**Cost Without Use of Research Product**
ANNUAL AGENCY COSTS ***Table B-1 (12)***	DATA NOT AVAILABLE	
ANNUAL USER COSTS ***Table B-2 (14)***	NOT APPICABLE	
Total ANNUAL COSTS (15) = *(12)+(14)*	DATA NOT AVAILABLE	
Total Cost Savings Per Year $CS = (15)_{with} - (15)_{without}$	DATA NOT AVAILABLE	
Total Annual Research Funding *(I)*	**$ 1 Million**	
Ratio of Total Cost Savings over Research Funding *(TCS/I)*	**UNKNOWN**	

Timber Bridge Research Program
PART C – Environmental Impacts

Table C-1. Environmental Impacts

Environmental Impact	**Weight** (5 = critical, 0 = Not Applicable)	**Level of Impact** -1 = negative impact	0 = none	1 = low	2 = medium	3 = high	**Score** (level * weight)	**Max Score Possible** = (max level *weight)
Improvement in Air Quality or Emissions Reduction	5							15
	0							0
Noise Abatement	5				2		10	15
	0							0
Wetland and nature preservation	5							15
	0							0
Recycling of Materials	5							15
	0							0
Aesthetics, etc	5							15
	0							0
Others (please mention)	5							15
	0							0
Total							10	15
Measure Score (total score / max score)	--							0.67
RATING								GOOD

Timber Bridge Research Program
PART D – Customer Satisfaction

Table D-1. Customer Satisfaction

Primary Performance Measure	Weight (5 = critical, 2 = somewhat)	Level of Satisfaction 1 = low; 5 = high					Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
		1	2	3	4	5		
Awareness of Technology or Specifications	5				4		20	25
Ease of Implementation	5				4		20	25
Acceptance of Technology	5		2				10	25
Value and importance	5			3			15	25
Predicted impact on future technologies	5			3			15	25
Other								
Total							80	125
Measure Score *(total score / max score)*								**64%**
RATING								**GOOD**

Timber Bridge Research Program

Table E-1. Overall Scorecard

PART	PERFORMANCE MEASURE	RESULT
A	ACHEIVEMENT OF RESEARCH OBJECTIVES	**EXCELLENT (76%)**
B	COST SAVINGS	**UNKNOWN (Detailed cost data not available. 1609 Highway bridges built using timber but cost data is not available)**
C	ENVIRONMENTAL IMPACTS	**GOOD (67%)**
D	CUSTOMER SATISFACTION	**GOOD (64%)**

STUDY #7

Temporary Works Research Program

Introduction – This program was initiated around 1989 following the failure of the MD 198 temporary bridge structure over MD 295. In the aftermath of the tragedy, Maryland Senator, Barbara Mikulski, spearheaded the congressional initiative for the research. Prior to its existence, there were no AASHTO-approved codes or standards for temporary works. Contractors were responsible for designing the structures used.

Motivation and Objectives of the Program – The objective of the program therefore was to develop guidelines for states to use in building bridge temporary works, including formwork, falsework, shoring, and scaffolding.

Program History – Following congressional directive for the research, the program was initiated in 1989. Subsequently, the FHWA formed the Scaffolding, Shoring, and Forming Task Group to guide the program. Later on, AASHTO adopted two key documents that resulted from the research effort: (a) the "Construction Handbook for Bridge Temporary Works" and (b) the "Guide Design Specifications for Bridge Temporary Works" and published them as AASHTO documents. The ASCE has also developed standards for design loads for temporary projects using the research results of this program.

Participating Agencies – The lead research agency is the FHWA with specific involvement of the TFHRC Structures Lab. Members of the technical advisory committee included personnel from FHWA, The Transportation Research Board, state DOTs, and industry groups.

Accomplishments and Outputs – Results of the program include the following synthesis and guide documents:

"Falsework, Formwork and Scaffolding for Highway Structures" (FHWA-RD-91-062)
"Guide Design Specifications for Bridge Temporary Works" (FHWA-RD-93-032)
"Guide Standard Specifications for Bridge Temporary Works" (FHWA-RD-93-031)
"Construction Handbook for Bridge Temporary Works" (FHWA-RD-93-034)
"Certification Program for Bridge Temporary Works" (FHWA-RD-93-033)

Implementation and Technology Transfer – Implementation of the temporary works research and technology transfer programs took many forms including the following:
Reports through the TFHRC website
Website of the U.S. Forest Service (Morgantown)
TRB joint booth of the FHWA and the U.S. Forest Service
International and local conferences

Source:

Sheila Duwadi, FHWA

Temporary Works Research Program
PART A – Research Output and Usage

Table A-1. Achievement of Research Objectives (10%)

Primary Performance Measure	**Weight** (5 = critical, 2 = somewhat)	**Level of Achievement**				**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		0 = not met	1 = barely met	2 = partially met	3 = fully met		
Stated objective of program/project	5				3	15	15

Additional Measures	**Weight** (5 = critical, 2 = somewhat)	**Level of Achievement**			
		0 = No	1 = Yes	--	--
Research Reports published by FHWA	4		1	4	4
Papers published in Peer Reviewed Journals	3		1	3	3
Awards or Citations for Product	2		1	2	2
Total				24	24
Measure Score *(total score / max score)*					1.00

Table A-2. Types of Products from Research (20%)

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Level of Development				Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
		0 = not developed	1 = initial stage	2 = partially developed	3 = fully developed		
Specifications (including Design, construction, inspection, testing, maintenance)	5				3	15	15
	0						0
Guidelines/Handbooks (including tables, charts, monographs, etc.)	5				3	15	15
	0						0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5						15
	0						0
Advanced Technology and New Equipment (including construction, inspection or testing)	5						15
	0						0
Software Tools (design, analysis, management, testing, inspection, etc.)	5						15
	0						0
Advanced state-of-the-art procedures (e.g., methods, techniques); Exploratory Research Results	5						15
	0						0
Technology Transfer (including websites, clearinghouses, workshops, etc.)	5						15
	0						0
Total						30	30
Measure Score *(total score / max score)*							1.00

Table A-3. Adoption for Implementation (30%)

Performance Measures	Weight (5 = critical, 0 = Not Applicable)	Time Scale for Adoption				Score *(level * weight)*	Maximum Score Possible *(max level * weight)*
		4 = 0-5 yrs	3 = 5-10 yrs	2 = 10-15 yrs	1 = >15 yrs		
Time required/taken for research products to be adopted	5	4				20	20
	0						0
Performance Measures	**Weight** (5 = critical, 0 = Not Applicable)	**Level of Adoption**				**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		) = No	1 = Somewhat	2 = Fully			
Specifications (including Design, construction, inspection, testing, maintenance)	5	Have the specifications been adopted as National Specifications by AASHTO or appropriate standards Agencies?				10	10
				2			
	0						0
Guidelines/Handbooks (including tables, charts, monographs, etc.)	5	Do DOTs, FHWA, AASHTO, Colleges, or similar organizations and institutions adopt the guidelines/handbooks?				10	10
				2			
	0						0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5	Are the materials developed available commercially?					10
	0						
Advanced Technology and New Equipment (including construction, inspection or testing)	5	Are the technologies and equipment in regular use by transportation agencies (excluding pilot projects)?					10
	0						
Software Tools (for design, analysis, inspection, testing or management)	5	Public Applications: Is the software available for use by agencies and public Specific Agency Applications: Has the software application been completely installed, tested and is currently used?					10
	0						
Technology Transfer Applications (including websites, clearinghouses, workshops, etc.)	5	Have technology transfer applications like websites, clearinghouses, workshops etc. been created and implemented?					10
	0						
Total						40	40
Measure Score *(total score / max score)*							1.00

Table A-4. Extent of Use at the State-Level (40%)

Performance Measure	Weight (5 = critical, 0 = Not Applicable)	Time Scale for Popular implementation				Score (level * weight)	Maximum Score (max level * weight)
		4 = 0-5 yrs	3 = 5-10 yrs	2 = 10-15 yrs	1 = >15 yrs		
Time required/taken for research products to be widely implemented	5	4				20	20
	0						0
Performance Measures	**Weight** (5 = critical, 0 = Not Applicable)	**Extent of Use by Agencies, Institutions and Others within the States**				**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		0 = none	1 = few[1]	2 = several[2]	3 = widespread[3]		
Specifications (including Design, construction, inspection, testing, maintenance)	5	Number of States using the specifications				15	15
					3		
	0					0	0
Guidelines/Handbooks (including tables, charts, monographs)	5	Number of States that recommended the use of the guidelines				15	15
					3		
	0					0	0
Improved Conventional and New Innovative Materials (including primary materials like HPS, secondary materials like Rapid Setting Polymers, etc.)	5	Number of States with reported applications of the materials					15
	0					0	0
Advanced Technology and New Equipment (including construction, inspection or testing)	5	Number of states who have procured the equipment or the technology					15
	0					0	0
Software Tools (for design, analysis, inspection, testing or management	5	Number of states with users of software				5	15
	0					0	0
Technology Transfer (including websites, clearinghouses, workshops, etc.)	5	Number of States which have requested additional information about technology or Number of states where NHI courses were conducted				5	15
			1				
	0					0	0
Total						55	65
Measure Score *(total score / max score)*							0.85

none – *no state and local agencies, institutions or other agencies use the research*
[1] **few** – *less than 20% of the States (10) have state and local agencies, institutions and others using the research*
[2] **several** – *20% to 50% of the States (25) have state and local agencies, institutions and others using the research*
[3] **widespread** – *more than 50% of the States (more than 25) have state and local agencies, institutions and others using the research or if the product has been used by national international agencies.*

Table A-5. Overall Score for Measurement of Research

Performance Measure	Relative Measure Weight (w)	Measure Score (s)	Weighted Score (w*s)
A.1. Achievement of research objectives	10%	1.00	0.09
A.2. Types of Products from Research	20%	1.00	0.20
A.3. Adoption for Implementation	30%	1.00	0.30
A.4. Extent of Use/Number of Users of Research Product	40%	0.85	0.34
TOTAL SCORE {∑ (W.S)}*100	100%		**93%**
RATING			**EXCELLENT**

Temporary Works Research Program
PART B – Cost Savings

B.1. Agency Cost Savings

Table B-1. Agency Cost Savings

Research Program/Project				
Unit of measurement (Check appropriate unit)	Per sq. foot ______ Per Lane-Mile ______ Per Bridge ______ Per Application __X___ Other (Please Specify) ___________________			
Definition of Typical Infrastructure	**e.g., bridge: 150-ft span, 45-ft wide, 2 piers**			
Existing or Potential Number of infrastructure elements on which research product has or could be applied (N) (i.e., Number of Applications)	**DATA NOT AVAILABLE**			
Capital Cost Savings of "activity" per Unit (If project reduces capital costs) NOT AVAILABLE				
Benefit Areas	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
– Design Labor Savings (expressed in $)				
– Construction Materials ($)				
– Construction Labor ($)				
– Worker Injury or Death ($)				
– Other ($)				
Cost Per Unit (1)				
Total Capital Costs (2) = (1)*(N)				
Planned Service Life (in years) (S)				
Total Capital Cost for enhanced service life = (3) = (2)*(S_{with}/$S_{without}$)				
Total Annualized Capital Cost (AC) for enhanced service life (4)	NOT AVAILABLE			
AND/OR Operating Costs Savings Per Unit				

AND/OR Routine Maintenance Cost Savings (If project reduces routine maintenance costs) NOT AVAILABLE				
Cost of Inspection	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
Maintenance Frequency				
Average Maintenance Labor Costs ($)				
Average Equipment Costs ($)				
Maintenance Management Labor Costs				
Maintenance Labor Injury or Death ($)				
Other				
Annual Cost per Unit (5)				
Total Annual Routine Maintenance Costs = AR (6) = (5)*(N)	**NOT AVAILABLE**			
AND/OR Major Rehabilitation and Reconstruction (R&R) Cost Savings (If project reduces major R&R costs)				
Costs Per Major R&R	**Applicability** (Yes = 1, 0 = No)	**Cost With Use of Research Product**	**Cost Without Use of Research Product**	**Differential**
Average Maintenance Labor Costs ($)				
Average Maintenance Material Costs ($)				
Average Equipment Costs ($)				
Maintenance Labor Injury or Death ($)				
Other ($)				
Cost of Major R&R (7)				
Total Cost of R&R (8) = (7)*(N)				
Service Life Enhancement (in years) (S)				
Total R&R Cost for enhanced service life = (9) = (8)*(S_{with}/$S_{without}$)				
Total Annualized Major R&R Cost (AM) for enhanced service life (10)				
Total Annual Operating Costs = (11) = *(6)+(10)*				
Total Annual Agency Costs = (12) = *(11)+(4)*	NOT AVAILABLE			

B.2. User and Safety Cost Savings

Table B-2. User and Safety Cost Savings

User Cost Savings (If project produces user benefits)				
Savings Area	**Applicable** (0 = No; 1 = Yes)	**Annual Costs (Dollars)**		**Differential**
		Cost With Use of Research Product	**Cost Without Use of Research Product**	
Travel **Time** Cost				
Vehicle **Operating Cost**				
Property Damage				
Injury				
Loss of Life (Fatality)				
Annual costs (13)				
Total Annual User Costs (14) = (13)*(N)	**NOT AVAILABLE**			

B.3. Overall Cost Savings

Table B-3. Overall Cost Savings

Ratio of Cost Savings to Research Funding Calculations		
	Cost With Use of Research Product	**Cost Without Use of Research Product**
ANNUAL AGENCY COSTS ***Table B-1 (12)***	DATA NOT AVAILABLE	
ANNUAL USER COSTS ***Table B-2 (14)***	DATA NOT AVAILABLE	
Total ANNUAL COSTS (15) = *(12)+(14)*	DATA NOT AVAILABLE	
Total Cost Savings Per Year $CS = (15)_{with} - (15)_{without}$	DATA NOT AVAILABLE	
Total Annual Research Funding *(I)*	_	
Ratio of Total Cost Savings over Research Funding *(TCS/I)*	**UNKNOWN**	

Temporary Works Research Program
PART C – Environmental Impacts

Table C-1. Environmental Impacts

Environmental Impact	**Weight** (5 = critical, 0 = Not Applicable)	**Level of Impact**					**Score** (level * weight)	**Max Score Possible** = (max level *weight)
		-1 = negative impact	0 = none	1 = low	2 = medium	3 = high		
Improvement in Air Quality or Emissions Reduction	5							15
	0							0
Noise Abatement	5							15
	0							0
Wetland and nature preservation	5							15
	0							0
Recycling of Materials	5							15
	0							0
Aesthetics, etc.	5							15
	0							0
Others (please mention)	5							15
	0							0
Total								90
Measure Score (total score / max score)	--							
RATING								NOT APPLICABLE

Temporary Works Research Program
PART D – Customer Satisfaction

Table D-1. Customer Satisfaction

Primary Performance Measure	**Weight** (5 = critical, 2 = somewhat)	**Level of Satisfaction** 1 = low; 5 = high					**Score** *(level * weight)*	**Maximum Score Possible** *(max level * weight)*
		1	2	3	4	5		
Awareness of Technology or Specifications	5					5	20	25
Ease of Implementation	5				4		20	25
Acceptance of Technology	5					5	25	25
Value and importance	5					5	25	25
Predicted impact on future technologies	5			3			15	25
Other								
Total							105	125
Measure Score *(total score / max score)*								**84%**
RATING								**EXCELLENT**

Temporary Works Research Program

Table E-1. Overall Scorecard

PART	**PERFORMANCE MEASURE**	**RESULT**
A	ACHEIVEMENT OF RESEARCH OBJECTIVES	**EXCELLENT (93%)**
B	COST SAVINGS	**UNKNOWN (Data not available)**
C	ENVIRONMENTAL IMPACTS	**NOT APPLICABLE**
D	CUSTOMER SATISFACTION	**EXCELLENT (84%)**

APPENDIX C

Overview of Other Programs and Projects Studied

Part I. Program Overviews

Hydrology and Hydraulics Program

Introduction – Prior to this program, no guidelines existed on how to estimate the depth of scour on bridge piers, and most hydraulic analyses were based on a one-dimensional model. In addition, 25% of U.S. bridges had unknown foundations and there was no method available to prioritize the analysis of these bridges.

Motivation and Objectives of the Program – Understanding hydraulics and hydrology as they apply to highway structures is a necessity for the proper design of bridges and other drainage structures, especially during extreme events such as major floods and washouts. The objectives of the research therefore were: (a) to improve drainage practice for the highway system and (b) to safeguard bridges from damage due to flooding.

Program History – The hydrology and hydraulics program has been ongoing over the past 50 years. The FHWA maintains a hydraulics laboratory to conduct research to improve drainage practice for the highway system, to develop improved methods for designing bridge substructures with improved hydraulic capacity, and to safeguard bridges from damage due to flooding (such as improved scour prevention measures). The program Task Force received an ASCE Award on Bridge Scour.

Participating Agencies – Research in this area is supported through staff, contract research, and cooperative research with other agencies. Performing agencies include the U.S. Army Corps of Engineers, the U.S. Geological Services, and numerous universities. Co-sponsors to the FHWA include the Tennessee Valley Authority, the Bureau of Reclamation, FEMA, and the U.S. Forest Service. The program also serves as a liaison for the National Cooperative Highway Research Program (NCHRP) projects related to hydraulics and hydrology, and as a source of technical support and advice for State DOT's concerning major State planning and research studies.

Accomplishments and Outputs – As a result of this program, three hydraulic engineering circulars (HEC15, HEC20, and HEC23) have been developed for National Highway Institute (NHI) Training courses, a two-dimensional model has been created, and numerous reports published.

Implementation and Technology Transfer – Implementation of the hydrology and hydraulics research and technology transfer programs took many forms including NHI training courses, HEC circulars (#1 - 25), and Hydraulic Engineering conferences.

Sources:

Sterling Jones, FHWA
TFHRC website: www.tfhrc.gov/hydraulics

Superpave Program

Introduction – Superpave gives highway engineers and contractors the tool they need to design and construct asphalt pavements that perform better and last longer under extremes of temperature and a wide range of traffic loads. Many variables determine the appropriate pavement for a particular location. One size certainly does not fit all. A pavement that wears well and lasts beyond its expected life on a rarely traveled highway in the Nevada desert could crack and rut within months of use in a much colder Minnesota on a busy metropolitan road that carries a heavy daily volume of stop-and-go traffic. Even within the same geographic area under similar climatic conditions, the type of traffic, including trucks, can make a major difference. Superpave enables the hot-mix asphalt designer to customize the pavement components to create a pavement that provides optimal durability and longevity. This customization, in turn, cuts costs by reducing repairs and the need for early replacement. "The idea is to *get in, get out, stay out*," says Rick Dunn, research and technology engineer in the Federal Highway Administration's (FHWA) New York Division. Extended service-life and less maintenance provide a host of other benefits, including fewer road closures and traffic delays.

Motivation and Objectives of the Program – Superpave researchers seek to improve the performance of flexible pavements through a greater understanding of the fundamental chemical and physical properties of asphalt binders and mixes.

Program History – Superpave was one of seven core technology areas originally identified for implementation under the Strategic Highway Research Program (SHRP), a 5-year research effort established by Congress in 1987. Through a provision in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), Congress provided more than $100 million through 1998 to support the development of SHRP products, with approximately $40 million going to Superpave.

Participating Agencies – Research and technical support are sponsored by FHWA

Accomplishments and Outputs – Superpave research has resulted in performance-based tests, equipment, and procedures for both binders and mixes. The procedures and evaluation methods encompassed under Superpave assess binder and mix performances in terms of the most common causes of pavement failure: pavement deformation (rutting), fatigue (structural) cracking, and low-temperature (thermal) cracking. Superpave also considers the detrimental effects of age hardening and moisture damage on these distresses. By applying Superpave principles, engineers and designers can customize the binder and mixture to make the most appropriate mix for a particular pavement's environmental and traffic conditions.

Implementation and Technology Transfer – Located at the FHWA Offices of Pavement Technology in Washington, DC, and Infrastructure Research and Development at the Turner-Fairbanks Highway Research Center in McLean, VA, the national experts on Superpave provide assistance to the States in a variety of ways. "We've worked with States to put together implementation strategies," says Tom Harman, asphalt pavement team leader, "to help them establish training programs, and with research and development."

As asphalt pavement technology continues to evolve, new solutions are emerging. “We’re refining and redeveloping equipment and specifications,” says Harman, citing a handful of past and current activities, including the refinements to the Pressure Aging Vessel (used to age asphalt binders in the laboratory) and the Direct Tension Test (used to assess low-temperature properties of the asphalt binder).

Sources:

Public Roads September/October 2002, “Superpave Comes of Age” by Cathy Frye http://www.tfhrc.gov/pubrds/02sep/10.htm

List of Transportation Pooled Fund Studies http://www.tfhrc.gov/site/active2.htm#019

Part II. Project Overviews

Automated Geotechnical Information and Design System (AGIDS)

Introduction – Automated Geotechnical Information and Design System (AGIDS) is a new initiative that allows geotechnical and structural engineers to quickly and economically obtain information and evaluate design alternatives from a centralized computer source of databases. These databases are connected by developing commonality features and a user interface application for performing cross queries, correlations, and engineering analyses. Several of the data bases already contained modules for performing correlations, predictions, and analyses; however, they needed to be linked through a multi-user workstation that contains an interactive system for automatically generating design solutions based on interactive user input. Such a system takes most of the guesswork out of geotechnical design, and replaces it with an objective, quantitative system that supports sound management decisions.

Motivation and Objectives of the Project – The motivation for the AGIDS project is to integrate all of the FHWA research quality technical databases, plus the information databases in geotechnology, into a comprehensive design aid system. The main objective of this project has been to develop improved procedures for the design and construction of bridge foundations, retaining wall systems, and other geotechnical projects through the use of internet and database technology.

Project History – This is a relatively new initiative. The project began in January 2002.

Participating Agencies – The FHWA initiated the AGIDS project with data gathered from the literature, State Highway Administration files, other agencies, and foreign organizations.

Accomplishments and Outputs – A wealth of research-quality geotechnical data have been gathered from the literature, SHA files, other agencies, and foreign organizations for placement in a series of FHWA geotechnical databases to increase the effectiveness of current and future research efforts to improve design and prediction methods. These tools are also an effective way for practitioners to improve their state of the practice on routine design work.

Implementation and Technology Transfer – Each database can be utilized as a stand-alone information source with its own information management and analysis modules, plus user interface applications. Each has a statistically meaningful source of high-quality data that can be used for the development and verification of new or improved analysis methods or simple design checks by providing a fast, convenient, and economical source of project specific or generic information for inclusion in reports within minutes, instead of days or weeks. The database also allows users to:

- obtain cost comparisons quickly for budget documents
- compare technical sufficiency and economic data on alternative designs
- locate existing site investigation data and historical load test data rapidly to assist in preparing plans
- compare various construction methods

- download data and perform comparative analyses for multiple design alternatives
- perform correlations between various geotechnical parameters
- obtain data to assist in design of instrumentation plans

Regardless of the project stage, the needed information can be obtained rapidly, reducing time and costs to formulate plans and evaluate design alternatives, which in turn will lead to reduced uncertainty in the project development phases. A more confident design process will reduce overall geotechnical and foundation costs.

Sources:

Chapter Five "Geotechnical Stand-Alone Studies" from "Quarter Century of Geotechnical Research", Accessed at: http://www.tfhrc.gov/structur/gtr/century/chap05/chpt05.htm
List of Transportation Pooled Fund Studies, Accessed at:
http://www.tfhrc.gov/site/active2.htm#038

COST – Concrete Optimization Software Tool

Introduction – COST (Concrete Optimization Software Tool) is an online design/analysis system developed to assist concrete producers, engineers and researchers in determining optimal mixture proportions for concrete.

Input Requirements – COST requires the following input:
One to five performance criteria (e.g., slump, 28-day strength, etc.) and specification requirements for each performance criterion (e.g., minimum strength, allowable slump range, etc.) Two to five mixture components and lower and upper limits on each component's proportions. Material properties needed to determine mixture proportions and costs (specific gravities, absorption, cost, etc.)

How it Works – With appropriate input from the user, COST uses statistical experiment design (DEX) principles to generate a set of trial batches for an experimental plan. The user runs trial batches, which consist of batching, mixing, fabricating specimens, and performing necessary tests. The test results (data) can then be entered into COST for analysis and optimization. Cost uses appropriate statistical analyses, both graphical and numerical, to assist the user in determining optimal mixture proportions to meet the particular project requirements.

Potential Applications – There are two likely scenarios in which COST would be used:
The first (and probably most common) would be to proportion a concrete mixture to meet a set of performance criteria while minimizing the cost of the mixture.
Another possible objective is to maximize or minimize one or more responses (for instance, to achieve the highest possible strength).

Sources:

Simon, M.J., Lagergren, E.S., and Snyder, K.A., *Concrete Mixture Optimization Using Statistical Mixture Design Methods*, in Proceedings of the PCI/FHWA Int'l. Symposium on High Performance Concrete, 230-244, 1997.

Simon, M.J., Lagergren, E.S., and Wathne, L.G., "Optimizing High-Performance Concrete Mixtures Using Statistical Response Surface Methods," in Proceedings of the 5th International Symposium on Utilization of High Strength/High-Performance Concrete. Norwegian Concrete Association, Oslo, Norway, 1311-1321, 1999.

Simon, M.J., Snyder, K.A., and Frohnsdorff, G.J., *Advances in Concrete Mixture Optimization*, in Creating with Concrete, 1999.

HIPERPAV Project

Introduction – HIPERPAV is a user-friendly, Windows-based program that provides guidance on the design and construction of concrete pavements. A two-module program, HIPERPAV contains a set of guidelines that helps the end-user predict and thus prevent potential pavement performance problems. HIPERPAV is only a tool to help the state and contractor make a better decision based on the factors present. In the past, a lot of decisions have been made arbitrarily. HIPERPAV can act as a guide for better decision-making.

Motivation and Objectives of the Project – To open up newly constructed pavements within days or hours after the work is completed, pavement contractors in the early 1990s used "fast-track" concrete mixes that gain strength rapidly but can be damaged severely if placed under adverse weather conditions. In response to this problem, this research was initiated with the aim of maximizing the performance of fast-track pavement through proper design, selection of pavement materials, construction, and environmental factors. Another goal was to develop an understanding of how fast-track concrete's high heat of hydration (a chemical reaction during setting) interacts with pavement curing methods, environmental conditions, and design criteria. Above all, the project aimed to translate the research findings into a usable tool for wide-scale, practical, and immediate application in the field.

Project History – The research contract was awarded in 1993 to The Transtec Group of Austin, TX. HIPERPAV was born in 1996.

Participating Agencies – FHWA initiated research on the development of construction guidelines for fast-track jointed plain concrete pavements (JPCP).

Accomplishments and Outputs – HIPERPAV evaluates the potential for uncontrolled cracking in new concrete pavements and for de-bonding of bonded concrete overlays during construction. This program considers the impact that specific construction procedures, mix and pavement designs, and environmental factors might have on distress during construction, and therefore on the overall long-term behavior of a pavement. HIPERPAV can help achieve the following:

- Ensure a high-quality product at a minimal cost
- Optimize pavement and overlay designs to ensure high performance
- Optimize the design and temperature characteristics of a mix
- Reduce uncertainties about long-term performance

HIPERPAV II is the next generation of the prior HIPERPAV software program. The primary functions of the software program include: (a) assessing the behavior of jointed JPCP performance beyond the 72 hour limit of the current program, and factors that may influence that performance; and (b) predicting early-age behavior of continuously reinforced concrete pavement (CRCP). The software will be released in mid 2003.

Implementation and Technology Transfer – HIPERAV has undergone extensive validation. All its models were tested for accuracy during a recent series of experiments. Real pavements throughout the US were instrumented to monitor their early age strength and stress development during this validation effort. The software was then used to predict these measured properties. It yielded reliable results for a range of design, environmental and construction conditions. In addition, a number of experts including academics and practitioners have reviewed the software for validity.

Sources:

HIPERPAV homepage, Accessed at: http://www.tfhrc.gov////////pavement/pccp/hipemain.htm
J. Mauricio Ruiz, Robert Otto Rasmussen, and Patricia Kim Nelson. "Paving the Way", *Public Roads*, July/August 2002, Accessed at: http://www.tfhrc.gov////////pubrds/02jul/05.htm

Impact-Echo Method for Measuring Distributed Damage in Concrete Study

Introduction – Like GPR, the Impact-Echo Method is another non-destructive technique for measuring distributed damage in concrete pavements.

Motivation and Objectives of the Study – There have been a number of cases of early failure of concrete due to microcracking from expansive forces. This research was initiated to develop a non-destructive technique to quantify the extent of this distributed damage using discrete time Fourier transform analysis.

Participating Agencies – The FHWA funded research at Cornell University for the impact-echo method.

Accomplishments and Potential – Accomplishments to date include the demonstration that the method can detect microcracking on the order of 1%. Arial Soriano, formerly of S. Dakota DOT had the following to say about the test method:

- "The department is confident of the reliability of the impact-echo test method." While "the results of other tests can vary depending on weather conditions or traffic noise, the impact-echo technique provides consistent information regardless of weather or traffic."

- The impact-echo method is extremely fast. "One person can now do in half a day what it used to take a coring crew a week to do."
- The device is also a useful tool for controlling quality in new construction. By measuring the thickness of a concrete pavement, the highway agency can quickly determine if a just-placed pavement meets the job specification.

Implementation and Technology Transfer – Implementation and technology transfer is through the development and distribution of a commercial software package.

Contacts:

David Huft S. Dakota DOT 605-773-3292, daveh@dot.state.sd.us
Gary Crawford, FHWA 202-366-1286, gary.crawford@fhwa.dot.gov

Sources:

http://www.tfhrc.gov/////structur/struc98/ch5.htm#ch5-24
"Impact Echo Device Gives Quick, Reliable Information on Concrete Condition."
http://www.fhwa.dot.gov////winter/roadsvr/CS048.htm

Performance Related Specifications (PRS) Project

Introduction – In the 1980s and 1990s, States imposed pay reductions on contractors if products were less than ideal. Such decisions were based on "engineering judgment". Prior to this project, two main types of specifications existed: (a) methods specifications and (b) quality assurance specifications. Both had faults and flaws including, inability to specify optimum requirements, the fact the contractor's pay does not necessarily reflect product performance, and that the contractor does not understand what it takes to get warranted performance. Under methods specifications, everything is accepted, and adversarial relations between contractors and State Highways would be created when contractors strictly follow instructions, yet problems later arose. Under the second type of specification, improvements were made, but neither the State nor the contractor knew how the pavement would perform. It also assigned responsibilities to the contractor, and assigned responsibility to the Highway Agencies on what to expect.

Motivation and Objectives of the Project – The main goals of this project have been two-fold: (a) to improve on existing construction specifications for both asphalt and Portland cement concrete paving and (b) to develop and implement specifications based on effective predictors of pavement performance with appropriate incentive and disincentive clauses based on these predictors. This includes defining what factors contribute to good pavement performance and developing performance models reflected in terms of constructed quality. The development of a definition for high performance concrete pavement should complement these ongoing efforts on performance-related specifications.

Project History – The FHWA has had an ongoing effort regarding performance-related specifications for pavements, which began in 1987. For research into performance related specifications for concrete pavements, a five to six member committee of materials and pavement engineers as well as contractors served on advisory panels of three out of five contracts. For asphalt pavements, a nineteen-member NCHRP panel advised the research effort. *Participating Agencies* – Sponsoring agencies include FHWA, state highway agencies, and NCHRP.

Accomplishments and Outputs – Results of this project thus far include the following:
Individual reports by individual contractors. See TFHRC website.
Software package (PAVESPEC 3.0) to do three things:

- Set up specifications
- Allow contractor to figure out what pay to get
- Analyze risks associated with specifications.

New test developments in asphalt concrete, Best and most recent report on PRS for asphalt to be released soon by NCHRP. HMASPEC Software being developed in follow-up NCHRP study to be validated. Both PCC and asphalt have PRS Specifications.

Implementation and Technology Transfer – Implementation of the PRS research and technology transfer programs are planned to take many forms.

For Concrete – technology transfer will be accomplished through dissemination of reports and software, training for users, and provision of funds to State Highway Agencies to test and evaluate PRS.

For Asphalt– technology transfer will be accomplished by getting the specifications adopted by AASHTO

Sources:

Peter Kopac, FHWA (concrete)
Terry Mitchell, FHWA (asphalt)
AASHTO Innovative Highway Technologies – High Performance Concrete: Transition Plan 2000, accessed at: http://leadstates.tamu.edu/hpc/transition_plan_present.stm

Rapid Chloride Permeability Test for Concrete Study

Introduction – Prior to the development of this test, one would cast about 12” by 12” of concrete and pond it with salt water for a period of time (say 1 year, 180 days or 90 days, etc.) and then check the level of permeation. The need for a procedure that can produce results within a day led to the development of this test known as the Rapid Chloride Permeability Test. Currently the AASHTO T27-93 “Electrical Indication of Concrete’s Ability to Resist Chloride Test" is used as a short-term test to predict the chloride penetration in concrete. This information is used to evaluate new mixes, to accept or reject new concrete according to specifications, and to evaluate in-place concrete. The main concern is how well the concrete will protect reinforcing steel from corrosion. This is performed by subjecting a water-saturated, 50-mm thick, 100-mm diameter concrete specimen to a 60 V applied DC voltage for 6 hours. The test cylinder is sandwiched between 2 reservoirs, one containing a 3.0 % NaCl solution and the other a 0.3 M NaOH solution. The total charge passed through the concrete is determined in order to rate the concrete against a predetermined scale of penetrability.

Motivation and Objectives of the Project – The objectives of the RCP Test were: (a) to develop and test rapid destructive permeability device, which can be used in the laboratory on sections of concrete such as cores, taken from structures; (b) to develop and test a rapid nondestructive permeability device which can determine the permeability of rigid concrete members (such as bridge decks) in field installations.

Project History – The initial research took place between 1978 and 1981 and resulted in the Rapid Chloride Permeability Test, which is *the standard* in the USA. It was necessitated largely because winter salting of bridge decks accelerates the diffusion of salt to reinforcements, which leads to cracking. The request for a faster method led to the development of the Rapid Migration Test, which is described in the next overview.

Participating Agencies – The FHWA was a sponsoring agency.

Accomplishments and Outputs – Results of the original research are outlined as follows:
Project Report: "Rapid Determination of the Chloride Permeability of Concrete", FHWA/RD-81/119, August 1981

The Standard Test Method was incorporated in the following:

- AASHTO Test Method: T277 (for over 15 years)
- ASTM Standard: C1202 (for buyers and sellers)
- Design of a test instrument, which is being manufactured by companies around the U.S. The test takes 6 hours to complete following material preparation for 24 hours.

Implementation and Technology Transfer – Implementation of the RCP research and technology transfer programs took many forms including the following:

- Publications and Presentations
- Writing of Standards and presenting them for adoption
- Assisting States in acquiring test equipment
- Testing samples for interested parties
- Establishing a "Help-Desk" to answer technical questions from users.

Sources:

Terry Mitchell, FHWA
"On the Road Testing Roads." *Public Roads*, July/August 2002, Accessed at:
http://www.tfhrc.gov///pubrds/02jul/04.htm
"Recent Publications" *Public Roads*, January/February 2002, Accessed at:
http://www.tfhrc.gov///pubrds/janfeb02/recpubs.htm

Stanish, Hooton, and Thomas. "Testing the Chloride Penetration Resistance of Concrete: A Literature Review." FHWA Contract DTFH61-97-R-00022

Rapid Migration Test Project

Introduction – The Rapid Migration Test is performed by subjecting a concrete test cylinder 50-mm thick and 100-mm in diameter to an applied DC voltage of 30 V and a 3% NaCl solution in limewater on one side and limewater on the other. Instead of monitoring the passage of chloride ions by measuring the chloride concentration of the downstream solution, the depth of the chloride penetration is found by splitting open the sample. A colorimetric technique is applied in which a silver nitrate solution is sprayed on the concrete containing chloride ions. A chemical reaction occurs in which the chloride ions bind with the silver to produce silver chloride, a whitish substance. However, in the absence of the chlorides, the silver bonds with the hydroxides present, causing the concrete to produce a brownish color. Thus the position of how far the chloride ions penetrated into the concrete cylinder can be seen. This test addresses some of the shortcomings of the rapid chloride permeability test, namely actual chloride ion movement and temperature rise, but still has limitations in regard to the inclusion of conductive materials in the concrete mix.

Motivation and Objectives of the Project – Many owners and engineers have questioned the Rapid Chloride Permeability Test (AASHTO T-277) and its equivalent ASTM C1202 in the past for their consistency and accuracy. The main criticisms are that the current passed is related to all ions in the pore solution (not just chloride ions), that the measurements are made before steady-state migration is achieved, and that the high voltage applied leads to an increase in temperature – especially for low quality concretes – which further increases the charge passed. Thus this test, known as the Rapid Migration Test, was developed to supplement or replace the previous test. The Rapid Migration study was initiated in 1997 to identify or develop a test for predicting chloride penetration in concrete that could be used for evaluating new mixes, for accepting or rejecting new concrete according to specifications, and for evaluating in-place concrete. The test was intended to follow up on and supplement or replace AASHTO T-277.

Participating Agencies – The FHWA sponsored the research that was undertaken at the University of Toronto and the University of New Brunswick. The Portland cement concrete products lab at the Turner Fairbanks Highway Research Center participated in round robin evaluation of the proposed test method.

Accomplishments and Outputs – Results of the new project include: (a) the report, FHWA-RD-00-142, (b) a prototype equipment, and (c) a draft provisional test method. This provisional standard is on ballot for AASHTO approval. If approved, it will be published as a provisional standard in June 2003.

Testing and Evaluation – The results from the Rapid Migration Test (RMT) on numerous types of concrete were compared to those from the Rapid Chloride Permeability Test (RCPT) and those from more accurate long-term tests. In all cases the correlation between the long-term tests and the Rapid Migration were equal or slightly better than those of the RCPT. In addition, the RMT was determined to be applicable to a wider range of concretes than the RCPT.

Stanish, Hooton, and Thomas of the University of Toronto assert: overall, RMT appears to be a viable alternative for evaluating the chloride penetration resistance of concrete.

Implementation and Technology Transfer – Implementation of the RMT research and technology transfer programs took many forms including report distribution, conference presentations, and by forwarding the research output through the AASHTO approval process.

Sources:

Marcia Simon, FHWA

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"Transition Plan January 2000." *AASHTO Innovative Highway Technologies,* Accessed at: http://leadstates.tamu.edu/hpc/transition_plan_present.stm

Use of Improved Structural Materials in Marine Pilings Project

Introduction – Before this project's inception in April of 1979, conventional concrete piles had to be frequently inspected and repaired, as their reinforcing steel would quickly corrode in salt environments. The structural integrity of woodpiles was often compromised from marine animals boring into them, causing them to have less strength and service life. Corrosion resistant concrete either prevents the salt from reaching the rebars or the salt water goes slowly. It costs more and must be specially manufactured, but requires fewer inspections and repairs. Once a manufacturer is equipped for production, the cost of the piles is not very much more than conventional concrete. Benefits include longer life, less repair, and greater safety.

Motivation and Objectives of the Project – The purpose of this project was to evaluate the feasibility of manufacturing precast, prestressed marine piles from (a) polymer concrete, (b) polymer impregnated concrete, (c) internally sealed concrete, and (d) latex modified concrete.

Project History – This study was initiated in 1979 and ended in December of 1982. Of the 4 types of piles investigated, only polymer concrete piles were rated unsatisfactory. However, Japan has started using them.

Participating Agencies – FHWA sponsored this research. The main investigation was performed at the Oregon DOT.

Accomplishments and Outputs – Resulting from this project is the FHWA report "Use of Improved Structural Materials Systems in Marine Piling" (FHWA-RD-OR-83-3) and subsequently other evaluation reports after many years of performance.

Implementation and Technology Transfer – Targeted users of this work include coastal state highway agencies, bridge piling applications, offshore oil platforms, boat piers, etc. Implementation of the research and technology transfer programs took many forms including reports and slide presentations, demonstration projects and NHI Training Courses.

Source: Peter Kopac, FHWA

Vessel Collision Design of Highway Bridges Project

Introduction – The collapse of a bridge due to vessel collision is a rare and sporadic event. Vessel collision accidents that do not result in the collapse of a bridge are generally not reported; there is no legal requirement to do so. The only reported bridge collapses due to vessel collision since 1991 are on bridges where the specifications developed under this project were not in use at the time of construction. The specifications may be used to assess retrofit requirements, as well as new construction requirements. However, this is not a widespread practice because it is not mandatory.

Motivation and Objectives of the Project – The objective of the project was to develop a methodology, in specification format, for assessing the risk and computing design loads for vessel collisions with bridges over navigable waterways.

Project History – Prior to this study, the Louisiana DOT and the firm, Modjeski and Masters, had developed a procedure for assessing the risk of vessel collision. Greiner inc. had also developed another procedure as part of a one-time study for the Maryland DOT. Both procedures were used in the development of the FHWA/AASHTO methodology under this contract. Other states did not have any systematic method in use.

The project began in late 1987 and ended in 1991. It had two review panels: one for the FHWA contract, the other for its adoption as an AASHTO Specification. While the project was underway, several requests came in from state DOT's and the Massachusetts Port. Because AASHTO member states were included in the project oversight from the beginning, AASHTO began proceedings to adopt the specifications immediately after completion of the FHWA contract. It became available in 1991 as a Guide Specification. In 1998, it was included as a section in the LRFD Bridge Design Specifications, which will become the standard specifications for bridge design in 2007. Until then, designers have access to the Vehicle Collision specification through both publications.

Since the specifications became available through AASHTO shortly after completion of the FHWA contract, it has never been distributed through FHWA channels. An accompanying

training course, however, is available through the NHI, and was requested by state DOT's periodically in the 1990's. A study is underway in Florida to refine the barge and barge-tow portions of the specifications.
Participating Agencies – This was a pooled-fund study that combined funds from FHWA and State DOT's of New York, North Carolina, Florida, Alabama, Mississippi, Louisiana, Texas, Missouri, Minnesota, California, and Washington.

Accomplishments and Outputs – The primary results of the project are the following:
It became available in 1991 as a Guide Specification.
In 1998, it was included as a section in the LRFD Bridge Design Specifications, which will become the standard specifications for bridge design in 2007.
Also, FHWA developed a Training Course to enable engineers to develop proficiency in using the new specifications. The course is still available through the NHI.

Implementation and Technology Transfer – Implementation and technology transfer occurred through the 1991 Guide Specification, the 1998 inclusion as a section in the LRFD Bridge Design Specifications, and an FHWA developed Training Course available through the NHI.

Sources: Eric Munley, FHWA

User Guidelines for Waste By-Products in Pavements Project

Introduction – The manual prepared under this project covers nineteen waste and by-product materials from the domestic, industrial, and mining sectors and six high-volume pavement construction applications. For each material, information on material origin, sources, and properties is provided. In addition, application-specific information (for specific material-application combinations) is provided, including past performance, engineering properties, processing requirements, design and construction, and unresolved issues. General guidance on environmental and cost issues, and a general outline on determining the suitability of a material in an application are also provided. The manual is distributed in loose-leaf format for ease of use and to allow future updates and expansion.

Motivation and Objectives of the Project – Prior to preparation of this manual, there were lots of information in scattered sources on use of waste byproducts. Users had to wade through too much material to retrieve information needed. The objectives of this project therefore were two fold:

1. To compile available information on use of pavement waste products into a single user-friendly manual of the most important information.

2. To develop a concise, easy-to-use manual containing the latest available information on the use of waste or by-product materials in pavement construction applications.

Project History – The project began in 1995 and was completed in 1998. It involved an advisory panel of representatives from state DOT's, environmental groups and industry associations. The resulting manual provides technical guidance for highway and materials engineers, waste and by-product generators, and others involved in making decisions regarding the use of waste and by-product materials in highway construction. While there are no formal requests to revise the manual, there are informal discussions among FHWA personnel for an update study as new advances and materials come to light.

Participating Agencies – The FHWA sponsored this project.

Accomplishments and Outputs – The output of this project is the guide manual, which is available in the following three formats:

<u>Printed</u>: User Guidelines for Waste and by-Product Materials in Pavement Construction, FHWA-RD-97-148
<u>Web-based</u>: Guidelines coded in HTML and put at TFHRC website
<u>CD</u>: (a) By TFHRC
(b) By Recycle Materials Resource Center (RMRC) at the University of New Hampshire.

Implementation and Technology Transfer – Technology transfer was accomplished by the following methods:

- Distributed reports and CD to States and FHWA
- Presentations at conferences
- Through the TFHRC website
- Promoted by RMRC

<u>Sources</u>: Marcia Simon, FHWA

Ground-Penetrating Radar Imaging (for Asphalt Pavement Thickness) Project

Introduction – Work on this project was done through the Strategic Highway Research Program (SHRP-P-397). The project itself was an evaluation. The following two points are worth noting:

- Although probably a little less accurate than core sampling, GPR compensates by allowing multiple readings in close proximity to each other for better overall accuracy without physical destruction of existing pavements.

- The use of GPR is not necessarily for cost reduction. GPR enables collection of more complete decision information than through core sampling. With better decisions, cost savings are realized in the long run.

Motivation and Objectives of the Project – Before adoption of GRP technology, pavement thickness was measured by taking core samples out of the pavement; this is destructive of existing pavements. The objective of this project was to evaluate the occupancy of pavement layer thickness as determined from GPR measurements.

Project History – The project was begun in December 1991 and was completed in July 1992.

Participating Agencies – The sponsor was the National Research Council with FHWA funds and oversight. Texas A&M University and INFRASENSE, Inc. (with Kenneth R. Maser) were the two agencies that mainly conducted the GPR research.

Accomplishments and Outputs – The research revealed that the GPR technology provided reasonable accuracy.

Implementation and Technology Transfer – FHWA Headquarters personnel conducted a demonstration project with the Public Works Department of the District of Columbia.

Sources: Cheryl Richter, FHWA

APPENDIX D

Project and Contact Lists

	List of Program / Project Areas		
	New Technology and Innovation	**National Design and Data Standards**	**New and Conventional Materials**
Programs	**High Performance Steel Research Program**	**High Performance Steel Research Program**	**High Performance Steel Research Program**
	High performance steel development (HPS 690W Cu-Ni)	High performance steel development (HPS 690W Cu-Ni)	High performance steel development (HPS 690W Cu-Ni)
	Bill Wright		
	202-493-3053		
	bill.wright@fhwa.dot.gov		
	Geotechnical Research Program	**Geotechnical Research Program**	**Geotechnical Research Program**
	Automated Geotechnical Information and Design System (AGDIS)	Automated Geotechnical Information and Design System (AGDIS)	Automated Geotechnical Information and Design System (AGDIS)
	Al Dimillio	Al Dimillio	Al Dimillio
	202-493-3035		
	al.dimillio@fhwa.dot.gov		
	Hydrology and Hydraulics Program	**Timber Bridge Research Program**	**Timber Bridge Research Program**
	Seismic and Radar Scour Instrumentation	Standard Plans for Timber Bridge Superstructures	Timber bridge monitoring studies
	Strategies for Managing Unknown Bridge Foundations	Development of crash worthy bridge railing systems	Environmental considerations for wood preservatives
	Enhanced Abutment Scour Studies for Compound Channels	Timber bridge monitoring studies	
	Scour Instrumentation and Deployment Methods, Mobile Equipment	LRFD Calibration for Wood Bridges	
	Sterling Jones	Sheila Duwadi	
	202-493-3043	202-493-3106	Sheila Duwadi
	sterling.jones@fhwa.dot.gov	sheila.duwadi@fhwa.dot.gov	202-493-3106
			sheila.duwadi@fhwa.dot.gov
		Temporary Works Research Program	
		Guide design specification for bridge temporary works	
		Guide standard specification for bridge temporary works	
		Certification program for bridge temporary works	
		Construction handbook for bridge temporary works	
		Synthesis of Falsework, Formwork and Scaffolding for Highway Bridge Structures	
		Sheila Duwadi	
		202-493-3106	
		sheila.duwadi@fhwa.dot.gov	
		Hydrology and Hydraulics Program	
		Seismic and Radar Scour Instrumentation	
		Strategies for Managing Unknown Bridge Foundations	
		Enhanced Abutment Scour Studies for Compound Channels	
		Scour Instrumentation and Deployment Methods, Mobile Equipment	
		Sterling Jones	
		202-493-3043	
		sterling.jones@fhwa.dot.gov	
Projects		Vessel Collision Study	
		Eric Munley	
		202-493-3046	
	Epoxy coated strands	Epoxy coated strands	
	Paul Virmani		
	202-493-3052	WebNBI	
	paul.virmani@fhwa.dot.gov	Steve Chase	
		202-493-3038	
	Impact Echo	steve.chase@fhwa.dot.gov	
	Glenn Washer	John Hooks	
	202-493-3082	202-493-3023	
	glenn.washer@fhwa.dot.gov	john.hooks@fhwa.dot.gov	
	Rapid Chloride Permeability Test for Concrete	Performance related specifications for highway construction for both concrete and asphalt	Superpave Program
	Terry Mitchell	Terry Mitchell	
	202-493-3147	202-493-3147	
	terry.mitchell@fhwa.dot.gov	terry.mitchell@fhwa.dot.gov	
		Kevin Stuart	
	Superpave Program	202-493-3073	
	Tom Harman	kevin.stuart@fhwa.dot.gov	

TFHRC Program and Project Managers Interviewed

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High Performance Steel Research Program
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Epoxy Coated Strands Study
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Web NBI
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Rapid Chloride Permeability Test for Concrete
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Ground Penetrating Radar
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Ground Penetrating Radar
Cheryl Richter
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The CTE (Coefficient for Thermal Expansion) test method
Marcia Simon
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HRDI Research Partners Interviewed

Timber Bridge Program
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U.S. Forest Service
180 Canfield Street
Morgantown, WV 26505
304-285-1530
FAX: 304-285-1587
ecesa@fs.fed.us

Michael Ritter (contacted)
U.S Forest Service
Forest Products Laboratory
608-231-9493
FAX: 608-231-9567
mritter@fs.fed.us

HPS, Epoxy Coated Rebars Project
Claude Napier
FHWA, Virginia Division
Claude.Napier@fhwa.dot.gov

GPR, Epoxy Coated Rebars Project
Gerry Clemena
Virginia Transportation Research Center (VRTC)
Gerardo.Clemena@VirginiaDOT.org

Ann Shemaka (Contacted)
FHWA Offi e of Bridge Technology
National Bridge Inventory
ann.shemaka@fhwa.dot.gov

Users of Research Products Interviewed

Ken Hurst
Kansas DOT
Temporary Works Program

APPENDIX E

Data Collection Template

PROJECT INFORMATION TEMPLATE			
1. Project/Program Title			
2. Begin Date	3. End Date	4. Sponsoring Agency(ies)	5. Project Manager/ Investigator(s), Phone Number
6. TFHRC Lab involved in Research (if applicable)		7. Project/Program Cost	8. Local FHWA Personnel Involved with Research
9. Project Technical Advisory Panel Members and Organizations			
10a. Overall Research Objective (If available online, please mention source: TFHRC website, FHWA, EDL, etc.)			
10b. What was the existing practice to address the problem(s) before research results were implemented?			
11. Result of Research – Reports, Software, Specifications, Materials, Methods, testing instruments, etc. (If available online, please mention source: TFHRC website, FHWA, EDL, etc.)			
12. Target Users and Applications			

PROJECT INFORMATION TEMPLATE			
13a. What agencies have requested the results of this project?	Name	Organization	
13b. To whom were the results/products of the project communicated?			
14. If applicable, where are the results/ products of this project available?			
15. List any commendations or awards received for the project.			

IMPLEMENTATION AND APPLICATION OF RESEARCH PRODUCTS

16. How was technology transfer carried out for the project?	
17. Is the result/product being used by agencies or organizations?	_ Yes _ No _ Not Applicable
18. If No, why is the product not being used (Check any or all of the possible reasons)?	1. High cost of implementation 2. Additional research needed 3. Difficult to change state practices 4. Institutional issues
	5. Other Reasons, Please Specify
19. What agencies/ departments have used the results of the research?	

20. What are the reported outcomes of using the products developed for this project/program? (Reported outcomes are defined as outcomes experienced by users of the research products.)	Savings in (If applicable, Please Specify Unit of Measurement)	
	Agency Cost	_ Yes _ No _ Not Applicable
	User Cost	_ Yes _ No _ Not Applicable
	Time	_ Yes _ No _ Not Applicable
	Increased User Safety	_ Yes _ No _ Not Applicable Unit:
	Increased Worker safety	_ Yes _ No _ Not Applicable Unit:
	Serviceability Enhancement	_ Yes _ No _ Not Applicable Unit:
	Infrastructure Security Enhancements	_ Yes _ No _ Not Applicable Unit:
	Others (Please specify)	

PROJECT INFORMATION TEMPLATE	
21. Have there been any follow-up or requests for updates/ revisions? If yes, please specify nature of request and response.	
22. Have there been any new developments since the completion of the project/ program in the study area? If yes, please specify.	
23. Has there been an evaluation report conducted on this project? If yes, please provide report.	
24. Other Comments Please feel free to use this space for any other additional information or comments or if the space provided for previous questions was insufficient. Please use additional pages if necessary	

INTERVIEW GUIDE FOR USERS OF TFHRC-HRDI RESEARCH PRODUCTS

Background

The **Turner Fairbanks Highway Research Center - Office of Infrastructure R&D (HRDI)** continually improves the nation's infrastructure by conducting high quality research with a national scope and focusing on national interest. Research needs are continuously identified through outreach processes by our researchers with their State and local governments and industry counterparts. The Office of Infrastructure R&D pursues advanced research initiatives, which are outside the realm of State highway agencies. HRDI operates 13 onsite experimental and analytical laboratories at the Turner Fairbanks Highway Research Center supporting the testing of new research methodologies and innovations. Further, HRDI trains and houses technical experts consisting of research scientists and engineers to assist the FHWA Core Business Units, Resource Centers and the worldwide transportation community.

Because of its commitment to high quality research, HRDI needs to assess its programs to maximize resources and yield greater benefits. This process involves not only identifying the benefits of research anecdotally, but also quantifiably. The establishment of a viable and meaningful system of performance measurements will enable HRDI research managers to take stock of where they currently stand and more accurately assess progress toward program objectives, goals of the agency, and the Department.

Objectives

Develop a framework of contextualized measures that may be used by researchers at HRDI to quantify the benefits of their research. Secondary objective will be to share these measures within the RD&T organization for the purpose of developing a comparable suite of measures quantifying the benefits of their own research.

As a first step in developing performance measures, the users of HRDI research will be interviewed to obtain detailed information about the demand for infrastructure research, benefits, costs and concerns of implementing the research outcomes.

Questionnaire

The interview guide is aimed at collecting valuable information about the benefits of HRDI research as experienced by the users. Please try to answer the following questions in as much detail as possible. Please use the space provided at the end of the questionnaire for any additional comments regarding the benefits of infrastructure research and development.

1. Name

2. Organization

3. Official Title/Position

4. What areas of transportation infrastructure would like research products to be available?

5. Are you aware of TFHRC-HRDI Research?

6. If yes, what products of TFHRC-HRDI have you used?

7. What conditions drive demand for the product and how it can, or has, helped provide “real world” benefits?

8. Were research outputs readily available and accessible to all your potential uses?

7. How well are the research results and data accepted and used by your agency?

8. Is your organization satisfied with the outcomes from implementation of research results?

9. What is the added value of the products or benefits or cost-savings resulting from the implementation of the research?

10. What are the impacts of implementing research results (e.g., reduction in construction cost, safety improvement, reduction in congestion)?

11. What are the costs involved in implementing research results?
    11a. What are the costs to the agency?
    119b. What are the Transportation User Costs?

12. What are the constraints and problems associated with the implementation of HRDI research results?

13. What areas need additional research before they can be effectively implemented?

14. Have you adopted any new standards, practices, and products that evolved from HRDI research?

15. How can TFHRC-HRDI further help in enhancing the use and implementation of research products?

16. Other Comment